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Business Model-the Perspective of Systems Thinking and Innovation

Edited by
Anders Hansen Henten and Iwona Windekilde

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Preface to ”Business Model–the Perspective of Systems Thinking and Innovation”

The business model concept has gained a prominent position both in academia and among practitioners during the past 30+ years. Although businesses have always followed different kinds of business models, the business model concept started being widely used and developed as e-commerce gained popularity, with the commercialization of the Internet and the emergence of web technologies. This was radically new, and while the previous business literature previously had discussed business strategies, the new types of business options that erupted with e-commerce called for a unifying concept.

At first, the focus was mostly on taxonomies of business models, as in all other attempts to understand new or newly discovered phenomena. This was relatively quickly followed by an interest in defining ontologies of elements of business models and of defining the concept of business models itself. This is an ongoing process with more or less variation in definitions; however, in spite of the now relatively long track record of the business model concept, it has still not been sufficiently theorized. Various theories, indeed, underpin different elements that go into business modelling, but the concept and modelling approaches as such have seldom been subject to more general theorizing. The extent to which this is a problem can be discussed, but the implication is a lack of coherence in the business model literature.

One of the aims of this Special Issue of *Systems* is to contribute to a stronger theoretical basis for the business model concept. This includes a focus on the systemic character of business models and the systems approaches that this entails. Another important aspect is to allocate more attention to innovations of business models. The new business models that emerged with e-commerce and e-business as such were in themselves innovations. However, innovations of business models have received too little attention. Most of the business models analyzed and discussed in the business model literature have been rather static instead of dynamic. This is the reason why this Special Issue of *Systems*, entitled ‘Business Model—the Perspective of Systems Thinking and Innovation’, has been developed.

The Special Issue includes papers that aim at developing theories relating to business modelling and papers that analyze business model developments based on case studies. Most of the papers have an explicit systems-thinking approach, and business model innovations is a cross-cutting theme, explicitly stated in paper titles or otherwise dealt with in the papers. With 15 papers in the Special Issue, there is self-evidently a variety in the topics and approaches of the papers, but they all contribute to the advancement of the field of business model studies and represent novel steps in direction of systems thinking and business model innovation in business modelling research.

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Article

Using Systems Thinking to Illustrate Digital Business Model Innovation

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Abstract: Digital business model innovation is discussed by bringing together systemic innovation and digital innovation. Applying the Rich Picture technique, the complexity transpiring in the digital innovation of the business models is illustrated. Further, a real world example is presented and discussed in relation to systemic innovation and digital innovation. This study further contributes by shedding light on the added complexity brought by digital innovation but also the need for a combined and mixed systems thinking approach.

Keywords: digital business model innovation; digital innovation; systems thinking; Rich Picture; complexity; Netflix

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1. Introduction

Advancement of digital technologies has spawned profound innovation opportunities. This impact is observed across a number of industries, which are being reshaped by digital technologies. In order to strive in the ever changing landscape, organizations need to embark on continuous digital innovation efforts. Digital innovation is defined as "the process of combining digital and physical components to create novel devices, services or business models, bundling them to constitute and enable market offerings, and embedding them in wider sociotechnical environments to enable their diffusion, operation and use" [1] (p. 433). Systemic implications and complexity stemming from digital innovation have become key concerns for both research and practice.

In this paper we focus on digital business model innovation as an instance of systemic innovation [2] and digital innovation [3]. According to Amit and Zott [4] (p. 4) "a business model is about 'how to do business', and business model innovation is about 'how to do business in new ways'". Utilization of holistic thinking has been voiced as a powerful approach for business model innovation, by both strategic management literature [5] and, recently, systems thinking literature (e.g., [2]). In the same line of reasoning, we also argue for the potential of systems thinking to address digital business model innovation. Systems thinking is a transdisciplinary perspective which enables complex and multidimensional environmental, social, and organizational real world situations to unfold and be tackled. Systems thinking is a holistic approach which provides a language and a set of tools tackling underlying patterns and structures, mental models, and relationships (e.g., [6–13]). It can be viewed as a practical application of various systems ideas [14]. Despite the appreciation of systems thinking for business model innovation, previous literature (e.g., [15–17]) mostly assumes the hard systems approach and considers business models as systems. However, the application of systems thinking to business model innovation remains mainly blackboxed [18].

We aim to contribute to a contemporary phenomenon of our society—digitalization. By using the Rich Picture technique (e.g., [9]), a systems thinking tool, we illustrate relationships, entities, and underlying structures of the dynamic multifaceted complexity of digital business model innovation. Further, this is an attempt to bring together systemic innovation and digital innovation through the notion of digital business model innovation.

In what follows, we first provide a brief summary of business models and digital business model innovation. We then proceed with a brief outline of related work, which brings together business models and systems thinking. This is followed by an illustration and description of the complex situation of Digital Business Model Innovation along with a practical case example. The paper is finalized with a discussion and concluding remarks on future prospects.

2. Business Models

The business model concept elevated with the emergence of the Internet, which gave rise to new forms of business practices [19]. Since then, the concept has proliferated and earned a prominence in both academia and practice [20]. A detailed review of the business model body of research, its evolution, classification of the literature, and its dynamics is out of the scope of this paper, since the scholarly work contains many such reviews already (for thorough reviews, see, e.g., [20–24]).

Despite the increased importance, there is no consensual definition on business models [22], and scholarly work is quite dispersed [20]. Massa et al. [22] classify the burgeoning literature into three main strands, which provide different interpretations of business models. The first strand considers business models as properties of real organizations, where the business model depicts the organization's activity system, which explains how the business is conducted. The second strand interprets business models through a cognitive prism. It specifically views business models as cognitive representations [25], held in managers' mental models. This cognitive framing, often recognized as "dominant logic" [26], shapes the decision making and subsequent innovation efforts. It is recognized to be a main barrier to spot market opportunities, shape the innovation journey [27], and yield value from digitalization. The third perspective according to Massa et al. [22] interprets business models as simplified versions of real systems, represented as formal conceptualization of activities.

Nevertheless, among the scattered work across disciplines [20], there is a noted consensus on two points: firstly, the core of business model notion is the value creation and capture; and secondly, a business model represents a boundary spanning concept, hence demanding a holistic scrutiny [28,29].

In the work of Amit and Zott [19], a business model emerges as an analytical concept derived from a thorough scrutinization of traditional theories of value creation, value chain [30], resource based view [31], Schumpeterian innovation [32], strategic networks [33], and transaction cost economics [34]. In their work, Amit and Zott [19] conclude that the digital realm challenges the conventional understanding of value creation, and the traditional theories of value creation cannot fully grasp digitalization and its implications. These theories alone can only provide partial explanations; therefore, Amit and Zott [19] propose the business model as an aggregated concept to account for digitalization and its implications. Whereas their initial work focused on transactions, the latter work assumes an activity system perspective [5,28]. Nonetheless, as Zott and Amit [28] (p. 219) argue, these two perspectives do not cancel each other out; instead they are "two sides of the same coin", because the link between activities is enabled through transaction mechanisms [28]. The activity system perspective as presented by Zott and Amit [28] is a comprehensive way of understanding and explaining the value creation and delivery, by depicting business model as a purposeful assemblage of interconnected and interdependent activities performed by the organization, but also other actors in the ecosystem. Activity is defined as "as the engagement of human, physical, and/or capital resources of any party to the business model (the focal firm, end customers, vendors, etc.) to serve a specific purpose toward the fulfillment of the overall objective" [28] (p. 217). Specifically, they define the business model as depicting "the content, structure, and governance of transactions designed so as to create value through the exploitation of business opportunities" [28] (p. 511). The three elements that characterize the business model are content, structure, and governance. Content, or the "what" of business models, describes the activities that are conducted in order to deliver value propositions to satisfy a market need. Structure, or the "how" element of business models, refers to the way the activities are connected, their sequence, as well as their contribution to the business model in terms of whether they have a primary or supporting character. Governance, or the "who", describes the actors responsible for performing the activities and underlying control mechanisms [28].

Amit and Zott [19] and Zott and Amit [5,28] identify and further elaborate four main drivers of value creation, which organizations activate alone or in combination. These drivers revolve around which business models could be designed, include novelty, lock-in, complementarities, and efficiency. Novelty refers to novel configurations of activities, actors, and relationships. Efficiency refers to the way organizations configure their activity systems to gain greater efficiency through the reduction of costs. Complementarities according to Zott and Amit [28] refer to the creation of synergies between offerings, activities, actors, and/or resources, which would result in greater value than each of them separately. The lock-in theme is argued to be present when companies, through activating mechanisms such as switching costs or incentives, prevent customers from drifting away to other competitors. Moreover, Amit and Zott [19] argue that value drivers are not mutually exclusive. One or several drivers can be present in the very same business model, and often they solidify each other [19]. This becomes more evident especially in the volatile digital context.

Business models are dynamic [35], especially in the light of constant and ongoing digital evolution. Therefore, digital innovation of business models becomes an imperative for survival in the ever changing ecosystem.

Digital Business Model Innovation

As mentioned above, the concept of the business model gained considerable popularity in both academia and practice seemingly as a result of advancement of digital technologies [20]. Hence, the business model concept is intrinsically related to digitalization. Digital technologies themselves do not contribute to value creation and capture. Instead they must be leveraged and exploited in novel ways which yield value creation and capture, that is, through business models, as a concept which bridges the technological aspects with economic aspects such as value creation and capture [36].

Digital business model innovation represents an instance of digital innovation, along with product and process innovation [3]. Fichman et al. [3] (p. 330) define digital innovation as "a product, process or business model that is perceived as new, requires some significant changes on the part of adopters, and is embodied in or enabled by IT". Further, according to the authors, digital business model innovation refers to novel forms of value creation and capture enabled by digital technologies. In other words, digital business model innovation refers to the ways organizations harness the potential of digital technologies to create and capture value in a novel way, not only for themselves but also other actors in the ecosystem. Following Zott and Amit [5] and Snihur and Zott [37], we perceive digital innovation of business models as the changes in the content (introduction of new activities, modification of existing ones, and/or elimination of some activities), structure (novel ways of activity linkages), and/or governance (introduction of new actors who conduct activities), all enabled by digital technologies. In this paper, digital business model innovation does not solely imply a full transition or transformation to digital, but also it includes a hybrid model, where the non-digital way of doing business coexists with the digital.

There is a consensus that business model innovation is intrinsically complex and difficult (e.g., [27,37]). The difficulty emerges due to the high interdependency between the elements of the business model resulting in the innovation of the whole activity system [5]. However, what makes digital innovation of business models particularly complex is specific attributes such as the decoupling between form and function and content from medium, blurred boundaries, different dynamics, and value co-creation (e.g., [38–40]).

These attributes inherent in digital technologies represent the cornerstone for digital innovation [38] and digital business model innovation, respectively. Digital innovation is regarded as a "new innovation regime" [40], distinct from other forms of innovations [41]. The properties of digital technologies afford a large degree of flexibility and make digital innovation a process and an outcome with no clear defined boundaries and agency of innovation [41]. Digital innovation of business models entails an entirely different dynamic. The ubiquitous nature of digital technologies eliminates barriers, hence affording the entrance of new actors in incumbent contexts [38]. Digital innovation challenges the traditional notion of value creation and instead assumes that value is co-created by "aggregating recombinant technology components by interacting with diverse resources and often across firm boundaries" [39] (p. 488). This results in blurred industry boundaries and gives rise to a new competitive dynamics [38].

Whereas digital innovation presents ample opportunities, it also creates challenges and complexities particularly for incumbent organizations [42]. Digital innovation breaks with the traditional assumptions shaped by the industrial innovation logic [40]. Oftentimes digital innovation demands incumbents to maintain the existing practices and the way of doing business alongside the new digital logic, which gives rise to tensions and complexity [42].

3. Business Models and Systems Thinking

This section provides a summary of the related research on the relationships between business models and systems thinking. The review of the literature uncovers two interrelated strands: one which focuses and views business models as systems, and another which centers on the potential of systems thinking to address business model dynamics.

3.1. Business Model as a System

There is an overall consensus that business models denote a system. A variety of definitions make inferences to the business model representing a system (e.g., [19,25,43]). For example, according to Zott and Amit [28] (p. 216) business model represents "a system of interdependent activities that transcends the focal firm and spans its boundaries". So according to them, the business model is a system composed of interrelated activities centered and conducted by the focal organization but also includes other activities performed by other actors outside the firm and even industry boundaries. As evident from the definition, a business model implies a system-level approach [37] to explaining how firms do business [28]. Similarly, Martins et al. [25] (p. 99) claim that the business model depicts "the designed system of activities through which a firm creates and captures value". These definitions, along with others, in addition to making inferences to the term system, do not make specific associations to the systems thinking literature. In a closer look, these definitions resemble the definition of a system by Meadows [8], who defines a system as not "just any old collection of things. A system is an interconnected set of elements that is coherently organized in a way that achieves something" [8] (p. 11). However, there are also studies that make explicit relations between business models and systems thinking. For example, Berglund and Sandström [43] considers business models as open systems, not having an isolated existence, but being a part of and dependent upon a larger ecosystem. Massa et al. [16] go further, claiming that business models represent "complex systems" According to them, a complex system is "a system comprising a large number of parts characterized by non-linear interdependencies, together creating a whole that is more than the mere sum of its parts" [16] (p. 59).

We concur with the view that the business model represents a complex system. However, that is not the core focus of this paper. This perspective represents the static view of business models [35], and according to Midgley and Lindhult [2], the early stages of systems sciences, which regard systems as complex real world phenomena to be objectively captured. Whereas it would be interesting to extend this view further, that is a recommendation for future research. In this paper, we instead focus on the dynamic perspective of business models [35], specifically on the value and potential of systems thinking to tackle the complexity that transpires in digital innovation.

3.2. Business Model Innovation from a Systems Perspective

In addition to just merely viewing business models as systems, several scholars have applied systems thinking in the business model area (e.g., [15,17,44,45]). Halecker and Hartmann [44] argue that the existing body of research fails to provide insight into how systems thinking can be applied to business model innovation. Nevertheless, some later papers have shed some light in that regard. This section provides an overview of a number of scholarly works on business model innovation from a systems perspective.

Velu [15] draws parallels between general systems theory [46] and business models. In that light, Velu [15] advocates systems thinking as a suitable perspective for understanding the dynamics of business models. He provides a conceptual systems thinking framework based on Distinctions, Systems, Relationships, and Perspectives (DSRP) by Cabrera and Cabrera [11] for overcoming cognitive barriers. This type of barrier is considered as one of the main challenges to business model innovation [27]. Cavallo et al. [17] advocate the system dynamics for addressing the evolution of business model innovation. Through the "Causal Loop Diagram" (CLD), the authors map the interrelationships between the different elements of the business model in the innovation process. In neither of these scholarly works we can identify how systems thinking approaches have been carried out and applied to business models.

In contrast to the above mentioned studies, Hindle and Vidgen [47] embrace a soft systems approach to business model innovation. They combine Soft Systems Methodology [9] with business model canvas [48] and propose the Business Analytics Methodology as a systematic tool for modelling and facilitating business model innovation. Similarly, Pereira et al. [45] utilized Soft Systems Methodology (SSM) in combination with business model canvas [48]. The authors applied the seven step model of SSM as a pre-stage to the business model canvas modelling, which was further developed to the SSM Learning Cycle (e.g., [49]). We see a limitation in applying the seven step model, as it is not iterative and not as "soft" as the SSM Learning Cycle. Another systems thinking approach addressing Business Model Innovation is, for instance, the work of Halecker and Hartmann [44], who propose the Integrated Systems Approach as an overarching model with the potential of including hard and soft systems approaches. However, the study does not clearly unfold how the combination of the hard and soft approaches comes into play. Monat et al. [18] discuss the challenges of the practical application of systems thinking. They attribute the failures of several businesses as a lack of adopting systems thinking. In a recent study, Midgley and Lindhult [2] focus on systemic innovation from a systems perspective. They classify systemic innovation into five categories: (1) technologically driven innovation, (2) policy and governance development to support innovation, (3) transition to a sustainable society aiming for more desirable patterns of production and consumption, (4) collaboration between multiple and interdependent actors embedded in an ecosystem, and (5) thinking in terms of systems. Thus, Midgley and Lindhult [2] argue for systems thinking as a fruitful theoretical and methodological approach to enhance the understanding of business model innovation.

Previous studies on the intersection of business models and systems thinking have advocated systems thinking as a promising approach to business model innovation. However, studies on the complexity emerging from the digital innovation of business models are scarce, and there is further major potential in addressing how systems thinking can be applied to address digital business model innovation.

4. Illustration of Digital Business Model Innovation

Up to this point we have presented the literature on the complex nature of business models, and the additional complexity emerging from digital innovation. Gharajedaghi [10] states "We see the world as increasingly more complex and chaotic as we use inadequate concepts to explain it. When we understand something, we no longer see it as chaotic or complex" (p. 24). He further argues that a holistic language, a language of systems, enables the chaos to unfold and the complexity to be understood. In the same vein, Cabrera [50] argues that systems thinking makes it possible to see the complex reality of the natural real world, that is, to look deeper and uncover patterns, systems structures, and mental models.

For this paper we have chosen the Rich Picture technique of the Soft Systems Methodology. The Rich Picture technique offers a non-linear approach to show relationships, entities, structures, and viewpoints (e.g., [9]) and hence provides a more comprehensive picture of the phenomenon. Figure 1 illustrates a generic overview of business models and digital innovation, i.e., digital business model innovation. The Rich Picture is then explained using theories of business model and digital innovation. The Rich Picture will first be explained from the business model perspective and thereafter expanded with the digital innovation dimension, hence providing an overview of the complex and dynamic nature of digital business model innovation.

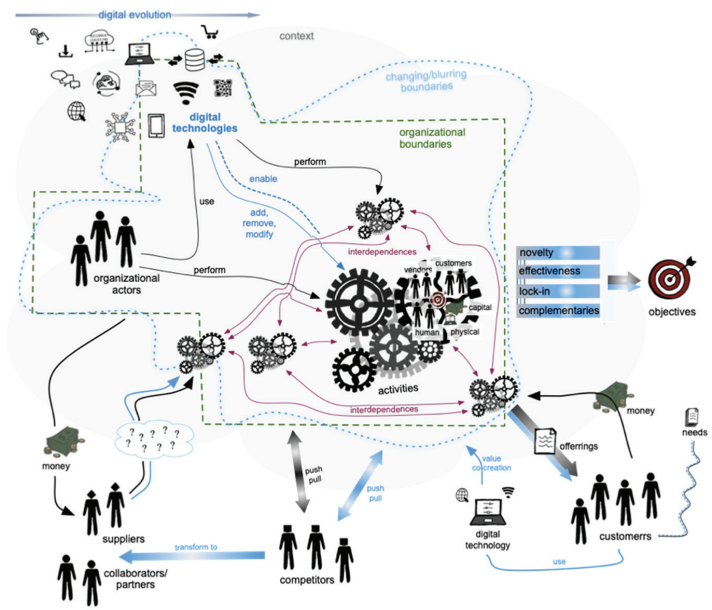

Figure 1. Rich Picture of Digital Business Model Innovation.

This section is then finalized with a presentation of a practical case example.

4.1. Generic Rich Picture of Digital Business Model Innovation

In the Rich Picture in Figure 1, the process and outcome of digital innovation is illustrated with blue colored lines. The green dashed line illustrates the traditional boundaries (non digital) of the organization. The black colored lines illustrate the relationships, and the maroon lines illustrate interdependencies (i.e., the structure).

Zott and Amit [28] define a business model as a purposeful activity system of interdependent and interrelated activities, performed by the organization and other actors in the ecosystem in order to produce an offering to fulfill a market need. In the Rich Picture above, this is illustrated as follows: The grouping of cogwheels in the center of the picture illustrates the activities (i.e., the content). Each activity is interdependent and interrelated to other activities, as illustrated with two sided maroon colored pointing arrows. The activities, as described by Zott and Amit [28], consist of several sub activities (each individual cogwheel should be understood as a single activity) where an activity has an objective (red and white bullseye in the middle of the larger cogwheel), humans, vendors, customers (illustrated as stick figures), capital, and/or physical resources illustrated in the lower right side of the large cogwheel in the middle. Illustrated as stick figures with round heads at the middle left side of the figure, the organizational actors perform the core activities. However, some activities could be performed by other actors outside the organization boundaries such as suppliers (stick figures with diamond heads, a cloud with question marks illustrated in the middle—lower left side and the customers in the middle—lower right side). The offering (products and/or services) is illustrated in the lower right side of the figure and is also an integral part of the gray–blue boxes in the middle right side of the figure. The gray–blue boxes are part of the objective of the organization's business model (illustrated as a red–white bullseye) and as part of that fulfilling a market need [28], exemplified by the needs of the customer illustrated in the lower right side of the figure.

The four sources of value creation, i.e., novelty, effectiveness, lock-in, and complementarities [28] are represented as grey–blue boxes in the middle right side of the figure). The dark gray color illustrates the value creation in a non-digital context, while the blue color represents digital technologies and digital driven innovations. The second trait of business models is its boundary spanning nature (e.g., [28]), illustrated in the lower part of the figure, divided into three parts. First, in the left corner, the suppliers are illustrated providing services, tools, raw material, etc. (illustrated as a cloud with question marks). Second, competition is illustrated in the middle, and third, the customers, who have different needs due to digitalization, are illustrated with a blue dashed line at the right end of the figure. The organization aims to fulfill the customers' needs by providing offerings (illustrated in bold arrows in the middle of the lower right corner) in return for receiving financial value (represented as money).

Digital technologies, as the main enablers of digital innovation [38,39], are illustrated in the top left corner together with the digital evolution illustrated as a moving forward arrow. The digital technologies (illustrated inside and outside of the organization boundaries) challenge the way value is created and captured [28], and this is illustrated throughout the picture in blue color lines, arrows, and boxes/shadows. Digital technologies affect the three elements of the business model [28]: content or the *what*, which entails the activities conducted (illustrated with a solid blue arrow in the middle of the figure), the structure or the *how*, which represents the way these activities are connected and their sequence (illustrated as a dashed blue line in the middle of the figure) and governance, which refers to *who* perform the activities (illustrated with a solid black arrow in the middle of the figure), where these actors include internal actors, the technology, and/or actors outside organizational and even industrial boundaries.

As illustrated with the dashed blue line, digitalization has blurred and even changed organizational boundaries. Examples of this impact include the blurred and changing roles and relationships of actors within the ecosystem; customers can become co-creators of value (illustrated in the right side corner of the figure); or competitors, who become collaborators, hence having multiple roles (illustrated as a bold blue arrow in the lower middle and left side of the figure).

A final highly important aspect to consider is the context in which the organization is embedded. The context is represented by a large cloud in the Rich Picture. It should be noted that due to digitalization, the organizational boundaries can end up outside of the incumbent context, and other actors who reside outside the organization might be within or outside the specific context.

4.2. Digital Business Model Innovation in Practice

There are several case examples of different companies who struggled or managed to leverage the potential of digitalization in order to create unprecedented innovations and value. In this light, drawing on previous studies, we present an example of digital business model innovation. The case example is Netflix, which is a global company in the digital media landscape. It is impossible in this section to include detailed aspects of business models in terms of content, governance, and structure. Therefore, this is not intended to be an exhaustive depiction, but a mere generic overview.

Netflix has been the subject of an array of scholarly work (e.g., [51–54]) as a case example of a successful business model innovation but also as a success story of an ambidextrous organization [54].

Netflix is characterized by three major business model innovation leaps: DVD rental service, content streaming, and production of original content [52,54]. The business model innovation of Netflix had far-reaching implications for the video rental market first, resulting in the bankruptcy of other competitor companies, e.g., Blockbuster. Later on, Netflix managed to enter new markets (film industry) and competed with Hollywood studios (e.g., Warner Brothers, Paramount Pictures, Universal Pictures) [53] and also was nominated and won several awards.

Snihur and Zott [37] illustrate the Netflix business model in the end of 1990. Netflix utilized novel technologies at that time, namely DVDs and the Internet, for delivering its offerings, which were movies on DVD. As Snihur and Zott [37] describe, Netflix introduced novel activities such as transactions through the website and mailing of DVDs, in addition to internal technology optimization related activities. To enable this, they partnered with several actors such as movie studios and DVD producers but also with a shipping company (U.S. Postal Services). Moreover, Netflix innovated the structure of the business model, where customers performed order transactions online and received the movies in their homes instead of picking them up at physical video stores [37] (p. 556). For a fixed monthly subscription, customers could rent unlimited movies [51].

A few years later, Netflix shifted the focus of the business to online streaming and content production [54]. This innovation was characterized by changes in all three elements of the business model: content, governance, and structure. Netflix offers an extensive, on-demand, ad-free library of content, through a rather simple and efficient subscription model [52]. In terms of the business model content, Netflix's activity system is composed of a multitude of interrelated activities ranging from provision and delivery of DVDs, to content acquisition; licensing, streaming, and production and commissioning of own original content; various local language content productions [53]; activities related to future video game offerings; and data analytics to understand and predict customer behavior in order to improve and provide personalized experience, marketing, and recommendations [51,52]. The majority of activities is conducted internally but Netflix also collaborates closely and relies on several other actors. To name a few, Netflix collaborates closely with content providers, producers, and creators. Moreover, as Fagerjord and Kueng [52] explain, distribution of the content is dependent and enabled by content delivery networks (CDN) and technological infrastructures, e.g., Internet and Mobile service providers. Amazon Web Services enable the international billing infrastructure, and Netflix has delegated data processing tasks to them [52]. Further, as they explain, all these various actors who partake in the business model collect data from one another. Technology enables almost all activities, delivery of services, and the data analytics, which is the cornerstone of Netflix business model [52]. Other collaborators include smart TV companies, the gaming industry, and local partners for local language productions. Customers use different technological devices to view the content. They have control of the selection of the movies, when they want to watch them, and through which means. They watch them in the convenience of their own home [53].

A brief analysis shows that Netflix creates value by drawing on four drivers of value creation as presented by Zott and Amit [28] and Zott and Amit [5]. Similarly, some mechanisms activate several of the drivers. Netflix creates value for its users by providing original unique content (*novelty*), which they cannot find in other platforms, at least not with ease. The original content also serves as a *lock-in mechanism*. Netflix also provides a user-friendly interface, with easy selection possibility, and so-called "binge watching" [52], which refers to access to several episodes and/or entire seasons of TV series at one time [52]. Moreover, it provides an uninterrupted possibility of content consumption regardless of the devices. All these factors serve as lock-in mechanisms. *Efficiency* is another activated source of value creation. Netflix provides an efficient, inexpensive way to watch movies [52], with convenient and straightforward pricing, and the possibility of offline downloading [55]. *Complementarities* are another noticed value driver. Complementaries are evident in the bundling of various content (enormous library), distribution channels (desktop, tablet, mobile, apps, film festivals), and users, such as allowing several members of the same household to have access to different content. The latter could also be perceived as a lock-in mechanism.

The success of Netflix is attributed to the long-term innovative vision of the management, who were able to see beyond the market needs [54,56]. Most importantly, however, their success did not hinder Netflix to see beyond. Management of Netflix did not hesitate to disrupt their own legacy business model, which was still successful. In an interview by Jaworski [56], a former manager of Netflix states "If you're obsessed about upsetting your legacy business, you're screwed to begin with" (p. 187). This potential to use digital technologies in a novel manner, the capacity for managing ambidexterity, and the continuous start-up mindset [54] enabled Netflix to move from a retailer and enter another market space, that of the film studios.

5. Discussion

In this paper we conceptualize and illustrate digital business model innovation as an instance of systemic innovation [2] and digital innovation [3,5]. This paper brings together these two strands under the notion of digital business model innovation. Whereas in Fichman et al. [3] this representation of digital business models is obvious in the definition itself, in Midgley and Lindhult's [2] work, we see digital business models falling in at least four of their categorizations of systemic innovation, namely technologically driven innovation, transition to a sustainable society aiming for more desirable patterns of production and consumption, collaboration between multiple and interdependent actors embedded in an ecosystem, and thinking in terms of systems. The case used in this paper, although used to illustrate the digital business model innovation, also sheds light on the systemic features of the digital business model innovation of Netflix.

We argue that the digital business model innovation of Netflix was technologically driven. In the end of the 1990s, Netflix used the technology at that time (DVD, Internet) in an innovative manner which resulted in changes of the movie rental industry. The technology driven innovation also led to societal changes, resulting in the changing behavior and norms of customers. Netflix reinvented the way movies are delivered and consumed. The implication is that Netflix significantly influenced the needs and behavior of customers. Rather than buying and owning products, customers now have access to a large bundle of content and instead consume content on demand. These changes can also be seen in relation to other external actors. Netflix's business model innovation was enabled by a collaboration between several actors. Each business model innovation leap introduced new actors with distinct capabilities, such as, first, the U.S. Postal Service, and later, Amazon Web services, Internet and mobile providers, TV companies, and local partners, among others. Digital technologies were a crucial actor in every innovation leap of the Netflix activity system. The fifth categorization of Midgley and Lindhult [2], that is, thinking in terms of systems, is discussed in relation to the characteristics of digital technologies which have given rise to these innovations.

In this study, the business model is conceptualized as a potential of using technologies to create value [36], not only for the individual company but also for other actors in the ecosystem. Features of digital technologies, respectively, the decoupling of the content from the medium, was the main enabler of innovations in Netflix. The dematerialization of information made these innovations possible; however, it was the ability of Netflix to reap the potential of digitization which made them become a leader and disrupt an incumbent sector. The success of Netflix is attributed to the long-term innovative vision of the management and their ability to disrupt their existing and rather successful business model. This was for instance highlighted in Jaworski [56]. In the case of Netflix, although the sources we have drawn upon do not refer to systems thinking, we observe traces of systems thinking into Netflix innovation efforts. In addition to the technology, Netflix managed to fully align other factors and actors into its digitalization journey, which transcended the boundaries of the organization and disrupted an established market. This feature of systemic innovation resonates with the cognitive research strand on business models (e.g., [22]); however, it moves beyond the managers' mental models in the innovation process to the whole of the actors partaking in the innovation.

In line with Midgley and Lindhult [2] we see that the last category also influences all other categories of systemic innovation. In the case of Netflix this is observed in the changes of managerial mindset, customer behavior, competition, and collaboration, all due to digital technologies and digitalization.

Further, as a result of digitalization, boundaries are transcended but also fluid [41] and hence more complex. Digital innovation affects all elements of business models and thereby adds levels and additional dimensions to the complex dynamic nature of business models. With the Rich Picture we have captured and illustrated this complexity. This systems thinking technique has provided us a systems language to depict the activities, the relationships, the offerings, and the co-creation of value, as well as the actors and their shifting roles. The Rich Picture in this paper brings together business models and digital innovation in an emerging overview within the larger business model context.

Nevertheless, what we present is generic and covers the main components of digital innovation of business models. It is challenging and even impossible to cover all complexity and multidimensionality of digital business model innovation as a real world phenomena. Therefore, it is crucial to acknowledge unique features such as the organizational context area and also the aim and the purpose of a project focusing on digital business model innovation.

Further, it is important to have in mind that the case we have presented was established in the breaking point of the digital era and represents a successful case of digital business model innovation and ambidexterity. Traditional incumbent organizations from different sectors (e.g., law, newspapers, car industry, healthcare) face additional complexities in their digital business model innovation journey.

The systems thinking perspective, which has been voiced by several other authors (e.g., [16–18]), has immense potential to address and tackle the complexity of digital business model innovation. Furthermore, due to the dynamic multifaceted complexity, we see the need for several systems methodologies to cover different dimensions of the complexity and hence reaching a more holistic understanding of the phenomena.

6. Concluding Remarks

In this paper, through the review of previous literature, the use of Rich Picture, and presentation of Netflix, we depict the emerging complexity from digital innovation. We show that each digital innovation leap brings about changes in business models' constellations, hence adding several levels and different dimensions to the complexity. Further, the outcome of this study shows that the complexity is salient across several aspects, such as offering, activities, relationships between the activities and actors, and their roles. In order to explain, explore, and tackle the dynamic complex situation of the digital business model innovation, a more comprehensive approach is needed. We therefore suggest a combined and mixed systems thinking approach for addressing digital business model innovation (e.g., [57,58]). Applying such an approach allows systems methodologies to be combined with methods with different strengths and focuses, hence gaining a more holistic understanding of digital business model innovation. In line with Midgley and Lindhult [2], we advocate for the potential of a combined and mixed systems thinking approach. We strongly encourage such an application in future research frontiers related to digital innovation.

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systems

MDPI

Article

Multisided Platforms: Classification and Analysis

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Abstract: The multisided platform (MSP) is an essential business construct in the digital economy. Some of the largest companies in the world—including Google, Amazon, and eBay—exploit the MSP in their business models. Fundamental insights into the MSP are crucial to understand the business operations of the digital economy and how new innovative digital services are adopted in the market. The MSP ecosystem is complex and dynamic, and involves heterogeneous stakeholders with different business motivations. This paper classifies the various types of MSPs, distinguished by the network effect between user groups. Moreover, this paper shows how the original diffusion model of Frank Bass can be extended to analyze the temporal evolution of multisided platforms. Analytical models using coupled sets of ordinary differential equations are developed for several examples of two-sided platforms. For some of these examples, analytical solutions are found.

Keywords: digital business models; digital economy; network effects

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1. Introduction

Fundamental strategic questions in market analysis are related to how the market for new innovations evolves as a function of time. Will it start developing at all? How fast will it grow? At what time will the market start to generate revenues? When will the market reach saturation? These were, for example, the key questions when the Global System for Mobile Communications (GSM) was developed during the 1980s. The market departments of several telecommunications carriers questioned whether mobile communications would ever become an important asset in their portfolio [1]. Cellular mobile communication is a simple "single-sided" service, and, even in such a simple case, it is difficult to produce good and reliable forecasts for the evolution of the technology. Answering these questions is much more difficult for multisided platforms since, by definition, several market segments with entirely different value propositions interact and evolve simultaneously. In several cases, it is, therefore, not enough to study the evolution of each market segment alone. This is one of the questions explored in this paper, in particular, if and how the interaction takes place between market segments. The answer to this question is one of the key subjects of Sections 4 and 5.

The purpose of this paper is to shed light on some of these questions for multisided platforms (MSPs) with strong network effects between the user groups. In particular, the paper studies how initial growth may be stimulated and how fast the different market segments will grow. We will use simple mathematical models based on standard analyses of nonlinear dynamic physical systems (see [2] for an introductory text on nonlinear dynamic systems). These models are just idealized approximations for the evolution of real multisided markets. Nevertheless, the models may uncover basic characteristics concerning the temporal evolution of the platform businesses that are important for strategic decisions.

Two comprehensive overviews of the literature on the economics of MSPs are presented in papers by Sánchez-Cartas and León [3] and Abdelkafi et al. [4]. The papers referred to in these studies consider the economics of multisided platforms from different perspectives, such as design, dynamics, performance, regulations, and policies. These papers provide insight into important areas, such as the pricing of platform services, interactions, and network effects between the different market segments of the platform, the behavior of users, competition between platforms offering equivalent services, problems associated with regulations, and the formation of de facto monopolies. There are also a few studies concerning the dynamics of these platforms, in particular the initial evolution of the platform service—see, e.g., [5,6]. These papers are concerned with two types of problems: the service initiation problem (“chicken and egg” problem) and the competition between platforms offering similar services. However, none of the papers address the temporal evolution of platform services using analytic or system dynamic methods.

In their book [7], Cusumano et al. offer a comprehensive introduction to business models and several other aspects of multisided platforms, covering most of the business aspects of multisided platforms also referred to in the articles by Sánches et al. and Abdelkafi et al. However, the book does not contain explicit analyses of the temporal evolution of platform services.

Our literature search has not revealed any mathematical studies concerning the temporal evolution of multisided platforms from launching to market saturation. In particular, the search has not revealed any examples wherein ordinary differential equations are used for this purpose. This observation exposes evident gaps in the study of the market evolution of multisided platforms.

The purpose of this paper is to fill this gap by developing new mathematical models for how network effects within (same-side) and between (cross-side) different market segments—or user groups—make the market segments interact and grow. The new mathematical models are inspired by the Bass model for the growth of consumer durables [8] by proposing how the differential equation developed by Bass can be extended to incorporate cross-side network effects. The theory is applied to the special case of two-sided platforms to derive closed-form solutions of differential equations. Analysis of more complex platforms can only be done by numerical methods and simulations. This is beyond the scope of this paper.

Our work is also inspired by the early studies of Arthur et al. on the path-dependent evolution of economic systems with strong network effects [9]. They study the temporal evolution of such systems using a discrete growth algorithm based on Polya urns. They show that the system may end up in any of several possible future equilibrium states, and not in just one predetermined state, as postulated by classical economic theory. For a comprehensive overview of the application of Polya urn models, see [10]. The application of Polya urns to complex systems, such as MSPs, is difficult. Therefore, unlike the work by Arthur et al., we will use the simpler and more direct approach of coupled nonlinear differential equations to study the temporal evolution of MSPs. We have not found any papers in the economic literature addressing the evolution of multisided platforms in this way (or by any other methods).

In summary, the main contributions of this paper with respect to multisided platforms are:

1. To show how to extend the Bass equation to MSPs with both same-side and cross-side network effects.
2. To classify two-sided platforms according to same-side and cross-side network effects, and to develop a generic set of first-order differential equations for each class.
3. To show mathematically that the initial growth of the platform may depend on the type of network effects in such a way that the market segments offered by the platform will not start growing unless there are some initial customers. This is often referred to as the “chicken and egg problem”. The strategic challenges are then (i) to identify whether this is the case for the platform and (ii) to determine how to persuade sufficient numbers of customers to start using the platform to reach a threshold at which the growth becomes self-sustained.

4. To show that, even with an initial customer base, network effects may result in long latency periods until the market reaches a level at which the revenues from the platform become positive. Such behavior has been observed for, for example, Facebook [11]. This is also a strategic challenge because long latency may motivate the platform provider to terminate the service prematurely.
5. To show that the market growth subject to strong network effects follows an S-curve shape, from slow initial growth (e.g., much slower than linear growth) to rapid growth after the market has exceeded a certain threshold.

The rest of the paper is organized as follows: Section 2 introduces multisided platforms. Section 3 provides the general analytical model for the temporal evolution of MSPs from launching to market saturation; in particular, how the differential equation developed by Bass can be extended to such platforms. To our knowledge, this is a new approach to studying the business potential of MSPs. Section 4 proposes a classification of two-sided platforms. It is shown that there are seven generic classes of two-sided platforms; that is, the complete analysis of two-sided platforms is limited to these generic classes. Section 5 is the main body of the paper, suggesting analytical models for each of the seven classes of two-sided platforms. This analysis is by no means complete, but it provides some insight into strategic issues related to the different classes, in particular the "chicken and egg" problem. Finally, Section 6 concludes the paper.

2. Multisided Platforms

This section discusses the background and related works of MSPs (Section 2.1), and details concerning market feedback, pricing, competition, business ecosystem, and market regulations (Sections 2.2–2.6).

2.1. Background and Related Works

In the MSP, two or more distinct user groups interact to produce mutual benefits for each other [12]. In many practical cases, there are just two groups—the multisided platform then becomes a two-sided platform. There is no essential difference between modeling two-sided and multisided platforms except that it becomes more difficult to solve the differential equations. Therefore, the mathematical description of the dynamics of such platforms is limited to two-sided platforms to derive closed-form expressions for the temporal market evolution of the platform. This is done in Section 5 based on the classification proposed in Section 4. The general conclusions from the simple models for two-sided platforms may still be extended to more complex platforms as elements for assessing business opportunities and strategic challenges.

Some of the largest companies in the digital economy are MSPs, for example, Google, Amazon, eBay, Uber, and Airbnb [13,14]. Some MSPs have even become the market leaders in their industry, sometimes even without owning expensive physical assets, e.g., Uber and Airbnb. There is tremendous value in connecting different user groups. Furthermore, there remains huge potential for implementing MSPs in several business and industry sectors, as well as public domains.

The basic business proposition for MSPs is to offer mediating services, following the value network concept defined by Stabell and Fjeldstad in [15]. In this value-generating model, the organization offers services that support direct or indirect interactions between users. The organization also manages contracts that allow the users to access and utilize the services. Examples of contracts are subscriptions, tickets, club memberships, and ownership of certain tokens (e.g., credit cards).

The mediation may take place between users in the same user group and between users in different user groups. Facebook offers direct mediation services between the users of the social medium, allowing them to interact. In addition, Facebook offers mediation services between two different user groups—advertisers and users—by collecting information about the users that the advertisers can exploit to target the marketing of their products. However, a basic requirement for an MSP is that there must be interactions between the user groups.

If this is not the case, then the platform just participates in independent business sectors and can be analyzed by standard business models. There are two main types of MSPs: digital MSPs and tangible MSPs. Digital MSPs mediate the exchange of digital goods and services, while tangible MSPs mediate the exchange of physical goods and non-digital services. Facebook and MasterCard are examples of digital MSPs, whereas Uber and Airbnb are examples of tangible MSPs. Tangible MSPs have also been termed “Online-to-Offline (O2O)” MSPs [16]. Examples of MSPs are shown in Table 1 ([14], Chapter 10).

Table 1. Examples of digital and tangible MSPs.

MSP	Type of Business	User Groups	Platform Type
Facebook	Social networking service	Users and advertisers	Digital
Kickstarter	Crowdfunding	Borrowers and investors	Digital
MasterCard	Point-of-sale transactions	Merchants and cardholders	Digital
New York Times	Newspaper	Readers and advertisers	Digital
Airbnb	Sharing service	Hosts and guests	Tangible
eBay	Electronic marketplace	Sellers and buyers	Tangible
Uber	Sharing service	Drivers and passengers	Tangible

Ardolino et al. [17] qualitatively described market feedback, pricing, competition, business ecosystem, and market regulation for MSPs. In a paper by Parker and Van Alstyne [18], the business prospects of two-sided platforms are analyzed using standard micro-economic supply and demand theory. The purpose of their paper is to show how companies can offer one of the products of the two-sided platform for free and, by this action, increase the total revenues generated by the platform. The characteristics discussed in these papers ([17,18]) are summarized in Sections 2.2–2.6.

2.2. Market Feedback

Network effects—or network externalities—are generated by positive feedback from the different market segments of the MSPs. There may be feedback from users in one user group to the users of the same user group—same-side network effects. In the simple market model of Bass, users subjected to such network effects are called imitators, as these are users that adopt a service or buy a product because others do so [8]. Feedback from one user group to another user group is called cross-side network effects. Both same-side and cross-side network effects may be positive—that is, increasing the probability that other users will adopt the service—or negative—that is, reducing the probability that other users will adopt the service or even persuade existing users to stop using the service. This paper considers only positive network effects.

2.3. Pricing

The pricing model, and hence the way revenues are generated, may be complex. Examples of price regimes of multisided platforms in the digital economy are:

- All user groups pay for the services they receive, for example, sellers and buyers using eBay and property owners and renters on Airbnb.
- Some users of a user group may pay for the services they receive, and other users may receive downscaled services for free, while other user groups (e.g., advertisers) may pay for all services they receive (e.g., advertisements and marketing). Examples of businesses applying such payment methods are electronic newspapers and Spotify.
- One or several user groups receive the services for free while other user groups pay for the services (e.g., Facebook and Google Search).

The last two pricing models are typical for MSPs if there is a strong network effect from one user group to another (for example, between users of Facebook and firms producing targeted advertisements). Subsidizing one of the user groups may increase the income generated by the platform rather than reducing it, since it may contribute to the growth of users in the other user group(s).

2.4. Competition

The platform may compete with other platforms offering the same services (e.g., Facebook and Myspace) or with entirely different platforms for capturing certain types of customers (e.g., Facebook and Google Search competing to attract advertisers). This type of competition may seem counterintuitive but is the most important competitive challenge for several platform operators. There may also be competition between the customers of the same user group (e.g., between drivers offering services over the Uber platform).

2.5. Business Ecosystem

Because of competition, the ecosystem for MSPs is more complex than other businesses. For this reason, the MSP must sometimes include stakeholders in its ecosystem analysis that are seemingly unrelated to the key business area of the platform. Therefore, standard business modeling tools may not capture all strategic issues the MSP is facing. Business models may, for example, fail to take cross-side network effects properly into account, and treat the various business segments independently.

2.6. Market Regulations

The existence of two or more user groups and strong network effects both within and between the user groups make it difficult to identify one regulatory regime that ensures fair competition and avoid market failures, such as the formation of monopolies. One particular problem is that the MSP is a monopoly in one market segment but not in other segments. For example, Facebook is a monopoly in the segment of social media services but not in the advertisement segment. The complexity of competition and the ecosystem may make it difficult to identify what can be regulated, the actual effects of the regulation and, in particular, how to avoid market failures.

3. A General Dynamic Model of MSPs

This section introduces the general dynamic model of the MSP (Section 3.1). Moreover, the section discusses the feedback function and the choice of parameters used in Section 5 (Section 3.2), and the combined effects of same-side and imitated cross-side network effects (Section 3.3).

3.1. The Model

Figure 1 shows a multisided platform with three user groups receiving different services from the platform via the links associating each user group with the platform. The model is extended to any number of user groups in an obvious way. The dynamic growth of each user group is determined by several factors:

- Existence of innovators—or early adopters—joining the group independently of other users.
- Existence of imitators joining the group because other users have done so—same-side network effects.
- Existence of cross-side network effects causing users to join the group because other users have joined one or several other user groups.

In a multisided platform, different products or services are offered to several user groups. The dynamic behavior of the system consisting of n user groups is then determined by a set of n first-order differential equations, one for each user group, derived from the Bass equation [8]. To be independent of scale, the relative number of users in each user group is used as the dependent variable, i.e., $u_i = U_i/M_i$, in which U_i is the absolute number of users having adopted service i and M_i is the absolute number of potential users in this user group. The values of u_i are then in the closed interval $u_i \in [u_{i0}, 1]$, in which $u_{i0} = u_i(0)$ is the initial value of u_i.

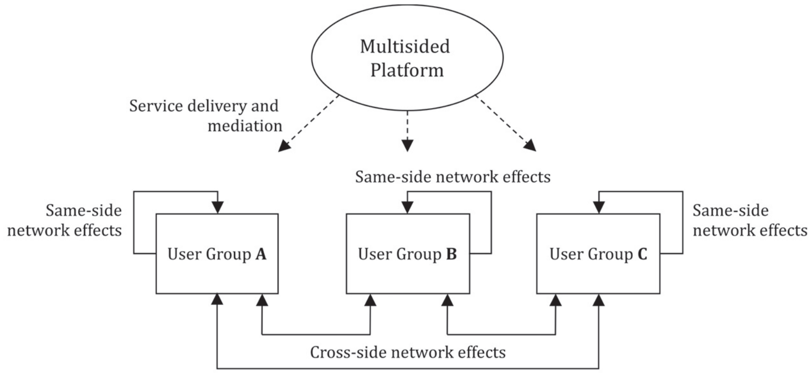


Figure 1. A multisided platform with three user groups—A, B, and C. Same-side and cross-side network effects within and between user groups, respectively, are indicated.

The Bass model describes how a new product is adopted by potential consumers. Using a more direct method than Frank Bass, the simple differential equation for the temporal evolution of the market of a single product can be written as

$$\frac{du}{dt} = (p + qu)(1 - u) \tag{1}$$

in which u is the relative number of adopters at a given time, p is the coefficient of innovation, and q is the coefficient of imitation [8]. The equation says that the change in the number of users adopting the service is proportional to the number of users that has not adopted the service yet $(1 - u)$. The proportionality factor $(p + qu)$ is the sum of the rate by which innovators adopt the service (p) and the rate by which imitators do so (qu).

The Bass model assumes that imitators and innovators can be modeled as two homogeneous groups of indistinguishable agents characterized by a uniform probability to adopt the service—that is, the probability of adopting is averaged over the distribution of individual decisions made by each agent. For large user groups, this is a good approximation that allows us to analyze the dynamics using simple differential equations. There are two significantly different special cases of the Bass equation, as below.

All users are innovators—that is, there are no network effects and $du/dt = p(1 - u)$. Since there are no network effects, the market starts increasing even if there are no initial customers, i.e., $u_0 = u(0) = 0$.

All users are imitators—that is, all users adopt the service because other users have done so. In this case, the equation becomes $du/dt = qu(1 - u)$. If there are no initial users ($u_0 = 0$), the solution of the differential equation will be $u = 0$ for all t, that is, no users will ever adopt the service. This is the mathematical evidence of the chicken and egg problem.

The models in Section 5 will use the first case if there is no same-side network effect. If there is a same-side network effect, the second case (with $u_0 > 0$) is used. The reasoning behind this choice is elaborated in Section 3.3. Cases where there are both imitators and innovators (i.e., using the full Bass equation) are not considered because this results in differential equations for which analytic solutions cannot be found. This case should be subjected to further study.

The Bass equation can be extended to multisided platforms by multiplying the original equation by the effect feedback all other user groups have on the adoption rate of a particular user group. The logic behind this choice is that the feedback from other user groups increases the likelihood that new users will adopt the service; that is, the adoption rate of the Bass equation is modified by a factor equal to the feedback function. The set of differential equations for the dynamics of the multisided platform then becomes

$$\frac{du_i}{dt} = (p_i + q_i u_i)(1 - u_i) F_i(u_1, u_2, \cdots, \hat{u}_i, \cdots, u_n), \tag{2}$$

in which the index i enumerates the user groups and the function F_i is the combined cross-side network effect generated by all other user groups. The symbol $\hat{u}_i$ means that the function does not contain the variable u_i. Without cross-side network effects (that is, $F_i = 1$), this reduces to a set of n independent Bass equations—each user group then evolves independently of how all other user groups evolve. It is also reasonable to assume that the feedback function can be written in the form:

$$F_i = \prod_{j \neq i} f_{ji}(u_j) \tag{3}$$

Here, f_{ji} is the feedback from user group j to user group i. The rationale behind this assumption is that the feedback from one user group depends only on the number of users of that group and is independent of all other user groups. For two-sided platforms, the set of differential equations is:

$$\frac{du}{dt} = (p_1 + q_1 u)(1 - u) f_{vu}(v) \tag{4}$$

$$\frac{dv}{dt} = (p_2 + q_2 v)(1 - v) f_{uv}(u), \tag{5}$$

in which we have, for simplicity of notation, set $u_1 = u$ and $u_2 = v$. We will use these equations in Section 5.

3.2. The Feedback Function and Choice of Parameter Values

One simple cross-side feedback function from users of type j to users of type i is $f_{ji} = s_i u_j$. We will call this feedback function imitated cross-side feedback. The rationale for this choice is twofold. If there are no users of one type, then there will be no users of the other type either. Moreover, it is assumed that the adoption rate for users of one category is proportional to the number of users of the other category. This is the reason why this type of feedback is denoted imitation. Facebook can be modeled as a two-sided platform consisting of the user groups social media users and advertisers. There is a same-side positive network effect between the social media users and a positive cross-side network effect from the social media users to the advertisers. However, if there are no social media users, there will be no advertisers. Moreover, it is reasonable to assume that the number of advertisements—and the revenues of Facebook—are proportional to the number of social media users on Facebook. On the other hand, there is no same-side network effect between advertisers; however, there may be a negative network effect from advertisers to social media users since advertisements may be viewed as unwanted distractions by some users. We do not include negative network effects in our model, but leave this for future research.

Another feedback function is $f_i = 1 + r_i u_j$. We call this composite growth feedback. The rationale behind this choice is that users of type i adopt the service even if there are no users of type j. In this case, the cross-side network effect only increases the adoption rate for users of type i if $r_i > 0$ (or reduces it if $r_i < 0$). One example of this feedback function is freemium services with several user groups, in which, for example, one user group is offered a limited set of services for free. The existence of other user groups paying for more advanced services may have a positive feedback effect on the freemium user group since it may increase the functionality of the free—or cheaper—versions of the product. The two feedback functions outlined—imitated cross-side feedback and composite growth feedback—will be used in the various cases analyzed in Section 5 for two-sided platforms.

Next, let us estimate reasonable values for the coefficients of innovation and imitation for two-sided platforms. If there are only innovators, the solution of the Bass equation is $u = 1 - e^{-pt}$ ([14], Chapter 18). If we assume that 50% of the users have adopted the service after five years, we find $p = -\ln(1 - u)/t \approx 0.14$. This is close to what has been observed for the mobile phone market in several countries [19]. Similarly, the solution of the Bass equation with only imitators is $u = u_0/\left[u_0 + (1-u_0)e^{-qt}\right]$ ([14], Chapter 18). Based on the statistics for Facebook [11], we set the initial number of users to $u_0 = 1\%$ and—presuming that $u = 50\%$ of the potential users adopt the service after $t = 10$ years—find $q \approx 0.46$. We also assume that the cross-side coefficient of imitation (s) is of the same order of magnitude as q. To investigate the imitated cross-side network effects, we use three values for s, namely 0.23, 0.46, and 0.92.

For composite growth feedback, we have not found empirical values for r. To investigate the effect of this feedback function, we have chosen, quite arbitrarily, 0.5, 1, and 2. The set of parameters is summarized in Table 2.

Table 2. Overview of parameters and initial values.

Parameter	Description	Initial Value
$u(t)$	Relative number of users in user group A	-
$v(t)$	Relative number of users in user group B	-
u_0, v_0	Initial relative number of users in group A ($u_0 = u(0)$ and group B ($v_0 = v(0)$)	0.01
u_T, v_T	Threshold value for a sustainable market size	0.1
t_u, t_v	Time to reach threshold value u_T and v_T, i.e., $u(t_u) = u_T$ and $v(t_v) = v_T$	-
p	Coefficient of innovation	0.14
q	Same-side coefficient of imitation	0.46
s	Cross-side coefficient of imitation	0.46
r	Cross-side coefficient of composite growth	1.0

These parameter values have no significance other than being used in the examples in Section 5. For real applications, the parameters are expected to vary considerably between different services designed according to a particular platform type, as well as between services designed for different platform types. Hence, analyzing real platforms and comparing them with theory requires the determination of empirical parameters for the specific business cases being studied.

3.3. Combined Effect of Same-Side and Imitated Cross-Side Network Effects

Let us use the values for the flow parameters calculated in Section 3.2 to estimate latency under the conditions that all users of type A are innovators, and all users of type B are imitators and subject to cross-side network effects of the type $f = su$, i.e., only imitated cross-side feedback, in addition to same-side network effects. This case is illustrated in Figure 2.

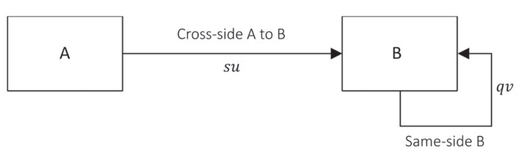


Figure 2. Two-sided platform with same-side and cross-side imitators.

The general set of differential equations for a two-sided market derived in Section 3.2 is:

$$\frac{du}{dt} = (p_1 + q_1 u)(1-u) f_{vu}(v) \tag{6}$$

$$\frac{dv}{dt} = (p_2 + q_2 v)(1-v) f_{uv}(u). \tag{7}$$

Setting $q_1 = 0,\ p_1 = p,\ p_2 = 0,\ q_2 = q,\ f_{vu}(v) = 1$, and $f_{uv}(u) = su$, the differential equations for u and v become:

$$\frac{du}{dt} = p(1-u) \tag{8}$$

$$\frac{dv}{dt} = suqv(1-v) \tag{9}$$

For small u and v, we have $1 - v \cong 1 - u \cong 1$. The solution of the first equation is then $u \cong pt$. Inserted in the second equation, this gives:

$$\frac{dv}{dt} = spqvt \tag{10}$$

$$v = v_0 e^{\frac{pqst^2}{2}} \tag{11}$$

The time it takes the number of users to reach the threshold v_T is then

$$t = \sqrt{\frac{2\ln(v_T/v_0)}{pqs}} \tag{12}$$

Suppose that the relative number of customers of type B must reach the threshold $v_T = 0.1$ before the service becomes self-sustained, and, moreover, that the relative number of initial customers of type B is $v_0 = 0.01$ (e.g., 10,000 customers in a population of 1 million). Using the values calculated earlier for p and q, and $s = 0.46$, it will take $t \approx 12.5$ years before the relative number of customers of type B reaches a market share of 10%. Hence, the situation wherein the adoption rate for customers of type B depends both on the number of customers of type A and all customers of type B being imitators cannot exist in real markets—the latency period is simply too long before the service generates any revenues. Only markets with weaker feedback functions are realistic in this case. Therefore, the composite growth feedback function $f = 1 + ru$ is used in cases wherein both same-side and cross-side network effects determine the dynamics of one or both user groups.

4. Classification

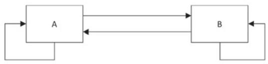
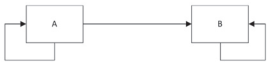
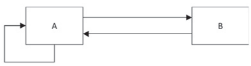
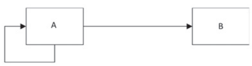
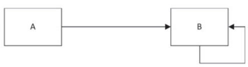
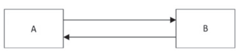
There are altogether 16 possible combinations of same-side and cross-side network effects in an MSP consisting of two user groups. However, the number of combinations that need to be analyzed can be reduced to seven cases, as follows. Cases in which there are no cross-side network effects are not included, since they will be reduced to two independent Bass equations. Some of the cases are made symmetrical by interchanging the dependent variables u and v. For example, the cases "same-side A, cross-side AB, cross-side BA" and "same-side B, cross-side AB, cross-side BA" are identical in this respect. As are are the cases "same-side B, cross-side AB" and "same-side A, cross-side BA". Table 3 summarizes the seven independent cases that need to be analyzed.

The type of cross-side network effects is indicated for each case based on the observations made in Section 3.2. That is, if there is no same-side network effect, then imitated cross-side effect is used, and if there is same-side network effect, then the composite feedback effect is used. The table also includes an example of a digital service that obeys a particular model and the corresponding user groups. The parameter values used in the models of Section 5 are not based on empirical analysis of the example service, but on the values suggested in Section 3.2. Hence, the mathematical models in Section 5 do not describe the example service as it exists in the real market but are only concerned with the qualitative behavior of the particular model. The innovator of a two-sided platform business can use the models:

- To identify whether the implementation is subject to strategic traps such as "chicken and egg" and long latency.
- To determine how each service of the platform is likely to evolve (following an S-curve or an exponential distribution).

- To use these observations to study the evolution of the money flow generated by the platform and future profit prospects.

Table 3. Overview of the various types of MSPs, their corresponding feedback, and example services.

Section	Model	Cross-Side Feedback	Example Service (User Groups)
Section 5.1		$1 + ru$ $1 + rv$	Airbnb (guests and hosts)
Section 5.2		$1 + ru$	Uber (drivers and passengers)
Section 5.3		su $1 + rv$	PayPal (users and merchants)
Section 5.4		su	Facebook (users and advertisers)
Section 5.5		$1 + ru$	Yelp (restaurants and reviewers)
Section 5.6		su sv	eBay (buyers and sellers)
Section 5.7		su	Google Search (users and advertisers)

5. Analysis

The set of differential equations for each case is derived from the equations in Section 3.2 and using feedback functions as shown in Table 3. For same-side network effects, we limit the analysis to a case wherein all potential users are imitators, that is, the same-side feedback function is $q_1 u$ for one type of users (A) and $q_2 v$ for the other type of users (B). For simplicity, we set $u(0) = u_0$ and $v(0) = v_0$ as the initial values of the dependent variables. In some cases, the market can only increase if the initial values are different from zero; that is, there must be a pool of users before the service can be marketed. In other cases, one or both of the initial values may be zero. In all practical cases, $u_0 \ll 1$ and $v_0 \ll 1$.

In some cases, we may derive closed-form analytical solutions of the market equations. In other cases, this is not possible. However, in all cases, approximate solutions for the initial growth of the market for the two user groups are computed, in particular, the time t_u and t_v (i.e., latency) it takes for each user group to reach the threshold (u_T and v_T) at which the growth becomes self-sustained. In these cases, we set $1 - v = 1 + rv = 1 - u = 1 + ru = 1$ in the differential equations, since $u \ll 1$ and $v \ll 1$. The latency is an important strategic parameter since the slow initial increase of a service does not always mean that the service will never become lucrative. In several cases, the slow increase is a result of either same-side or cross-side network effects, or both. For instance, the latency for Facebook—the time to reach $u_T = 10\%$ market share—was longer than five years [11].

The mathematical methods used for solving the differential equations can be found in any undergraduate textbook on calculus. The authors have used the handbook by Korn and Korn [20] as the reference, in particular, for solving integrals.

5.1. Same-Side Network Effects for Both User Groups and Cross-Side Network Effects between Both User Groups

In this case, there are same-side and cross-side network effects within and between both user groups, respectively. An example service of this case is Airbnb, with guests (user group A) and hosts (user group B):

- Guests benefit from hosts because of an increased number of potential accommodations.
- Hosts benefit from guests because of an increased number of potential customers.
- Guests benefit from other guests because of host reviews.
- Hosts benefit from other hosts because of guest reviews.

The model is illustrated in Figure 3.

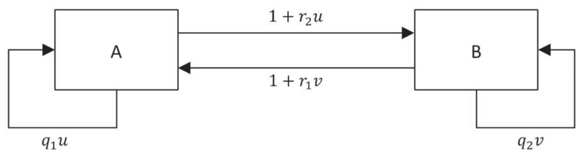


Figure 3. Same-side network effects for both user groups and cross-side network effects between both user groups.

As explained in Section 3.2, the cross-side feedback functions $1 + r_1v$ and $1 + r_2u$ are used in this case. The differential equations then become:

$$\frac{du}{dt} = q_1u(1 + r_1v)(1 - u) \tag{13}$$

$$\frac{dv}{dt} = q_2v(1 + r_2u)(1 - v) \tag{14}$$

Since $u = v = 0$ is the solution if there are no initial customers, the initial values of u and v must satisfy the conditions $u_0 > 0$ and $v_0 > 0$. Dividing the second equation by the first equation gives:

$$\frac{dv}{du} = \frac{q_2}{q_1}\frac{v(1 + r_2u)(1 - v)}{u(1 + r_1v)(1 - u)} \tag{15}$$

or

$$\frac{(1 + r_1v)dv}{v(1 - v)} = \frac{q_2}{q_1}\frac{(1 + r_2u)du}{u(1 - u)} \tag{16}$$

Integrating both sides, applying the initial conditions, and rearranging, we find easily

$$\frac{v(1 - v_0)^{1+r_1}}{v_0(1 - v)^{1+r_1}} = \left[\frac{u(1 - u_0)^{1+r_2}}{u_0(1 - u)^{1+r_2}}\right]^{q_2/q_1} \tag{17}$$

This is a transcendental equation that cannot be used directly to find a general solution for u and v. However, this equation can be used to estimate how the market behaves for large u and v. In this approximation, $u = v \cong 1$. We also set $1 - u_0 = 1 - v_0 = 1$. In this case,

$$v = 1 - \frac{u_0^{q_2/q_1}}{v_0}(1 - u)^{q_2(1+r_2)/q_1(1+r_1)}. \tag{18}$$

This formula can be used to estimate (say) how much users of type A lag behind users of type B (or vice versa) in adopting the service. Setting $q_1 = q_2$ and $u_0 = v_0$, then $v = (1 - u)^{(1+r_2)/(1+r_1)}$ as u approaches 1. If $u = 0.9$, then $v = 0.99$ if $r_1 = 0.5$ and $r_2 = 2$. On the other hand, if $v = 0.9$, then $u = 0.68$. This is only a crude estimate, as the approximation is inaccurate since the condition $u \ll 1$ is not satisfied in this case. However, the estimate indicates how users of type A lag relative to users of type B, or vice versa. As mentioned, both user groups adopt the service at the same rate initially. For small u and v, i.e., $1 - u = 1 - v = 1$, u and v is reduced to two independent differential equations with solutions

$$u = u_0e^{q_1t},\ v = v_0e^{q_2t}. \tag{19}$$

5.2. Same-Side Network Effects for Both User Groups and Cross-Side Network Effects from One User Group to the Other

In this case, there are same-side network effects within both user groups and cross-side network effects from user group A to B. An example service of this case is Uber, with drivers (A) and passengers (B):

- Drivers benefit from passengers because of an increased number of potential rides.
- Drivers benefit from other drivers because of passenger reviews.
- Passengers benefit from other passengers because of driver reviews.

The model is illustrated in Figure 4.

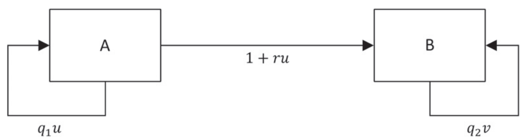


Figure 4. Same-side network effects for both user groups and cross-side network effects from one user group to the other.

The differential equations then become:

$$\frac{du}{dt} = q_1 u(1-u) \tag{20}$$

$$\frac{dv}{dt} = q_2(1+ru)v(1-v) \tag{21}$$

It directly follows that $u = 0$ is a solution of the first equation if $u_0 = 0$. The second equation is then reduced to the Bass equation for imitators only and evolves independently of u. Similarly, $v = 0$ is a solution of the second equation, reducing the set of equations to the Bass equation for u. Therefore, a non-zero solution exists for both equations only if $u_0 > 0$ and $v_0 > 0$. The first equation is independent of v and is solved directly:

$$u = \frac{u_0}{u_0 + (1-u_0)e^{-q_1 t}} \tag{22}$$

Inserting for u and separating the variables, the second equation becomes

$$\frac{dv}{v(1-v)} = q_2\left(1 + \frac{ru_0}{u_0 + (1-u_0)e^{-q_1 t}}\right)dt \tag{23}$$

or

$$\int_{x=v_0}^{v} \frac{dx}{x(1-x)} = \int_{x=0}^{t} q_2\left(1 + \frac{ru_0}{u_0 + (1-u_0)e^{-q_1 x}}\right)dx \tag{24}$$

Integrating both sides of the equation and solving for v gives

$$v = \frac{v_0 e^{(r+q_2)t}\left[u_0 + (1-u_0)e^{-q_1 t}\right]^{r/q_1}}{1 - v_0 + v_0 e^{(r+q_2)t}\left[u_0 + (1-u_0)e^{-q_1 t}\right]^{r/q_1}}. \tag{25}$$

It is evident from the differential equations that for small values of u and v, $u = u_0 e^{q_1 t}$ and $v = v_0 e^{q_2 t}$.

Figures 5 and 6 show the user adoption—$u(t)$ and $v(t)$—as a function of the time. The parameters are set to $u_0 = v_0 = 0.01$ and $q_1 = 0.46$ and plotted for different values of r and q_2 in Figures 5 and 6, respectively. The figures indicate the impact of the cross-side network effect on the growth of user group B. Observe that both $u(t)$ and $v(t)$ are S-curves, as expected since all users are imitators. Moreover, in Figure 5, observe that the user adoption in group B increases as the cross-side coefficient of composite growth (r) increases. This is expected since an increase in r means that the overall feedback for type B users increases. Increasing the parameter q_2 relative to q_1 also increases the adoption rate for type B users ($v(t)$), as seen in Figure 6.

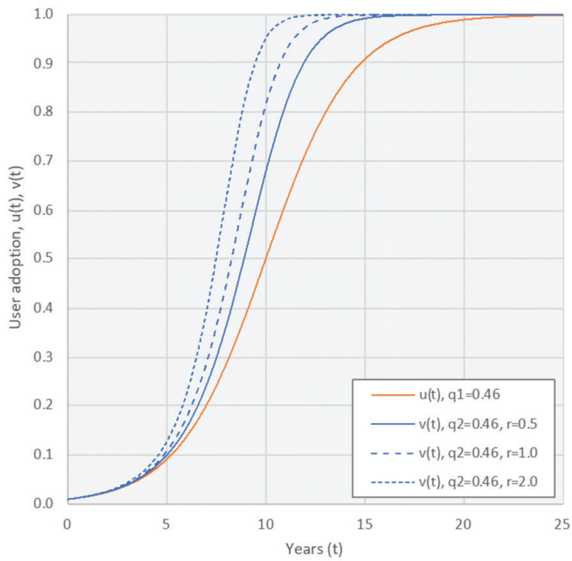


Figure 5. User adoption as a function of time for user groups A and B. The parameters are set to $u_0 = v_0 = 0.01$, $q_1 = q_2 = 0.46$, and $r = \{0.5,\ 1.0,\ 2.0\}$.

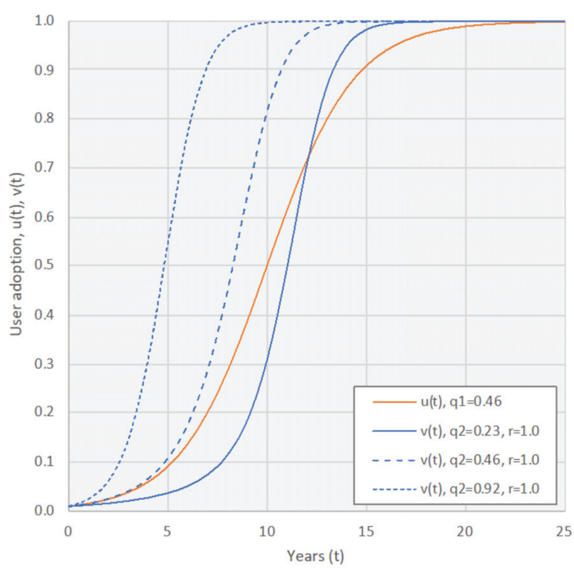


Figure 6. User adoption as a function of time for user groups A and B. The parameters are set to $u_0 = v_0 = 0.01$, $q_1 = 0.46$, $r = 1.0$, and $q_2 = \{0.23,\ 0.46,\ 0.92\}$.

5.3. Same-Side Network Effects for One User Group and Cross-Side Network Effects between Both User Groups

In this case, there are cross-side network effects between both user groups and same-side network effects in user group A. An example service of this case is PayPal with users (A) and merchants (B):

- Users benefit from other users because of potential peer-to-peer money transfers.
- Users benefit from merchants because of the shopping availability of e-commerce sites.
- Merchants benefit from users because of increased potential sales.

The model is depicted in Figure 7.

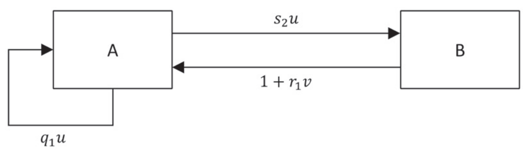


Figure 7. Same-side network effects for one user group and cross-side network effects between both user groups.

The differential equations then become:

$$\frac{du}{dt} = q_1u(1 + r_1v)(1 - u) \tag{26}$$

$$\frac{dv}{dt} = s_2u(1 - v) \tag{27}$$

In this case, $u = 0$ is a solution if $u_0 = 0$. Therefore, a non-zero solution exists if $u_0 > 0$ and $v_0 \geq 0$. For simplicity, we set $v_0 = 0$. Dividing the first equation by the second equation gives

$$\frac{du}{dv} = \frac{q_1(1 + r_1v)(1 - u)}{s_2(1 - v)} \tag{28}$$

with solution

$$u = 1 - (1 - u_0)e^{r_1q_1v/s_2}(1 - v)^{(1+r_1)q_1/s_2} \tag{29}$$

Inserting this in the second equation and rearranging gives t as a function of v

$$t = \frac{1}{s_2}\int_{x=0}^{v} \frac{dx}{(1 - x)\left[1 - (1 - u_0)e^{r_1q_1x/s_2}(1 - x)^{(1+r_1)q_1/s_2}\right]} \tag{30}$$

For small u and v, the differential equations become

$$\frac{du}{dt} = q_1u,\ \frac{dv}{dt} = s_2u \tag{31}$$

with solution

$$u = u_0e^{q_1t},\ v = v_0 + \frac{s_2u_0}{q_1}\left(e^{q_1t} - 1\right). \tag{32}$$

The latency period—the time to reach u_T and v_T—is then

$$t_u = \frac{1}{q_1}\ln\frac{u_T}{u_0},\ t_v = \frac{1}{q_1}\ln\left(1 + \frac{q_1(v_T - v_0)}{s_2u_0}\right). \tag{33}$$

Note that the latency period is independent of r_1. Setting $u_0 = v_0 = 0.01$, $u_T = v_T = 0.1$, and $q_1 = 0.46$, we obtain $t_u = 5.0$ years for type A users. Table 4 shows the latency t_v for type B users for three values of s_2.

Table 4. Latency in years for type B users.

s_2	0.23	0.46	0.92
t_v	6.4	5.0	3.7

Observe that the time to reach the threshold t_v increases when s_2 decreases. Furthermore, observe that $t_u = t_v$ when $s_2 = q_1$, in which the same-side network effects for user group A equal the cross-side network effects that user group B receives from user group A (note that in this case, the cross-side network effect from user group B to A is small enough to be ignored).

5.4. Same-Side Network Effect for One User Group and Cross-Side Network Effect from That User Group to the Other

In this case, there are cross-side network effects from user group A to B, and same-side network effects in user group A. An example service of this case is Facebook, with social media users (A) and advertisers (B):

- Users benefit from other users because of increased communication opportunities.
- Advertisers benefit from users because of increased visibility for their ads.

The model is illustrated in Figure 8.

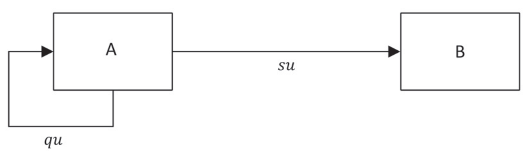


Figure 8. Same-side network effects for one user group and cross-side network effect from that user group to the other.

The differential equations then become:

$$\frac{du}{dt} = qu(1-u) \tag{34}$$

$$\frac{dv}{dt} = su(1-v) \tag{35}$$

In this case, $u = 0$ is a solution if $u_0 = 0$. Therefore, a non-zero solution exists if $u_0 > 0$ and $v_0 \geq 0$. For simplicity, we set $v_0 = 0$. The solution of the first equation is

$$u = \frac{u_0}{u_0 + (1-u_0)e^{-qt}} \tag{36}$$

Inserting this in the second equation and solving for v and setting $v_0 = 0$ gives

$$v = 1 - e^{-st}\left[u_0 + (1-u_0)e^{-qt}\right]^{-s/q} \tag{37}$$

Figure 9 shows u and v as a function of t for some values of s. First, observe that $u(t)$ and $v(t)$ follow each other closely when $q = s$, only offset by the difference in starting conditions. This is expected since the growth of type A and type B users will be approximately the same, given that the feedback in both user groups depends on the number of type A users only. Moreover, observe that $v(t)$ grows faster than $u(t)$ when $s > q$. In this case, the feedback in user group B is stronger compared to the feedback in user group A; in other words, the cross-side network effect from user group A to B is stronger than the same-side network effect within user group A.

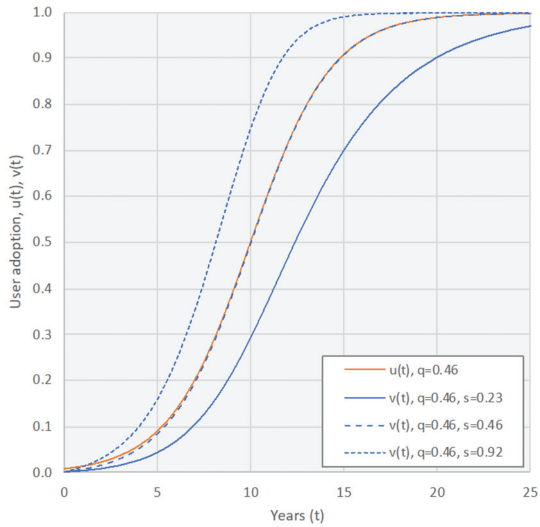


Figure 9. User adoption as a function of time for user groups A and B. The parameters are set to $u_0 = 0.01$, $q = 0.46$ and $s = \{0.23,\ 0.46,\ 0.92\}$.

The equation for v cannot be solved for t. However, dividing the first differential equations with the second and integrating, we find

$$v = 1 - \left(\frac{1-u}{1-u_0}\right)^{s/q} \tag{38}$$

Figure 10 shows v as a function of u. Observe that $v(t) \approx u(t)$ when $q = s = 0.46$. This also holds in general, i.e., when $q = s$ and u_0 is sufficient small. For larger u_0, this will not be the case.

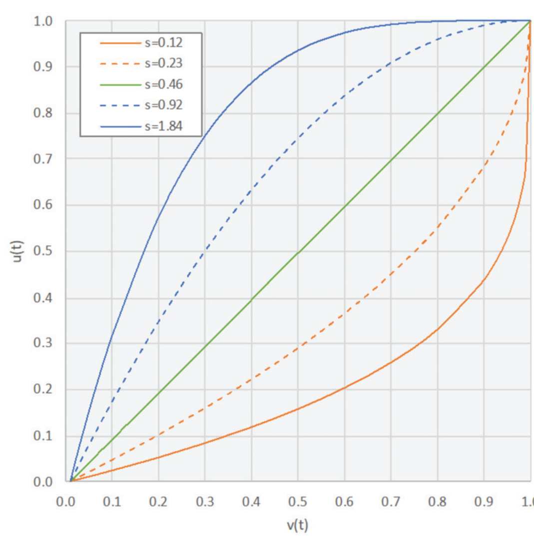


Figure 10. Adoption in user group A ($u(t)$) as a function of adoption in user group B ($v(t)$). The parameters are set to $u_0 = 0.01$ and $q = 0.46$.

5.5. Same-Side Network Effects for One User Group and Cross-Side Network Effect from the Other User Group

In this case, there are cross-side network effects from user group A to B, and same-side network effects in user group B. An example service of this case is Yelp, with restaurants (A) and reviewers (B):

- Restaurants benefit from reviews because of increased visibility.
- Reviewers benefit from other reviewers because of the restaurant reviews.

The model is illustrated in Figure 11.

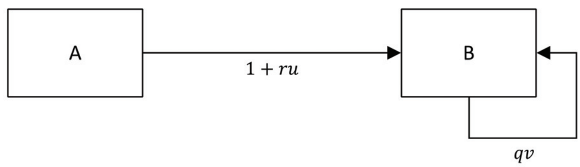


Figure 11. Same-side network effects for one user group and cross-side network effect from the other user group.

The differential equations then become:

$$\frac{du}{dt} = p(1-u) \tag{39}$$

$$\frac{dv}{dt} = qv(1+ru)(1-v) \tag{40}$$

In this case, $v = 0$ is a solution if $v_0 = 0$. Therefore, a non-zero solution exists if $v_0 > 0$ and $u_0 \geq 0$. For simplicity, we set $u_0 = 0$. This gives $u = 1 - e^{-pt}$. The second equation can be written

$$\int_{v_0}^{v} \frac{dx}{x(1-x)} = \int_{0}^{t} q\left[1 + r\left(1 - e^{-px}\right)\right]dx \tag{41}$$

Integrating and solving for v gives

$$v = \frac{v_0 e^{q(r+1)t}}{v_0 e^{q(r+1)t} - (v_0 - 1)e^{qru/p}} \tag{42}$$

For small u and v, using the differential equations and by setting $u = pt$ for small t, we find directly:

$$\begin{aligned} t_u &= \tfrac{u_T}{p}, \\ t_v &= \tfrac{\ln v - \ln v_0}{q} \end{aligned} \tag{43}$$

Figures 12 and 13 show user adoption for user groups A and B as a function of the time for various settings of q and r. First, observe that $u(t)$ undergoes logarithmic growth—as expected, since there are no network effects for user group A. Moreover, observe that $v(t)$ is an S-curve because there are both same-side and cross-side network effects for user group B. Note as well that the time to reach a certain threshold for user group B, e.g., $v_T = 0.1$, ranges from less than three to more than seven years, depending on the values of q and r. It is the product of the same-side and cross-side network effect, i.e., $q(1+ru)$, that determines the overall feedback for user group B.

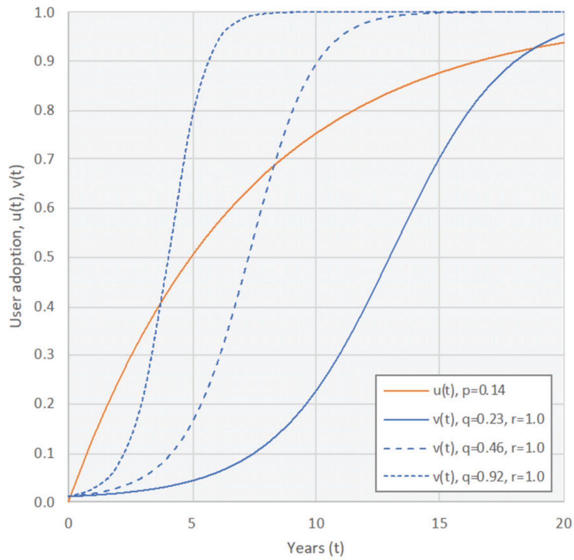


Figure 12. User adoption as a function of time for user groups A and B. The parameters are set to $v_0 = 0.01$, $p = 0.14$, $r = 1.0$, and $q = \{0.23,\ 0.46,\ 0.92\}$.

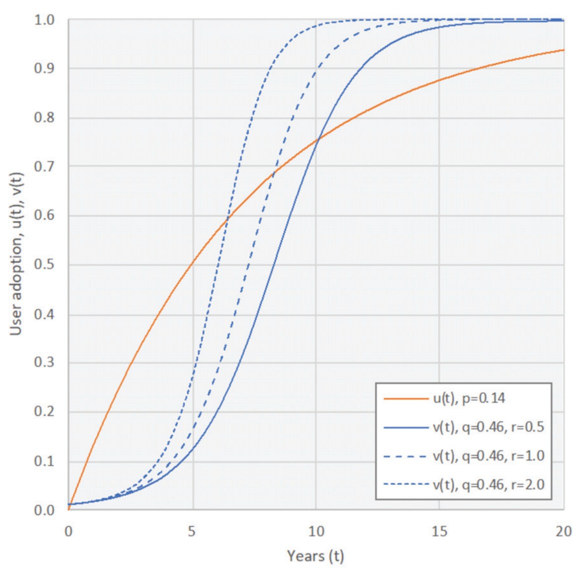


Figure 13. User adoption as a function of time for user groups A and B. The parameters are set to $v_0 = 0.01$, $p = 0.14$, $q = 0.46$, and $r = \{0.5,\ 1.0,\ 2.0\}$.

5.6. Cross-Side Network Effects between Both User Groups

In this case there are cross-side network effects between both user groups only. An example service of this case is eBay, with buyers (A) and sellers (B):

- Buyers benefit from sellers because of increases in items listed for sale.
- Sellers benefit from buyers because of increased potential sales.

The model is illustrated in Figure 14.

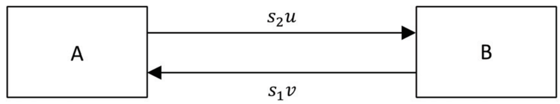


Figure 14. Cross-side network effects between both user groups.

The differential equations then become

$$\begin{aligned} \frac{du}{dt} &= s_1 v(1-u) \\ \frac{dv}{dt} &= s_2 u(1-v) \end{aligned} \tag{44}$$

Since $u = v = 0$ is a solution of these equations, the initial conditions must satisfy $u_0 > 0$ and $v_0 > 0$. Dividing the first equation by the second gives:

$$\begin{aligned} \frac{du}{dv} &= \frac{s_1 v(1-u)}{s_2 u(1-v)} \\ \left(\frac{1-u}{1-u_0}\right) e^{u-u_0} &= \left(\frac{1-v}{1-v_0}\right)^{s_1/s_2} e^{s_1(v-v_0)/s_2} \end{aligned} \tag{45}$$

This is a transcendental equation, so an analytic expression for u, v cannot be found. For small values of u and v, we have

$$\frac{du}{dv} = \frac{s_1 v}{s_2 u} \tag{46}$$

with solution

$$u = \sqrt{\frac{s_1}{s_2}\left(v^2 - v_0^2\right) + u_0^2} \tag{47}$$

The differential equation for v for small values of v is then

$$\frac{dv}{dt} = s_2 \sqrt{\frac{s_1}{s_2}\left(v^2 - v_0^2\right) + u_0^2} \tag{48}$$

with solution

$$\ln \frac{v + \sqrt{v^2 - v_0^2 + \frac{s_2}{s_1} u_0^2}}{v_0 + \sqrt{\frac{s_2}{s_1}} u_0} = \sqrt{s_1 s_2}\, t \tag{49}$$

This gives for t_v and, similarly, for t_u

$$t_v = \frac{1}{\sqrt{s_1 s_2}} \ln \frac{v_T + \sqrt{v_T^2 - v_0^2 + \frac{s_2}{s_1} u_0^2}}{v_0 + \sqrt{\frac{s_2}{s_1}} u_0},\; t_u = \frac{1}{\sqrt{s_1 s_2}} \ln \frac{u_T + \sqrt{u_T^2 - u_0^2 + \frac{s_1}{s_2} v_0^2}}{u_0 + \sqrt{\frac{s_1}{s_2}} v_0} \tag{50}$$

Figures 15 and 16 show the time to reach the threshold values $u(t_u) = u_T$ and $v(t_v) = v_T$ as a function of u_0 and s_1, respectively. Observe that both t_u and t_v decrease as u_0 increases—an increase in the initial relative number of users in user group A reduces the time to reach the threshold for both user groups. This is because the cross-side network effects between the user groups are mutually dependent on each other.

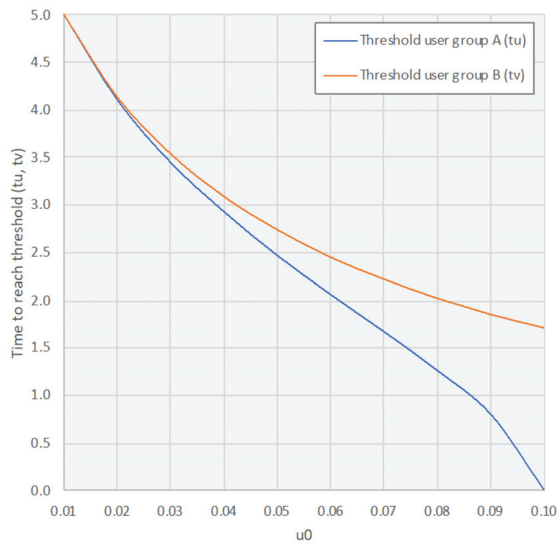


Figure 15. Time to reach threshold for user group A (t_u) and B (t_v) as a function of u_0. The parameters are set to $v_0 = 0.01$, $u_T = v_T = 0.1$, and $s_1 = s_2 = 0.46$.

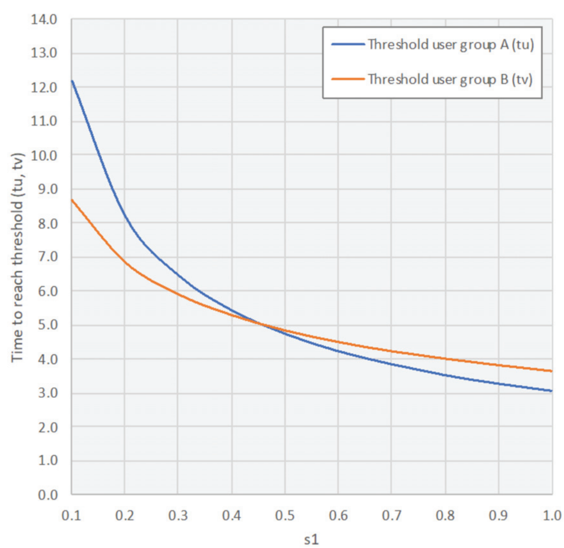


Figure 16. Time to reach threshold for user group A (t_u) and B (t_v) as a function of s_1. The parameters are set to $u_0 = v_0 = 0.01$, $u_T = v_T = 0.1$, and $s_2 = 0.46$.

5.7. Cross-Side Network Effects from One User Group to the Other

In this case, there are only cross-side network effects from user group A to B, as depicted in Figure 17. All new users to user group A are innovators, and the flow of new users is described as $du/dt = p(1 - u)$. Hence, there are no network effects in user group A—only in user group B. An example service of this case is Google Search, with users (A) and advertisers (B). The advertisers benefit from more users since this increases the visibility of their advertisements.

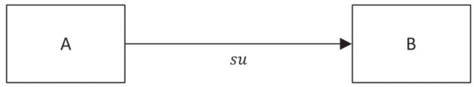


Figure 17. Cross-side network effects from one user group to the other.

The differential equations then become:

$$\frac{du}{dt} = p(1-u) \tag{51}$$

$$\frac{dv}{dt} = su(1-v) \tag{52}$$

In this case, the equations have non-zero solutions for initial conditions $u_0 = v_0 = 0$. The first equation then gives:

$$u = 1 - e^{-pt} \tag{53}$$

Inserting this in the second equation gives

$$v = 1 - \exp\left(-s\int_0^t u(x)dx\right) = 1 - \exp\left[\frac{s}{p}\left(1-e^{-pt}\right) - st\right] = 1 - e^{s\left(\frac{u}{p}-t\right)} \tag{54}$$

Figure 18 shows the user adoption as a function of the time. Observe that $u(t)$ undergoes logarithmic growth and $v(t)$ follows an S-curve. For a small value of t, $u(t)$ grows faster than $v(t)$. This is expected, since $v(t)$ depends on a certain size of group A users to generate cross-side network effects. For small u and v, we easily find that $t_u = -(\ln(1-u_T))/p$ and $t_v = \sqrt{2v_T/sp}$. For instance, for $u_T = v_T = 0.1$, $p = 0.14$, and $s = 0.46$, we find $t_u \approx 0.75$ and $t_v \approx 1.76$. Eventually, the growth of user group B induced by network effects becomes larger than the innovation-based growth of user group A.

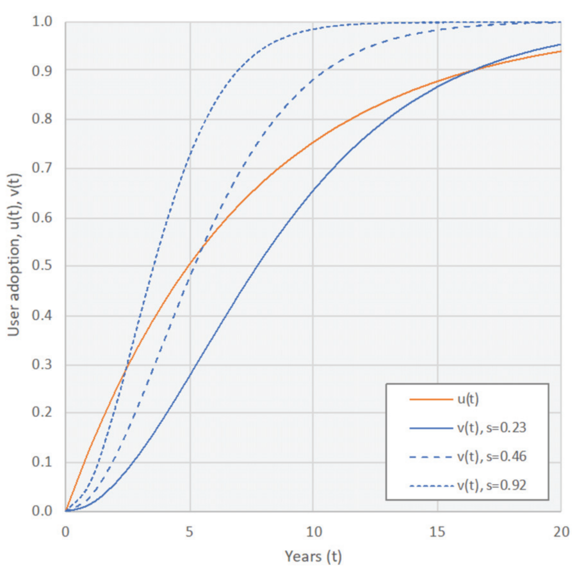


Figure 18. User adoption as a function of time for user groups A and B. The parameters are set to $p = 0.14$, and $s = \{0.23, 0.46, 0.92\}$.

6. Conclusions

This paper presents a comprehensive overview of the different types of multisided platforms, distinguished by network effects within and between user groups. The purpose of the models presented in the paper is to study the temporal evolution of user adoption of each service the platform is offering based on interactions between the user groups. We are not concerned with how and why these interactions take place—the main objective has been to show how the original diffusion model of Frank Bass can be extended to analyze the temporal evolution of complex structures such as multisided platforms. We have not been able to identify any previous studies in which such applications of the Bass equation have been examined. Neither have we found any examples in the literature wherein the temporal evolution of MSPs has been subjected to mathematical analysis.

Analytical models using coupled sets of ordinary differential equations are developed for several examples of two-sided platforms. For some of these examples, analytical solutions are found. However, in cases in which analytical solutions do not exist, solutions can still be found for the early user-adoption of the services. Such analysis may even be done on platforms that are much more complex than the ones that are considered in this paper by studying the equations for small values of market adoption, since these equations are much simpler than the equations describing the complete market evolution. Such analysis is particularly important since latency in user adoption is a critical strategic parameter for multisided platforms.

It is also demonstrated that, for some types of interaction between the user groups, the market will not start growing unless there are some initial users in one or both user groups. This is the "chicken and egg" problem for MSPs. From the form of the differential equations, it may be simple to see if $u(t) = 0$ is a particular solution to the equations and, hence, that a chicken and egg problem exists.

To study more complex platforms, for example, with nonlinear and more complex interactions, system dynamics may be used to derive numerical solutions (see, for example [21]). Another approach is to use agent-based models in which the users are modeled as autonomic agents taking decisions to adopt or not adopt the service based on actions taken by other users (see, for example, [22,23]).

Future research should (i) extend our analysis to include negative network effects; (ii) further develop the analytical models to more complex platform types, in particular, to study the initial growth problem (latency and the chicken and egg problem) to uncover strategic pitfalls and possible misjudgments such as early termination of the service because of no or slow initial adoption; (iii) use simulation methods such as system-dynamic and agent-based simulations to study more complex platform behavior; and (iv) apply the analysis to empirical business data.

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Demand-Side Economies of Scope in Big Tech Business Modelling and Strategy

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Abstract: The purpose of the paper is to discuss the issue of economies of scope in platform research and to attract attention to the importance of scope economies for the strength and growth of Big Tech corporations. Hitherto, most attention has been on network effects and demand-side economies of scale, on the role of platforms in lowering transaction costs, and on the importance of big data. More specifically, the research question addressed in this paper is how economies of scope, driven by the demand side, contribute to the strength of successful Big Tech corporations. The answer is related to two aspects: one is concerned with bundling of services and products, and the other with the acquisition and processing of data on users and their activities using digital services and applications.

Keywords: demand-side economies of scope; economies of scale; Big Tech corporations; business models

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1. Introduction

Big Tech corporations have become increasingly powerful organizations in various media, communications, and information areas. They have branched out into multitudes of different service and product areas. Amazon, for instance, started out in e-commerce selling books and has since then expanded into a wide variety of different areas, including audiovisual media, and has lately, in March 2022, acquired the MGM movie studio. Other Big Tech corporations have also expanded into large numbers of business areas. Apple, for example, developed a health app, which is, indeed, an app and, therefore, a piece of software. However, it takes Apple into an area of societal activities that it hitherto has had no experience with.

In the business literature, the most commonly used explanatory frameworks for analyzing the power and growth of Big Tech corporations are related to combinations of demand-side economies of scale based on network effects [1–3], transaction cost economics [4–6], and the use of big data on users [7,8]. These frameworks constitute very strong foundations for understanding how Big Tech corporations have become some of the strongest and most powerful corporations of our time, and at least the most valuable. Formerly, two-sided or multi-sided businesses have, indeed, existed, but only in niche areas and as niche activities. However, with digitalization, such business models have become the basis not only for strong and powerful corporations but also for the fastest-growing corporations during the past two decades.

However, demand-side economies of scale and transaction costs only partly explain the development paths of Big Tech corporations. These theories and analytical frameworks explain the extraordinary growth of the individual business areas of the corporations, but they do not explain the increasing scope of business areas in which they operate. For this purpose, an approach referring to economies of scope is needed. However, as with economies of scale, where network effects turn the issue 'upside down', focusing primarily on the demand side and not on the supply side, the same approach can be applied to economies of scope [9]. While economies of scope mostly focus on the supply side, discussing how different business areas can utilize common company resources and capabilities and can leverage synergies between different business areas, demand-side economies of scope seem to be important for the expansion of Big Tech corporations, as the synergies between different product and service areas on the demand side are drivers for the buying and use patterns of users, and as data on users not only form the basis for developing and marketing new products and services, but are intrinsic parts of their business approaches.

The research question addressed in this paper is how economies of scope, driven by the demand side, contribute to the strength of successful Big Tech corporations. This, all the more so, as most of the regulatory initiatives that are presently taken in the EU, as well as the US, primarily focus on scope aspects of the companies to be regulated—as with the Digital Markets Act (DMA) in the EU (2020/0374(COD)) and, for example, the American Innovation and Choice Online Act (S.2992) and the Platform Competition and Opportunity Act (H.R.3826) in the US. These acts are concerned with access of alternative suppliers of services to the platforms of the Big Tech corporations, so that the Big Tech corporations are not the only service providers taking advantage of the broad scope of services and applications that can be offered on the basis of such platforms. In spite of the great importance of scale economies, it is seldom the scale of dominant companies which is regulated; it is primarily the scope.

More specifically, the paper analyzes the business models and activities of the five Big Tech corporations often formerly called GAFAM—Google, Apple, Facebook, Amazon, and Microsoft—now, with the changed corporation names of Google (Alphabet), as well as Facebook (Meta), they could be called MAAAM (Microsoft, Apple, Amazon, Alphabet, and Meta), following their age as corporations chronologically.

First, there is a presentation of the concept of demand-side economies of scope. This is followed by descriptions of the MAAAM corporations. After this, there is an analysis section examining the concept of demand-side economies of scope in light of the company case descriptions. Finally, conclusions are drawn.

2. Methodology

The methodological approach of the paper is to discuss how theories on scope economies [10–12] can be developed into being applied from a demand-side perspective. Case analyses of the MAAAM corporations are used to examine whether a demand-side economies of scope approach can be helpful in understanding the strength of these companies. The empirical evidence presented in the case analyses is drawn from publicly available web sites and news articles. The expected result of the paper is an additional theoretical aspect of understanding the business models of successful Big Tech corporations—demand-side economies of scope, in addition to demand-side economies of scale and transaction cost economics.

3. Demand-Side Economies of Scope

Just as with economies of scale, economies of scope have traditionally been dealt with from a supply-side point of view. Ever since Adam Smith [13] (1994—first published in 1776), it has been general knowledge in economics that with divisions of labor and large production sites there can be cost savings per produced unit with an increasing scale of production—with certain limitations, depending on the industrial sectors in question and the development stage of a company. Economies of scope, meaning that there are costs savings per produced unit as an effect of using the same production facilities and capabilities for the production of different products and services, have never obtained the same degree of attention in economics as economies of scale.

The antecedent to the concept of economies of scope was the ‘multi-product firm’ concept. The multi-product firm concept was first discussed at length by [14], who referred to the limited number of previous and less extensive examinations of the issue by, e.g., [15].

Weldon [14] started out by stating that 'very little has been written on the multi-product firm'. In 1961, Pfouts [16] elaborated further on the concept of the multi-product firm. However, the first contributions to the economies of scope concept were developed by Panzar and Willig [10,11] and Teece [12]. The 1975 paper by Panzar and Willig [10], entitled *Economies of scale and economies of scope in multi-output production*, was an initial attempt at developing the scope concept, in addition to the scale concept. However, the scope concept was still much attached to the previous discussions on multi-output and multi-product firms. It was Teece [12] who, in his paper on *Economies of scope and the scope of the enterprise*, first unfolded the concept of scope economies to encompass not only the production costs of joint production of different products, but also the transaction cost elements that could be part of the equation. Panzar and Willig [11], in their paper on *Economies of scope*, included the input from Teece [12] and canonized the definition of economies of scope, which is the presently accepted definition.

In the 1981 paper, Panzar and Willig [11] write in the introduction to the paper: 'There are economies of scope where it is less costly to combine two or more product lines in one firm than to produce them separately'. In the conclusion, after having discussed various contributions to the topic, including Teece [12], they add: 'When the multiproduct cost function summarizes both the production and organizational costs of operating a firm, economies of scope is the precise condition required for the emergence of multiproduct firms in a competitive environment'.

This definition, however, views economies of scope entirely from the supply side. It is the potential cost savings on the supply side in terms of production costs and transaction costs which are at stake. The implications of the demand side for scope economies are not considered, and this is what this paper aims at examining.

In 2010, Henten and Godoe [9], in a paper entitled *Demand side economies of scope in bundled communication services*, discussed the idea of demand-side economies of scope in relation to bundled services such as triple and quadruple play. However, this paper was not the first to examine the concept of demand-side economies of scope. In a paper from 2004, Mueller [17] briefly touched upon the issue of demand-side economies of scope. In this paper, he differentiates between 'subject-side economics' (demand-side) and 'organization-side economics' (supply-side). In connection with 'subject-side economics', he mentions demand-side economies of scope and explains that the topic of network externalities sometimes is mislabeled as demand-side economies of scale, while it really is about demand-side economies of scope, he says. Mueller [17] first developed this idea in his book from 1997 on *Universal Service*, and, in the 2004 paper, Mueller [18] mentions that he is in line with Economides and White [19] on this. The idea is that, when more subscribers are added to a communication network—in this case, telephony—the utility for existing subscribers increases, as they get access to a new service, namely, calling or being called by a new subscriber. The keyword here is 'new service', meaning that a new product is added to the service they already get. This is why Mueller understands this as scope and not scale. Most people, however, understand this as economies of scale, as it is essentially the same service. In this paper, we side with this view and limit the concept of economies of scope to situations where essentially different products are produced and consumed.

If this understanding of demand-side economies of scope is accepted—namely, that there are advantages, induced by the demand side, in terms of savings on production and/or transaction costs per produced unit of production as an effect of using the same production facilities and capabilities for the production of different goods and services—then, the question is raised: What can such demand-side effects actually be?

First of all, it should be remembered that we are dealing with an interaction between those producing and those consuming and, therefore, there are feedback mechanisms between the supply and demand side. However, if we start with the mechanisms that have their point of departure on the demand side, the primary drivers are one-stop shopping, lowering search costs, and enhanced complementarity between related products and, therefore, convenience for users [20,21]. Companies can build on such mechanisms by bundling products and by tying in customers to bundles. Products that are bundled increase switching costs for users when switching to other products or bundles and then there are the implications of brands [22]. All these mechanisms are related to the demand side, and to the extent that they lead to increased consumption of the products made by specific companies, they may lead to advantages of both scale and scope on the supply side.

There is thus a positive feedback mechanism between the demand and the supply side. There is a virtuous cycle so that a demand-side effect may lead to a positive mechanism on the supply side, which may translate into a further demand-side effect. An important question is where the limitations to such positive feedback mechanisms and virtuous cycles are. This goes back to the discussions on multi-product firms, on the effects of specialization, and the more recent discussions on ambidexterity [23,24]. The ambidexterity literature tells us that businesses may have difficulties in operating in different market circumstances at the same time, and that specialization may be the answer to such difficulties. The limits to the advantages of scope economies are related to the advantages of specialization. Scale is supported by specialization, while specialization may be a barrier to scope.

A dimension that needs to be taken into consideration is the economies of scope on the horizontal level and the vertical level, respectively [25,26]. On the horizontal level, the issue is the extent to which there are scope advantages in producing and consuming different products where the joint production facilities and capabilities do not matter to the end user—as, for instance, with different kinds of audiovisual contents that are unrelated for the user. On the vertical level, the issue is the extent to which there are scope advantages in producing and consuming products where the production facilities and capabilities do matter to the end user—as, for instance, with Internet connectivity and content provision.

There is a strong case to be made that the new digital economy, to a large extent, is supported by scope economies—not primarily because of the possible scope advantages in offering network services bundled with content services, as mentioned above. In most cases, there are degrees of specialization with respect to network and content provision. The strength of the case also emanates from the use of data resources that are personal, as well as not attached to persons. The Big Tech corporations benefit extensively from all the 'big data' that they collect and process. The information that results from such collection and processing can be used in many related product areas, but also areas that seem relatively unconnected.

Data on users are extracted either voluntarily or, most often, automatically when users are interacting with digital services. These data are of essential value to potentially all industries and most certainly to the so-called Big Tech companies. This means that these industries are entirely dependent on their users in terms of input to their production. As in the case of demand-side economies of scale, where the number of users is an important part of the value of the product, the dependence on data input from users is the basis for the variety of products that companies offer. This is the reason why it can be argued that demand-side economies of scope constitute an essential mechanism in the digital economy.

4. Company Cases

In this section, five company cases are examined: Microsoft, Apple, Amazon, Alphabet (Google), and Meta (Facebook). These are the largest and most valuable US-based Big Tech companies. We could also have chosen to include China-based companies such as Alibaba and Tencent, as they operate in much the same manner as the US equivalents, which is also why there is no need to include these companies here, as they do not differ substantially from the US-based companies from the point of view of this paper. Furthermore, the five US-based companies cover different kinds of activities and business areas and, therefore, illustrate the variety of businesses which can be subsumed under the term Big Tech.

The focus of the analyses of the five companies is on the scope of their activities and what this means to the companies. The company cases consist of brief intros to the companies in question, the development of the scope of their activities, and a discussion of the importance of demand-side factors that contribute to the scoping of the companies. As can be seen from the previous theory section, there are basically two different categories of overall demand-side factors. One set of factors has to do with the bundling of services and products and the convenience and complementarity that this offers to users and the tying in that companies apply. Another set of factors is concerned with the data that the companies acquire regarding their users and how this helps the companies in providing a wide range of products and services.

The empirical material used for the analyses is based on news articles and information on the activities of the companies found on the web. A common source of information for four of the companies is the *Investigation of competition in the digital markets* by the majority staff of the Subcommittee on Antitrust, Commercial and Administrative Law of the Committee on the Judiciary of the US House of Representatives [27]. Microsoft was not subject to examination by this committee, and the empirical material regarding Microsoft comes from other publicly available sources. Information on acquisitions is from Wikipedia, where updated and detailed information on mergers and acquisitions for all five companies is available.

4.1. Microsoft

By March 2022, Microsoft was the world's third most valuable company, with a market capitalization of 2.1 trillion USD, according to Investopedia [28]. The revenue during the previous 12 months was 185 billion USD [28].

The factual historical information in the following is primarily based on the Wikipedia page on Microsoft [29] (2022) and the Britannica [30] equivalent. Microsoft was established in 1975, primarily based on an interpreter for the BASIC programming language. In 1980, Microsoft launched its first operating system, and the subsequent MS-DOS system became its first huge market success. MS-DOS became the operating system for IBM PC clones at the time, and in companion with IBM, Microsoft developed a similar operating system for IBM. In contrast to Apple, which developed hardware, as well as software, Microsoft stayed on the software side and has mostly done so ever since, with only a few exceptions, one of which basically failed, namely, the Windows Phone, developed on the basis of the take-over of Nokia's mobile device business, and one of which was successful, being the Xbox gaming machines.

In 1985, Microsoft launched Windows, which was a graphical development of MS-DOS. In 1990, the Microsoft Office suite was taken to market, which marked the extension of the scope of Microsoft products, founded on a bundling strategy. Based on Windows, the Office suite included the word-processing program Word and the spreadsheet Excel and clearly illustrated the strength of such a bundling strategy, almost entirely outcompeting the hitherto dominant word-processing program WordPerfect.

When the World Wide Web was launched in 1989 and became a global success in the mid-1990s with the Netscape browser, Microsoft was fast at adapting to the new circumstances for IT companies. The new operating system, Windows 95, became bundled with a web browser, Internet Explorer, and the web portal MSN, giving access to a range of Internet services and applications. Once again, this bundling strategy proved successful, as Internet Explorer quickly became the dominant web browser. However, the bundling strategy also became the object of public intervention in order to prevent anti-competitive behavior and the tying in of users. In the US, the Department of Justice, for instance, filed a motion to disallow the bundling of Internet Explorer with Windows, and later, the EU required Microsoft to produce versions of Windows without the Microsoft Media Player.

In the mobile Internet field, which really took off following 2007 with the iPhone by Apple, Microsoft has never been very successful. Microsoft developed its own Windows Phone operating system and took the chance of establishing an alliance with Nokia in 2011 when it turned out that Nokia on its own was not able to follow up on its astonishing success from the years before the iPhone and App Store. However, this alliance and the subsequent take-over of Nokia's device area was not successful either.

Since its start, it has been the software area where Microsoft has been the most successful and has maintained its role as one of the most prominent IT companies in the world. Currently, Office 365 is the trademark for a subscription-based arrangement, where bundles of Microsoft products are offered. This now also includes the Microsoft Teams platform, integrating video meetings, file sharing, etc. Such videoconference platforms have lately become an important part of the product portfolio of different companies, with Zoom dominating the world market, but with Teams increasing its market share. A natural extension of the software focus of Microsoft has also been cloud computing, where Microsoft Azure is the second largest cloud computing service in the world, with currently app. 20% of the world market, only surpassed by Amazon Web Services [31]. Driven by increasing data demand, Microsoft has, furthermore, taken a more active role in the undersea infrastructure market. The company has invested in a handful of subsea cable infrastructures globally.

Microsoft has, during its lifetime, branched out into various fields, which its activities regarding acquisitions document [32]. It was only after the initial public offering (IPO) in 1986 that Microsoft started its acquisitions. The largest acquisitions in terms of value have been Vision (drawing software, 2000), Navision (business software, 2002), aQuantive (digital marketing, 2007), Skype (telecommunications, 2007), Yammer (social networking, 2012), Nokia mobile phones (mobile phones, 2013), Mojang (video games, 2014), LinkedIn (professional social networking, 2016), GitHub (software development, 2018), ZeniMax Media (video games, 2020), Nuance Communications (speech synthesis and speech recognition, 2021), and Activision Blizzard (video games, 2022). All in all, Microsoft has made more than 225 acquisitions during its lifetime. The emphasis has been on software development, and on video games since the release of Xbox in 2001. Lately, social networking has also become an important part of the company, especially with the acquisition of LinkedIn.

Microsoft also has stakes in other companies [32]. The profile of these stakes is not very different from the acquisitions, but investments in telecommunications and cable television around the turn of the century and the later investments in undersea cables do stand out. As has been indicated, Microsoft has, since the release of the first Office suite, relied strategically upon a strategy of bundling and tying in users. This is how they have been building scope, based on demand-side economics. Data on their users have, furthermore, come to play an increasing role, especially with the growing emphasis on social networking.

4.2. Apple

By March 2022, Apple was the world's most valuable company, with a market capitalization of 2.6 trillion USD [28]. In terms of revenue, it was the world's third largest, with a revenue during the previous 12 months of 378 billion USD [28].

The basic historical facts in the following are based primarily on Wikipedia [33,34] and the *Investigation of competition in the digital markets* by the Subcommittee on Antitrust, Commercial and Administrative Law of the Committee on the Judiciary of the US House of Representatives [27]. Apple was founded in 1976, with its first product being the Apple 1 personal computer. For the next many years, Apple concentrated on its personal computers, both hardware and software. As opposed to most other personal computer brands at the time, Apple developed its own computer hardware, as well as software, comprising operating system, as well as specialized software tools, and created a 'walled garden' of Apple computer products, while other computer brands started basing their products on what came to be known as Wintel (Windows operating system and Intel processors).

This walled garden approach lost ground to the Wintel-based companies during the 1990s and Apple ran into serious economic problems. As a reaction, Apple started expanding its range of products, first with iMac and iPod and then with iPhone and iPad—and, just as importantly, with the App Store, which was launched in 2008. This added an entirely new business model setup for Apple, as the App Store is a platform where independent developers of applications can sell their apps to app users. Still, the App Store is a more closed environment than Android Market—now Google Play—as Apple wishes to have some control over the apps being sold on the App Store. The strategy of retaining control has thus continued. While most other mobile device brands use the common Android operating system and Google Play as their app market, Apple has its own operating system, iOS, and its own App Store.

For the past 10–15 years, the scope of products sold by Apple has grown considerably. The minimalist strategy that Apple followed for many years ended and has been followed by a strategy of expanding into a larger variety of products. Many of the products are different versions of the same line of products, but on the Apple Wiki apple.fandon.com website [35], 19 products are mentioned under the current hardware category, 7 operating systems are listed, 28 under the category of current software and services, and the largest category is current accessories and peripherals, with 74 products. In addition, even higher numbers of products are listed as discontinued.

Statista publishes statistics on the shares of Apple's revenues by product categories divided up into five categories: iPhone; Mac; iPad; wearables, home, and accessories; and services. The statistics show that, during the past decade, iPhone has continuously provided the largest share of revenues, fluctuating from app. 40% to app. 70%, but on average at a level between 50 to 60%. The revenues from Mac sales have decreased slightly from app. 15 to 10%, and iPad sales have decreased more considerably from app. 20 to less than 10%. The growth areas are wearables, home, and accessories, going from app. 5 to 10%, and services, going from app. 10 to 20%. This shows that it is the iPhone area that constitutes the largest revenue area for Apple by far, and that iPhone is the keystone for Apple. However, it also shows that the services category is the most important growth area for Apple.

Another way of looking at the scope of the company is the number of acquisitions that Apple has made during the past years. In the US House of Representatives report from 2020 [27] and on the Wikipedia *List of mergers and acquisitions by Apple* [36], the companies acquired since 1998 until August 2021 are listed. The Wikipedia list includes 123 companies, which corresponds to 4–5 acquisitions per year, and it should be mentioned that the list is probably longer, as Apple does not necessarily publish its acquisitions unless they are mentioned elsewhere. The product categories acquired are almost entirely within software and services. With respect to investments, undersea cable infrastructure has become an activity for Apple, as well as for the other Big Tech companies. With Ireland being an important stepping stone into the European market, Apple has invested in infrastructure between the US and Ireland.

Although Apple has thus spread into a variety of product types, Apple is the company among the five biggest US-based Big Tech companies that has, to the largest degree, limited its scope to product categories in the vicinity of its core hardware products—first and foremost, the iPhone—and the App Store. Every time an iPhone is sold, a whole ecosystem of services and applications is at the fingertips of the user. One cannot start using an iPhone, an iPad, or a Mac without deciding whether one wants to use a whole range of services and applications that one is confronted with when starting up. There is a very high degree of bundling of products and these products are also tied to one another so that some of the convenience for users is lost if not using the bundle of services and applications offered.

Bundling is thus an essential strategy for Apple. The other main type of mechanism to build demand-side economies of scope is, however, also highly important, namely, the collection and processing of user data for the purpose of developing a deeper knowledge on their users, making it possible to deliver packages of services and applications to users that tie the users into the ecosystem of Apple products.

4.3. Amazon

Amazon is currently the world's fifth most valuable company, with a market capitalization of 1.5 trillion USD [28]. In 2021, Amazon's revenue was app. 470 billion USD [28].

Amazon.com, Inc. was founded in 1994 as an online marketplace for books. The company has ever since expanded into an array of products and services, including general e-commerce, consumer electronics (Kindle e-reader, Fire tablets, Fire TVs, Echo devices), development and production of media content, book publishing, and logistics.

The primary sources of revenue come from retail sales (through online and physical stores). Other sources include third-party seller services (the commissions and related fulfilment and shipping fees), subscription services (fees associated with Amazon Prime memberships and access to content, including audiobooks, digital video, e-books, digital music), AWS, which is the world's biggest cloud infrastructure service provider (global sales of computing, storage, database, and other service offerings for start-ups, enterprises, government agencies, and academic institutions), and other sources (sales of advertising services) [37].

Amazon has enlarged its cross-category product/services offerings and delivery channels through a series of acquisitions. Since 1998, Amazon has acquired more than 100 companies. The acquisition of Audible in 2008 allowed Amazon to offer online audiobooks and podcast services. The acquisition of Zappos in 2009 gave access to many different types of products, such as shoes, clothing, handbags, and other accessories. Amazon extended the offerings of baby products, including clothes, car seats, strollers, and toys, by acquiring Quidsi (Diapers.com) in 2010. Since 2011, Amazon has begun to invest in technology start-ups to develop and improve Amazon Echo and expand its AWS division. Amazon's biggest acquisition of Whole Foods Market Inc. in 2017 allowed it to expand its online business to the brick-and-mortar Food and Beverage, Grocery, and Organic Food market, with 460 stores in the US, Canada, and the UK. In 2018, Amazon acquired Ring LLC, a home security and smart home company. The most recent acquisition of the film and television studio Metro-Goldwyn-Mayer (MGM) added more than 4000 film titles and 17,000 TV episodes to the Amazon Prime catalogue.

These acquisitions show that Amazon is moving deeper into several sectors, similarly to other Tech Giants. However, what is unique in Amazon's business development is its extremely broad selection of products, the vast investments in brick-and-mortar stores, a shipping infrastructure, and a submarine cable infrastructure. Until now, the company has been involved in five such cable projects [38]. Amazon's infrastructure also consists of planes, semi-trucks, vans, trailers, and drones [39].

Amazon customers are offered the Prime Membership programs. They can choose from over 15 million items that are available for free one-day delivery with no minimum purchase in the US [39]. Moreover, certain brands are only available on Amazon. Amazon uses Amazon Prime and other programs to lock customers into the Amazon ecosystem of shopping, streaming of movies, music, gaming, reading (unlimited access to books, magazines on any devices), sharing services, and shipping.

With its expansion of activities, Amazon has also gained access to a large group of customers and access to valuable customer data about online and offline customers' behavior. Access to customer data allows the company to increase the cross-selling of its products among its various business lines. In addition, Amazon has access to third-party seller data and uses it to identify and replicate the most profitable products on its marketplace. In November 2020, the European Commission opened the antitrust investigation into Amazon's use of third-party seller data to help develop its own private-label goods.

Amazon's strategy to build a strong ecosystem of devices and services for its Alexa platform generates additional insight into user behavior, which is used to inform and nudge users to buy new Amazon products. Customers have access to the wide array of Alexa-enabled devices (also third-party devices), due to the fact that Amazon does not charge third-party manufacturers for access to its integration services. As of 2020 [40], over 100,000 devices support interaction with Amazon Alexa. Amazon has been the leading vendor in the global smart speaker market since 2016. In 2021, Amazon had a share of the market of 26.4%. Amazon's closest competitor in this market is Google, with a 2021 market share of 20.5% [41].

4.4. Alphabet (Google)

Alphabet (Google) is the fourth most valuable company, with a market capitalization of 1.7 trillion USD [28]. In 2021, Alphabet's revenue amounted to app. 257 billion USD [28].

Google Inc. was founded in 1998 as an online search company. Since 2004, Google has extended its activities to a variety of other lines of business. Presently, Google is a subsidiary of Alphabet Inc. holding company and offers more than 80 products and services worldwide. The largest business is Google, which is reported in two segments: Google Services and Google Cloud [42].

Google Services' core products and platforms include ads, Android, Chrome, hardware, Gmail, Google Drive, Google Maps, Google Photos, Google Play, Search, and YouTube [42]. The main source of revenue is still advertisements. Other sources of revenue are generated from Google Play (sales of apps, in-app purchases, and sales of digital content), hardware sales (e.g., Google Pixel, Fitbit charge, Chromecast with Google TV, Google Nest Cams and Nest Doorbell, and other devices), and YouTube (Premium and TV subscriptions). Google Cloud business generates revenue from the Google Cloud Platform (infrastructure, platform and services, licensing, service fees and subscriptions) and Google Workspace (collaboration tools for enterprises). In order to support the rapid growth of cloud services, Alphabet is heavily investing in infrastructure under the sea. Presently, the company is the largest owner and investor in submarine cable networks worldwide. In total, Alphabet has invested in 20 subsea cable projects around the world [43,44].

Alphabet (Google) started its acquisitions in 2001. Until now, Alphabet has acquired more than 240 businesses. The most influential acquisitions are Android (2005), YouTube (2006), DoubleClick (2007), AdMob (2009), Motorola Mobility (2011), and Waze (2013). Alphabet business activities focus on both platforms and hardware. Those acquisitions have allowed Alphabet to build a large ecosystem of complementary services and products around the Google Search business. The Android operating system is available for license by third-party device manufacturers. It represents a different approach from Apple iOS, which is unavailable to other device manufacturers. All Google-supported devices have pre-installed Google Search, Google Play Store, and some of the most popular Google Services, such as the mapping service, Google Maps, the web browser, Chrome, as well as Gmail and YouTube. Google Search is set as the default search engine even on Apple devices. The Google Search engine is also tied closely to Google's own Shopping Services/platform. All Google Search results favor Google's own shopping services over services offered by competitors.

In 2018, the European Commission found evidence that, when an app is pre-installed on devices, it is used more than on devices where users must download it. The EC stated that more than 95% of all searches were made via Google Search on Android devices. On the other hand, on Windows Mobile devices, where Google Search and Chrome are not pre-installed, less than 25% of all searches were made via Google Search [45]. In the same report, the European Commission concluded that Google has engaged in two instances of illegal tying: first, the tying of the Google Search app, and second, the tying of the Google Chrome browser [45].

All those integrations of Google products and services tie users to Google platforms due to the ease of accessing them, a better deal offering, and good digital experiences across Google platforms. Through its universal sign-in account service and a large number of complementary products, services, and devices, Alphabet has managed to convince users to use services offered within their business ecosystem to a large extent. Moreover, if Android device users want to switch to another OS, they lose their data, contacts, and apps.

Alphabet is not only using its offering to tie app users but also app developers and cloud computing customers. For example, app developers have to use a core set of features from the Google Map Platform, and they are not allowed to use any component of the Google Maps core Services with mapping services provided by non-Google companies [46]. Moreover, developers need to have a Google Cloud account to have an API key to access Google Maps.

Another important aspect of Google's activities is the collection and use of data. Google's integration across markets allowed the company to capture increasing amounts of data. Google Android services are available on mobile phones, tablets, personal computers, TVs, smart watches, and other devices. Using Google services requires having a Google account, which means that the user profile exists on all Google platforms. Through the extension of online services, Alphabet can gain a broader picture of its users. This knowledge can be used to improve and expand its existing offerings.

4.5. Meta (Facebook)

Meta Platform, Inc. (Facebook Inc.), as of March 2022, has a market capitalization of app. 545 billion USD [28]. This makes Meta the world's ninth most valuable company [28]. The annual revenue for 2021 was app. 118 billion USD [28]. Presently, Meta is the largest social networking platform in the world.

Facebook was launched in February 2004. At first, only Harvard University students had access to the social network service. Since then, Facebook has acquired over 3.6 billion [47] active users who use one or more of Facebook's Family of Apps every month, and more than 200 million businesses use Facebook's tools to reach customers. In October 2021, Facebook Inc. changed its corporate name to Meta Platform, Inc.

Facebook's core services are completely free and supported by ads. Users can create their profiles, upload pictures, videos, and connect with other users across platforms and devices without paying for them. Meta substantially generates all of its revenue from advertising by displaying ad products on Facebook, Instagram, Messenger, and third-party affiliated websites or mobile applications.

Since 2004, the company has expanded far beyond its social networking platform. Services that are provided by Meta Platform, Inc. are Facebook, Instagram, Messenger, and WhatsApp, which are referred to by Meta as a Family of Apps, and Reality Labs. The company is also investing in subsea cable projects. So far, Meta is involved in two submarine cable investments and plans to invest in eight new submarine cables, which will be ready for service at the latest in 2025 [48].

Meta's Family of Apps was positioned at the forefront of the most popular social networking apps globally in 2021 [49]. Meta offerings include messenger services, photo and video sharing, augmented reality, and many other apps and services. The Family of Apps enables people to connect and communicate with friends, family, groups, and businesses, as well as to share and discover new content and common interest. All services are available through multiple devices such as mobile devices, personal computers, and others.

Reality Labs is a part of the company dedicated to augmented and virtual reality. It was established on 25 August 2020, and includes augmented, virtual reality, and Metaverse-related hardware, software, and content. In October 2021, the company announced that Reality Labs would begin to report its revenue separately from Facebook's Family of Apps [50]. The main focus of the Reality Labs division is the development of the Metaverse and augmented reality products, such as AR glasses and AI-powered software that track and respond to user activity. In 2021, Reality Labs reported losses of 10 billion USD. Zuckerberg explained that the company is investing in finding its next stage of growth: "... we're focused on the foundational hardware and software required to build an immersive, embodied internet that enables better digital social experiences than anything that exists today" [51].

Facebook's core activities related to social networking services have progressed towards a so-called de facto monopoly position over time. The growth of Facebook has been run by a strong network effect and lock-in mechanism based on very deep emotional ties among the participants. Since 2012, mergers and acquisitions have been key to growing Meta businesses. To date, the company has acquired nearly 100 companies. The main mergers and acquisitions of the company focused on: (1) popular companies within social networking and messaging services, of which the largest acquisitions have been, e.g., WhatsApp, Instagram, Face.com; (2) hardware and virtual reality companies, such as Oculus Virtual Reality, CTRL-labs, BigBox VR, Lemnis Technologies, Scape Technologies [52], etc., which are integrated with Reality Labs; (3) niche software companies; and recently (4) blockchain, e.g., Chainspace.

In the case of Facebook, horizontal mergers and acquisitions are clearly represented by the acquisitions of WhatsApp and Instagram. From the demand-side economies of scope perspective, those acquisitions increased the utility users can get from Facebook services. From simple connecting with friends, family, and communities of people to sharing photos and videos and calling each other for free.

The Facebook Platform has been designed in a way that makes it possible to connect the different applications to Facebook's social graph. At first, Facebook offered social networking possibilities mainly with friends and family. Later, Facebook introduced a more extensive social graph, which allows its users to network with distant/weak social ties as well. Features on the Platform, such as Groups, Events, Local pages, Messages, Wall, Likes and reactions, facilitate networking among people that share the same passion or between different communities. Facebook's family of products is the perfect example of product offerings that attract and keep users on the platform. Presently, beyond social interaction services, Meta offers Facebook shops (2015), Facebook Marketplace (launched 2016), and Facebook dating (2019). Facebook has also introduced services aimed at entertainment, e.g., Watch, Feeds, Facebook gaming (2018).

Bundling of products and services is also visible in Meta's new business activities related to virtual and augmented reality. The new virtual reality products (Oculus Quest 2 Virtual Reality Headset, Smart glasses) and platform (Horizon Worlds social VR platform) have been increasingly integrated with the Facebook social networking platform. The Metaverse brings additional convenience to users by enabling sharing immersive experiences with colleagues, friends, and family beyond 2D screens. Even though it was stated that everybody can use the Oculus products with only an Oculus account, in reality, without a Facebook account, users do not have access to any social features such as sharing gaming skills and scores.

Through social networking, content-oriented services, and the new virtual reality products, Meta has been able to tie in its users to the platform by offering differentiated services and a wide-ranging social experience. The integration of a broad range of products/services/applications on one platform makes it easier for users to have access and increase their satisfaction.

5. Analysis

The five companies described in the previous section differ in various ways. A few simple facts are listed in Table 1, and, in the following, we analyze their differences, as well as their similarities.

Microsoft and Apple are the two oldest of the five companies, founded in 1975 and 1976, respectively. They are not among the oldest IT companies as such but are from a period in time where computers reached residential users as personal computers. Amazon, on the other hand, dates to the beginning of the web and the dot-com bubble in the 1990s. Amazon barely survived the dot-com crash in 1999–2001 but has become one of the world's absolute biggest and strongest IT companies. This also applies to Google (later to be renamed Alphabet), which was inaugurated in 1998, and which also survived the crash. The last of the five companies, Meta, was established as Facebook in 2004. In contrast to the three first-mentioned companies, neither Google nor Facebook had a well-established business model when they were started up. They first built up a large base of users and later started making money on advertisements and knowledge on their users. The results have been amazingly successful, with Google (Alphabet) and Facebook (Meta) totally dominating the online advertisements market around the world.

Table 1. Simple company facts.

	Microsoft		Apple		Amazon		Alphabet (Google)		Meta (Facebook)	
Year of establishment	1975		1976		1994		1998		2004	
Value (USD)	2.1 T [1]		2.6 T [1]		1.5 T [1]		1.7 T [1]		545 B [1]	
Revenue (USD)	185 B [1]		378 B [1]		470 B [1]		257 B [1]		118 B [1]	
Number of acquisitions	≈226 [2] (1994 to 2022)		≈123 [4, 4A] (1998–2021)		≈110 [6, 6A] (1998–2022)		≈240 [8, 8A] (2001–2021)		≈100 [10, 10A] (2005–2022)	
Year	R&D (Mn) [3]	No. of acquisitions [2]	R&D (Mn) [5]	No. of acquisitions [4]	R&D (Mn) [7]	No. of acquisitions [6]	R&D (Mn) [9]	No. of acquisitions [8]	R&D (Mn) [11]	No. of acquisitions [10]
2021	20,716	14	21,914	2	56,052	5	31,562	5	24,655	5
2020	19,269	8	18,752	9	42,740	2	27,573	8	18,447	7
2019	16,876	13	16,217	6	35,931	9	26,018	8	13,600	7
2018	14,726	17	14,236	10	28,837	4	21,419	10	10,273	4
2017	13,037	8	11,581	12	22,620	12	16,625	11	7754	3
2016	11,988	10	10,045	8	16,085	7	13,948	17	5919	7
2015	12,046	17	8067	10	12,540	9	12,282	15	4816	6
2014	11,381	9	6041	9	9275	5	9832	34	2666	9
2013	10,411	5	4475	15	6565	4	7137	17	1415	10
2012	9811	6	3381	4	4564	5	6083	12	1399	10
2011	9043	3	2429	2	2909	5	5162	26	388	11

[1] Investopedia, 2022. https://www.investopedia.com/biggest-companies-in-the-world-by-market-cap-5212784, accessed on 6 May 2022. [2] Microsoft, 2022. Acquisition History Microsoft; https://www.microsoft.com/en-us/Investor/acquisition-history.aspx, accessed on 6 May 2022. [3] Microsoft, 2021. Microsoft Research and Development Expenses. https://statstic.com/microsoft-research-and-development-expenses/https://statstic.com/microsoft-research-and-development-expenses/, accessed on 6 May 2022. [4] Apple, 2021. List of mergers and acquisitions by Apple; https://en.wikipedia.org/wiki/List_of_mergers_and_acquisitions_by_Apple, accessed on 6 May 2022. [4A] GAFAM merger reviews (Apple ≈ 121): https://www.econ-da.com/news/gafam-mergers, accessed on 25 November 2022. [5] Apple, 2021. Annual Research and Development Expenses of Apple Inc., https://statstic.com/annual-research-and-development-expenses-of-apple-inc/, accessed on 6 May 2022. [6] Amazon, 2022. List of mergers and acquisitions by Amazon; https://en.wikipedia.org/wiki/List_of_mergers_and_acquisitions_by_Amazon, accessed on 6 May 2022. [6A] GAFAM merger reviews (Amazon ≈ 103): https://www.econ-da.com/news/gafam-mergers, accessed on 25 November 2022. [7] Amazon, 2021. Amazon research and development expenses. https://statstic.com/amazon-research-and-development-expenses/, accessed on 6 May 2022. [8] Alphabet, 2022. List of mergers and acquisitions by Alphabet: https://en.wikipedia.org/wiki/List_of_mergers_and_acquisitions_by_Alphabet, accessed on 6 May 2022. [8A] GAFAM merger reviews (Alphabet ≈ 240): https://www.econ-da.com/news/gafam-mergers, accessed on 25 November 2022. [9] Alphabet, 2021. Alphabet Research and Development Costs. https://statstic.com/alphabet-research-and-development-costs/, accessed on 6 May 2022. [10] Meta, 2021. List of mergers and acquisitions by Meta Platforms–Wikipedia. https://en.wikipedia.org/wiki/List_of_mergers_and_acquisitions_by_Meta_Platforms#cite_note-61, accessed on 6 May 2022; [10A] GAFAM merger reviews (Facebook ≈ 89): https://www.econ-da.com/news/gafam-mergers, accessed on 25 November 2022. [11] Meta, 2021. Facebook Research and Development Expenses. https://statstic.com/facebook-research-and-development-expenses/, accessed on 6 May 2022.

In fact, the five companies that are often lumped together as the five US-based Big Tech companies differ in many ways and do not represent a sector, which also—as pointed out by [53]—creates various problems in terms of regulation. As de Streel and Larouche [53] explain, the specific kinds of regulations that are presently being rolled out in the EU with the Digital Markets Act (DMA) are neither traditional competition regulation nor sector-specific regulations. The same applies to the US. However, the companies also have a number of commonalities. They all have been able to build strong elements of demand-side economies of scale, based on network effects, both single-sided and cross-sided. They have also built important aspects of demand-side economies of scope in the shape of bundling of services and products and assembling knowledge on their users. Furthermore, all companies have been very apt at constantly renewing themselves by continuously updating their core products and services and adding new product and service areas. They all have a high degree of ambidexterity as a core element in their strategy.

In Table 1, it is indicated that investments in R&D for all five companies have skyrocketed during the past decade. This especially applies to Amazon, which has gone from app. 2.9 billion USD of annual R&D investment in 2011 to app. 56 billion USD in 2021. With respect to investments in general, investments in undersea cables have become very important for all five companies. The Big Tech companies do not want to be too dependent on the arrangements of traditional telecom operators for international connectivity. In order to connect their server parks around the world, these companies invest heavily in undersea cables in particular. In the case of Meta, having capacity on networks to service their many end users in Africa is also important. Meta is currently involved in building the undersea cable 2Africa together with network operators. These investments of the Big Tech companies indicate that, though the focus for most of them is on software, services, and applications, they invest in network infrastructure when necessary. The scope of their activities thus develops into physical infrastructures.

Table 1 and the case descriptions also indicate that the five companies all have extensive acquisition strategies. However, a supposition saying that, over time, companies, when they become big, rely more on acquisitions than on in-house development of new products and services [54], is not supported by the data on these five companies. In addition, there can clearly be differences in the strategic approaches of the companies in this regard, including over time. However, from the data on acquisitions and on R&D investments, it is not obvious that the focus consistently varies between the companies.

The five companies analyzed obviously differ with respect to scope (and scale) in different ways. Table 2 presents seven dimensions related to the scope of companies. The scope of products and services offered is not equally broad. Apple, for instance, is more focused than Amazon. Furthermore, scope can vary with respect to being primarily horizontal and/or vertical. Microsoft, for example, has to a large extent stayed away from the hardware side and concentrated on software, except for a few instances, as opposed to Apple. The importance of Multi-Sided Platforms (MSPs) as central elements in their business strategies also differs. Amazon, Google, and Facebook started as two- or multi-sided platforms, while Microsoft and Apple have added these kinds of platform elements at a later stage, with LinkedIn in the case of Microsoft, which is still a sideline service area for Microsoft, and with the App Store, which has become a central part of the overall business strategy for Apple.

Table 2. Dimensions of demand-side economies of scope.

Focused vs. diversified	Are the product and service areas that a company offers relatively focused or diversified?
Horizontal and/or vertical	How much emphasis does a company have on horizontal and/or vertical scope and integration?
Scale and/or scope	What role do, respectively, scale economies and/or scope economies play?
Transaction and/or innovation platforms	Are the platform elements that a company includes transaction platforms and/or innovation platforms?
Centrality of MSPs	How central are multi-sided platforms to the overall business model of a company?
Bundling and/or user data	What role do bundling (and tying) and/or use of data on users play for a company?
M&A and/or indoor development	Does the addition of new business areas of a company primarily rely on mergers and acquisitions and or in-house development?

This also implies that the centrality of demand-side economies of scale and demand-side economies of scope varies between the companies. Demand-side economies of scale was initially not as important for Apple before the App Store as it was, all the while, for Amazon, Google, and Facebook, as well as for Microsoft and its Office products. Another important element that, for instance, Gawer [55] has discussed is the transaction and/or innovation character of platforms. The Amazon.com Online Stores and Google Store are clearly transaction platforms. The same applies to the App Store and Google Play in the application markets. Apple iOS, Google Android, and Amazon Web Services, on the other hand, are innovation platforms, which also applies to Microsoft Windows. Finally, that the most important elements in a demand-side economies of scope strategy are bundling and tying in and the use of data on users may also differ. However, this is more in the specific manners in which these strategies are used. Bundling, as well as the use of data on users, play a central role for all five companies.

6. Discussion

The concept of the scope of companies is closely related to discussions on the boundaries of companies. In a seminal paper from 2021, Gawer [55] analyzes the boundaries of digital platforms with respect to the interplay of firm scope, platform sides, and digital interfaces. The purpose is to enhance the understanding of how the boundaries of companies develop when taking the interplay between known research areas (firm scope, platform sides, and digital interfaces) into consideration, i.e., how can results from these research areas be used for extending our knowledge on the boundaries of firms—what determines the boundaries of firms? This is a topic that has been extensively researched by the transaction cost economics tradition (building on Coase [56] and Williamson, e.g., [57]), but also in the tradition of research into the resources and capabilities of companies (building on, e.g., Barney [58]), as Gawer [55]) emphasizes. In addition, as we have seen in the theory part of the present paper, the issue of transaction costs, at an early stage, entered the research on scope economies with the contribution by Teece [12].

However, the focus of the paper by Gawer [55] is on the boundaries of companies, while the focus of the present paper is on the basis for scope economies. This means that our focus is on the mechanisms facilitating scope, so to say, internally, and not on the boundaries nor how the companies in question cooperate with other companies belonging to the same ecosystem of companies. The two different foci, however, complement one another and should both be part of research on scope and boundaries, which was an important point made by Teece [12] in his paper on *Economies of scope and the scope of the enterprise*. Among the many good observations that Gawer [55] makes is that asset specificity in the IT area is relatively lower than asset specificity in many other production areas.

Computers are general-purpose technologies and software can be combined in innumerable ways. This is a strong basis for economies of scope, as new products and services can be combined with and build on existing hardware and software platforms. Whether this necessarily leads to extending the boundaries of individual companies or whether it leads to improved possibilities for cooperation between independent companies is an issue for empirical investigation and for concrete case studies. Insourcing or outsourcing is not only determined by whether it is technologically possible, and transaction costs, therefore, could be lower. It is also determined by the aim of building market power and the aim of appropriating the value added created by insourced activities.

The basic tenet of the present paper is that there are two main aspects of demand-driven/demand-side economies of scope, namely, bundling/tying and the use of data on users. The bundling aspect is easily understood and was already analyzed by Henten and Godoe [9] in 2010 with respect to triple and quadruple play offered by telecom companies (Internet access, telephony, IPTV, as well as mobile in the case of quadruple play). What drives scope in such cases is the complementarity and possible interoperability, and at any rate, convenience, for the users. Obviously, this 'convenience' can be 'assisted' by tying in customers to packages of products and services on the part of companies. Yet, it is the user side that drives the scope.

When one looks at the use of data on users, the issue is different. In this case, data are either voluntarily given by users or extracted from the users with or without their knowledge and consent. This knowledge is essential for improving and customizing existing services and products of the companies and for adding new service and product areas. In fact, knowledge on users has always been important for all companies; however, previously, this has mainly been background knowledge for developing and selling services and products. Today, data and knowledge on users are intrinsic parts of delivering the experience that services and products stage. The user side provides an essential input to development and production.

As in the case of demand-side economies of scale, there is obviously a relationship between the demand side and the supply side. Even though the mechanism that drives scale in the case of positive externalities in connection to network effects is on the demand-side, the hardware and software facilities on the supply side have to be provided in order to accommodate for the demand-side effect. The same applies to demand-side economies of scope. To the extent that the demand-side factors of bundling and data on users drive the scope of production, it is necessary to build scope on the supply side.

The fact that we have demand-side effects regarding scale, as well as scope, does not mean that the two kinds of mechanisms work in the same manner and with the same effects. Demand-side economies of scale, except for the cases where different companies work on the basis of technologies and standards, which are the same for all these different companies, potentially lead to winner-takes-all markets. Users agglomerate around one (or a few) technologies and companies in order to reap the benefits of network externalities. This does not, in the same manner, apply to demand-side economies of scope. In principle, the bundling effect works for individual users. There can easily be companies competing side-by-side on the basis of bundling strategies. With respect to the use of user data, this is different. If we only deal with strict customization, knowledge on the individual user could be sufficient. However, it is the combination of big data on many users and knowledge on the individual users which constitutes the basis for customizing, upgrading, and developing or incorporating new services and products.

For the companies to develop into gigantic tech corporations, it is thus the combination of scale and scope economies that creates this development track. This is clearly seen in the case of the Big Tech companies dealt with in this paper. They all combine elements of scale and scope economies driven by the demand side. This does not, however, mean that scale and scope always work well together and strengthen one another. There can be instances where emphasis is on scale and not scope. Facebook, for example, put all emphasis on building scale at the beginning. A scope strategy could easily have taken attention away from the prime activity of building scale. While scope can thus stand in the way for scale, the opposite is hardly the case. Though there can be instances and periods in time where companies do not wish to develop scale, in the long run, almost all companies strive for some level of scale. However, the calibration of scale and scope is an important strategic factor to take into consideration.

An important issue, when analyzing demand-side economies of scale and demand-side economies of scope, is whether these two aspects are somehow parallel (see Figure 1). In the sense that demand-side factors are important in both instances, there are similarities. However, there are also considerable differences. While demand-side economies of scale, based on network effects expanding the value of companies providing services and contributing to potential growth, are founded on the increased value to the users, with growing numbers of users and the relationships between these users, the bundling effect creating demand-side economies of scope is related to the individual user.

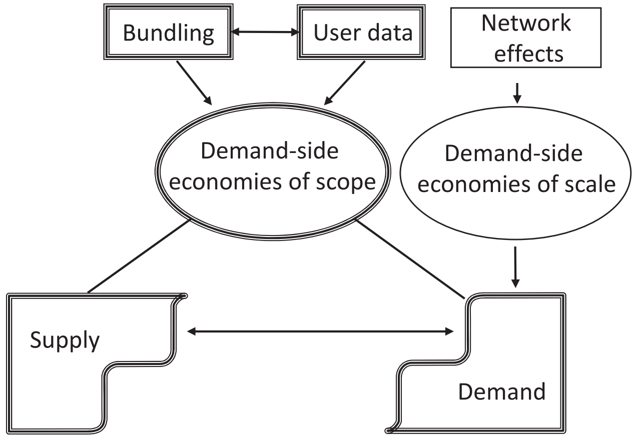

Figure 1. Demand-side economies of scale and demand-side economies of scope.

Yet another issue is data on users. In this case, companies acquire data on their users that can be utilized for customizing and upgrading existing services and products and for establishing new lines of production, as the user data can be utilized for different services and products. It is the combination of big data on many users and the knowledge on the individual user that facilitates this. Furthermore, these kinds of data can be used for tying in customers. Tying in is not only a question of forcing users to buy bundles of services and products. Knowledge on users can also be utilized for tying in customers, as the knowledge that companies have on their users facilitates customization and the creation of special relationships between companies and their users.

A basic difference between demand-side economies of scale and demand-side economies of scope is thus that demand-side economies of scale based on network effects could be said to work independently of the supply side. The increasing utility to the users and, therefore, the potential growing number of users develop as long as there is capacity on the network. Demand-side economies of scope, on the other hand, require interaction between the demand and the supply side. Bundling requires that the company provides the different services to be bundled, and use of data requires that the company takes advantage of these potentials. One could say that that demand-side economies of scale are based on an interaction between users on the demand side, while demand-side economies of scope are based on interaction between the demand and the supply side.

7. Conclusions

The overall purpose of the present paper is to attract attention to the issue of economies of scope for platform research. Hitherto, most attention has been on network effects and demand-side economies of scale, on the role of platforms in lowering transaction costs for the different sides of the platforms, and on the importance of big data. The latter point on data, however, has seldom been related to economies of scope, but has mainly been used to explain how separate service and product areas have been developed, applying user data.

In a sense, scope economies have been living a ‘shadow existence’, while all emphasis has been on demand-side economies of scale. Indeed, the importance of demand-side economies of scale can hardly be over-emphasized, but economies of scope are also essential for the impressive growth of Big Tech corporations. Indirectly, this has been accepted for a long time, as most regulatory interventions are aimed at the scope aspects of the corporations in question. There is thus a mismatch between the economic analyses of Big Tech corporations and the regulatory provisions being developed.

While scale economics has for a longer while been giving much attention to direct and indirect network effects, including two- and multi-sided markets/platforms, and has thus been emphasizing the demand side more than the supply side, this has not been the case with scope economics. Here, practically no interest has been on the demand side. Therefore, the primary aim of the present paper is to introduce the importance of the demand-side factors in the economies of scope related to Big Tech corporations.

There are two general areas driving demand-side economies of scope that are dealt with in the paper. One is concerned with bundling of services and products, and the other one with the acquisition and processing of data on users and their activities using digital services and applications. In the paper, six additional dimensions related to the scope of companies and their strategies are discussed, namely:

- Focused vs. diversified
- Horizontal and/or vertical
- Scale and/or scope
- Transaction and/or innovation platforms
- Centrality of MSPs
- M&A and/or in-house development

All these dimensions are important for the implications of scope economies for companies. A limitation of the paper is that these dimensions need to be further analyzed in order to better understand the scope of companies. Furthermore, in future research, the differences and similarities between demand-side economies of scale and economies of scope must be further examined. The prime purpose of the present paper has been to attract attention to the overall topic of economies of scope driven by the demand side. In addition, empirical research into M&As and in-house service and product development of Big Tech and other platform companies and the role of economies of scope, including demand-side economies of scope, need to be further developed. Moreover, an important line of research is how regulation of Big Tech develops and how analyses of demand-side economies of scope can contribute to improving regulatory measures.

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How Transformative Business Model Renewal Leads to Sustained Exploratory Business Model Innovation in Incumbents: Insights from a System Dynamics Analysis of Case Studies

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Abstract: The digital era and mounting sustainability pressures have reinforced incumbents' need to respond to radical innovation through business model innovation. Despite advancements in the literature on incumbent business model innovation, there are still open debates regarding strategies for achieving systematic innovation and poor integration between the literature on managing multiple business models and the strategic management of business model innovation. To address these gaps, we investigated three Brazilian incumbents that developed systematic business model innovation processes and analyzed their evolution. We followed a multiple case study methodology, deploying system dynamics as an analytical lens. Our findings showed that the evolution of innovation departments from business model renewal to exploration is based on a systemic tension between solving the core problems of the business and creating openness to innovation, innovation capabilities, and resources. By assigning the innovation departments a vital role in the renewed business model and exploring synergies to manage multiple business models, the companies create a "buffer" to sustain exploratory business model innovation. We suggest that the strategy for conducting business model renewal matters, especially when the renewal is transformative, aiming to shape the future. We contribute to incumbent business model innovation theory by showing the system dynamics behind the evolution from business model renewal to exploration and by connecting the management of parallel business models to the strategic management of business model innovation.

Keywords: business model innovation; system dynamics; incumbents; innovation management; exploration; renewal

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1. Introduction

The need for incumbents to respond to radical innovation through business model innovation (BMI) acquired momentum in the last 20 years. This was mainly because of digital technologies (e.g., the internet, big data analytics, cloud computing, mobile phones, the internet of things, and artificial intelligence) and mounting sustainability pressures (e.g., circular economy, grand challenges, sustainable development goals, and societal and regulatory demands), which created multiple possibilities for designing and proposing new BMs [1–3] as well as instability in competitive environments, thus reducing BMs' lifecycles [4–6]. Under such a context, the literature concluded that incumbents need BM renewal and BM exploration capabilities to build long-term resilience [7,8], highlighting the relevance of balancing exploitative and exploratory BMI [9–11].

The literature on achieving such a balance is still rather controversial, with ongoing debates on how to structure the configuration of "BMI engines". Chesbrough and Rosenbloom's [12] study of Xerox's spin-offs provided evidence that incumbents' dominant logic operates against exploratory behavior, though structural separation helps to avoid such pitfalls. This study had its roots in the interaction between radical technological innovation and BMI (e.g., Tongur and Engwall [13]; Kaulio et al. [14]), showing that technological incompatibilities favor structural separation. Similarly, Kuhlmann et al. [15] found that separation is fruitful with paradigmatic changes, such as moving towards circular BMs. Habtay and Holmén's [16] study provided empirical evidence that in cases of a combination of radical technological innovation and BMI, a separation seems superior, while under other conditions, an integrative strategy should be applied.

Despite research partially supporting the separation strategy, it does not come without challenges. Egfjord and Sund [17], for instance, investigated how separation generates a misalignment of perceptions among those responsible for the current BM and those responsible for the exploration of new BMs. Likewise, Sund et al. [11] investigated the barriers to exploring BMI. Their study showed that BMI engines have limited resources and capabilities, experiencing control pressures from the dominant BM to obtain results. Thus, integration mechanisms and balancing incremental and radical innovation might be needed. Another relevant barrier is the notion that adding a new BM is not always beneficial [9]. Besides the possible creation of unwanted complexity by adding new BMs, Hacklin et al. [7] showed that when the core BM is under threat, searching for new BMs draws attention away from saving the former, leading to catastrophic results. Thus, exploratory BMI is a sound strategy under stable environments, not only because it creates new revenue streams, but also because the proactive search for new BMs plays a major role in the ability to respond when the time of obsolescence arrives. Thus, the exploration of new BMs benefits incumbents' ability to respond to radical innovation [7,8,18,19].

These contributions, therefore, advocate against a separation strategy, reinforcing the significance of managing BM renewal and exploration in parallel and creating a portfolio of multiple BMs [20,21], whereby incumbents benefit from deliberately exploiting complementarities between parallel BMs [22], even under the existence of partial cannibalizations [23]. Markides' [24] seminal account provided a theoretical basis for understanding the exploration of such complementarities through degrees of integration between co-existing BMs while managing specific conflicts through partial separation. In line with this view, Khanaga et al. [25] showed that exploring touch points and integration between the obsolete BM and the substitute BM is beneficial for accelerating change while reducing organizational inertia.

Thus, the notion of incumbents benefitting from multiple BMs is rather contradictory to the idea of structurally separating the BMI engines to provide isolation from the influence of the core BM. The barriers to radical BMI also provide conflicting evidence, considering that the key barriers primarily stem from such a separation. Therefore, the literature focusses on understanding separated approaches and informing the need for integration mechanisms [11,15–17,26]. There are, however, fewer studies exploring in-depth cases aiming at understanding how the creation of integrated innovation departments can work to overcome existing barriers [11]. Moreover, despite the contradictory findings between both research streams, the literature on incumbent BMI has, to the best of the authors' knowledge, neglected the bidirectional impacts of managing parallel BMs on the degree of exploratory BMI by incumbents.

To contribute to filling these gaps, our study's objectives were to:

1. Investigate incumbent companies that have developed systematic BMI processes through an integrated approach.
2. Analyze the evolution of the investigated incumbents' BMI process.

As a methodological approach, we conducted a multiple-case study involving three large Brazilian incumbents and adopted a system dynamics analytical lens to develop our theories. Our findings showed that a structured approach to achieving BM renewal with positive outcomes leads incumbents to pursue exploratory BMI. This structured search, besides achieving BM renewal, generates, as relevant outcomes, an increase in the openness to innovation, the buildup of innovation capabilities, and the greater availability of resources. The systemic consequence is a tension that pushes companies towards exploratory behavior to harness the favorable conditions. We also found that this evolution from BM renewal to exploration is insufficient because of the significant time delays between deciding to explore new BMs and achieving significant returns. Hence, the systemic forces push in the other direction: the lack of (short-term) results reduces the openness to change and increases control. To prevent this, our findings encourage the creation of a "buffer" that consists of: (1) the assignment of a vital role in the renewed BM to the innovation departments; and (2) the exploration of synergies between the core BM and new BMs. Our cases suggested that the type of BM renewal matters for the creation of the "buffer". In particular, transformative BM renewal leads to the creation of white spaces inside novel paradigms, which the company can explore through new BMs, and tends to connect the innovation departments to the renewed BM's value proposition.

This study's contributions to the BMI literature are threefold. First, we contribute to the ongoing debate on the degrees of separation between BMI engines and the existing BM by providing evidence to suggest that integrated BMI engines that evolve from a transformative BM renewal strategy have positive impacts on solving potential barriers to exploratory BMI in incumbents. Second, we take the first steps in understanding how the management of multiple BMs through the deliberate pursuit of complementary new BMs as part of the renewed BM core logic plays a significant role as a "buffer" to support the longevity and the health of exploratory BMI. Third, we contribute to incumbent BMI theory by implementing the system dynamics lens to explain the key forces behind balancing BM renewal and exploration. Finally, our study contributes to practice by describing a process that can be followed by incumbent managers when creating their BMI engines.

The next section describes the theoretical background, including the business model and business model innovation concepts, the challenges and opportunities for incumbent BMI, and the bases for our analytical lens of systems thinking. Section 3 explains the methodological approach as well as the strategies for case selection, data collection, and analysis. In Section 4, we present our core findings from the case studies. Finally, we discuss this study's key contributions to the literature and implications for practice and suggest some future research avenues in Section 5.

2. Theoretical Background

2.1. Business Model Innovation in Incumbents

A business model is a dynamic concept encompassing a combination of internal components, often referred to as the value proposition, value capture, and value delivery [27], and their evolution to adapt to and anticipate external environmental changes [28]. As such, the BM, as a non-static concept, is a complex system in constant evolution. Its architecture builds internal consistency between components [29], which must be aligned to the external environment under continuous change.

As a complex system, the power of the BM concept lies in the interactions between its components [29], as the whole is greater (or smaller) than the sum of its parts [30]. Casadesus-Masanell and Ricart [31] referred to the components as choices directed by the strategy, leading to several consequences that should create complementarities and sensemaking, ultimately generating competitive advantages. The evaluation of the Ryanair case showed that every BM part was aligned with the value proposition of offering low-fare flights. Similarly, by explaining the concept of business models as models, Baden-Fuller and Morgan's [32] seminal account improved the understanding that BMs can be scale models, scientific models, and recipes. Condensing a complex system into a scale model, such as "the Ryanair model", "Rolls Royce's power-by-the-hour model", and "the McDonald's model", represents it as a (well-understood) coherent system, which can be, of course, broken down into more detailed parts for analysis as a scientific model and then represented as a recipe of ingredients (components) and preparation modes (their interrelations).

This notion is particularly relevant, as BMI is a result of not only deliberate design practices [27,33,34] but also organic evolution, often with less-extensive design processes, in the pursuit of competitive advantages [29,35–37]. In connection with this, it is worth differentiating the development of a startup, i.e., a new BM from scratch, and the innovation of existing BMs, as in the case of incumbents. For the former, there is no previous system, as the BM does not yet exist, and it is, therefore, often an outcome of design [33]. For the latter, the BM evolves and creates complementarities that strengthen its market position over time. Such conditions generate not only structural but also cognitive forces around a system that already works that tend to create rigidity and inertia to change [36–41]. Understanding the nuances inside the umbrella term BMI is crucial because, as Casadesus-Masanell and Zhu [42] argued, BMI is a "slippery construct to study." Thus, the particularities of each type of BMI lead to not only very different outcomes but also different managerial processes, capabilities, and challenges.

In a recent literature review, Foss and Saebi [43] created a typology for BMI by separating changes in the components (modular) and changes in the complex system (architectural), which could be new to the firm or the industry. However, it is still hard to grasp the differences between types of incumbent BMI based on such definitions. Volberda et al. [44] proposed a detailed typology considering the type of change, either transformative or evolutionary, and the strategic orientation in the ecosystem, either responding or shaping. As such, they provided a more fine-grained analysis of the possibilities of BMI by incumbents. For evolutionary changes, the BM renewal proceeds with no fundamental change in the BM logic. In cases of innovations (or societal changes) that dislocate the tight coupling between an incumbent's BM and the environmental conditions (e.g., customer behavior, technology, changing society, and customer needs), transformative changes in the BM are called for, demanding different approaches [7,8,25]. Responding and shaping refer, respectively, to the strategic positioning of adaptations to changes as they come and the attempt to induce the changes themselves, pioneering and creating the future.

Additionally, incumbents can explore new BMs, creating new ventures [7,11,12,26,36,45,46]. Finally, incumbents can also explore both paths, targeting ambidextrous behavior conducive to BM renewal and exploration [7,8,22,24]. Thus, for incumbents, the concept of BMI can represent different things, ranging from incremental changes to transformative changes, coupled with the possibility of creating new BMs from scratch. Bearing this in mind, we differentiate the various types of incumbent BMI as incremental BM renewal, transformative BM renewal, and BM exploration:

- Incremental business model renewal

This type of BMI may be an outcome of both diagnosis and design activities and evolutionary, less deliberate changes that occur during a company's search for increasing performance. In terms of the degree of change, it can be modular and/or architectural, but the core notion is that there is no radical change in the underlying BM logic, i.e., the changes tend to rely on additional value creation and delivery as means to increase the value flow and potentialize the value proposition already in place. As such, the core idea is to strengthen the position in the market, which is often represented by a greater willingness to change in order to obtain short-term results and is broadly supported by top management teams, considered the path-dependent solution [25,47]. A good example is the optimization of an existing BM by making it digital, i.e., through an online channel, to increase its reach and automate the value creation activities and its underlying business processes. In terms of challenges, naturally, any changes display inertia, but as the resulting changes fit the dominant logic [48], the barriers are lower and there is a reduced need for structured approaches to conduct [25].

- Transformative business model renewal

This type of BMI involves in-depth changes to the BMI logic, broadening or altering the customer bases, supply network position, and overall value proposition alongside value creation, delivery, and capture, i.e., a deep change in the organization's capabilities. As such, the value proposition is reconceived, which calls for the rethinking of the creation, delivery, and capture. Illustrations of transformative BMI are Rolls Royce's power-by-the-hour model [49] and the *Encyclopaedia Britannica* adaptation. The literature stresses that inertia [13,50,51], path dependency [52–55], and the potential cannibalization [23,25] of the business works against transformative BMI. Accordingly, the recommendation is for a separated, focused structure [37,56]. This type of BMI is often linked to a survival threat whereby the organization faces a situation in which the BM change is inevitable. However, the literature highlights the importance of proactivity and the realistic prognosis of the relevance of conducting transformative BMI as an opportunity to shape the future and improve an incumbent's capacity to respond to radical innovation [7,44].

- Business model exploration: corporate entrepreneurship

This type of BMI refers to entrepreneurial activities undertaken by incumbents to create and explore new BMs, such as startups, either to open new markets and create new revenue sources or to accelerate current BM performance [45,57]. This involves exploring new knowledge, resources, and partnerships to develop innovative value propositions and seize new business opportunities. It requires entrepreneurial vision from a company's board and top management, as its development is realized through corporate entrepreneurship or corporate venturing initiatives [58,59]. A good example is the undergoing strategic transformation of Bosch from a B2B manufacturing leader based on outstanding product innovation to a B2B leading provider of technological solutions based on internet of things and artificial intelligence [26]. As illustrated in the Bosch case, companies that pursue venturing BMI are primarily exploring the frontier of opportunities opened up by the digital economy and digital transformation. Moreover, as much as innovation itself has moved from the closed paradigm based primarily on internal R&D to open innovation based on interorganizational collaboration and access to external knowledge, venturing BMI has been characterized by strong external partnerships, particularly through corporate engagement with startups, i.e., incubation [60], acceleration [61], venture building, and corporate venture capital [62]. However, this BMI type presents barriers to incumbents, and many initiatives tend to collapse with time [11]. The first barrier is that experimentation and trial and error [48,63] are the underlying processes for BM exploration. This results in a resource-intensive process that takes a long time to achieve returns, depending on strong commitment. Startup founders, for example, depend on their entrepreneurial activities' success, and the literature shows that commitment is crucial [64]. This is not true for incumbents, as they already have a successful BM that they can easily turn to if the endeavors fail. Thus, issues such as goal incompatibility [48,65], managerial complexity [7], and a loss of focus [17] play a role in shaping the tendency to return to incrementalism.

Therefore, in the literature and in practice, attempts are being made to uncover ways of overcoming such barriers and determine the most suitable organizational structure for pursuing lasting BM exploration that allows companies to seize "white spaces" [66] for business opportunities. Moreover, the relationship between BM renewal and exploration needs further clarification, especially considering the literature's emphasis on both being vital for incumbents. This relationship can be either positive or negative. An excessive focus on BM renewal with an incremental goal, i.e., extrapolating from the current BM perspective, can hinder the ability to respond to discontinuities and constrain exploration [25,36]. The random exploration of new BMs can bring complexity, i.e., too many technological bases, high rates of cannibalization, and conflicts, leading to suboptimal BM management and consuming managerial attention [7]. Moreover, the challenges of generating relevant returns through new BMs [11] and the cognitive barriers relating a departure from the dominant logic [12,17,26] can induce barriers to exploratory BM, thus limiting future exploratory efforts. On the other hand, BM exploration is regarded as relevant to fostering experiments that can improve future envisioning, reduce dominant logic, and enhance BM renewal activity [3,7,8,36,63]. In this regard, the dynamics behind incumbent BMI and the relationship between BM renewal and BM exploration needs to be further studied. In particular, the balancing of renewal and exploration and the impacts of the various BMI types on each other remain understudied. To tackle these issues, we deployed systems thinking lens to better understand the dynamics behind incumbent BMI.

2.2. Sytems Thinking and Business Model Innovation

Systems thinking is a manner of understanding complex systems as a whole instead of looking at their parts individually [67]. The underlying notion is that the different parts of a system (e.g., businesses, ecosystems, or groups of people) are connected and that it is vital to understand how these parts affect one another. As such, it can be understood as a framework for analyzing and evaluating the interrelation between a system's parts rather than listing its parts, i.e., it helps uncover patterns of change rather than taking static snapshots. Senge [68] highlights how, for example, short-term solutions to business problems represent a remedy that can, although improving performance, worsen the root problem that caused the issue in the first place. One of the reasons for this is that alleviating the problem's symptoms works against setting up means to effectively solve the problem [68,69]. Furthermore, small changes in one part of a system can greatly affect the whole system [68].

In this regard, the literature provides a plethora of studies that have investigated the impacts of systems thinking on performance under different settings, such as sustainability [70], design thinking [71], public health and healthcare [72,73], and business performance [74]. The search for efficiency can begin by analyzing each member of an organization, with the goal of improving their individual performance. However, it is necessary to understand the mechanisms in place to determine how individual improvement affects performance—for example, the organizational processes, culture, and teamwork norms. For example, Cady's [75] study showed that interventions at the system level can significantly improve teams' performance when aligned with systems thinking concepts, i.e., the invisible (sometimes visible) mechanisms in which the individuals are embedded affect their mental models, thus shaping their interaction dynamics [76], highlighting the power of systems thinking for businesses.

Considering its relevance, the field of research on innovation management has explored the concept of systems thinking to, for example, explain decision making within the innovation process [77], understand and inform policy making to improve national innovation systems [78], and enhance the management and success rate of innovation projects [79]. BMs are broadly defined as complex systems [43,80–82], and there is wide recognition that innovations or changes in specific parts of a BM require systemic alignment in others [3,29,83]. However, despite the theoretical recognition, few studies have deliberately deployed a systems thinking analytical lens to understand BMI [84,85]. Nevertheless, the emerging literature has made advancements by proposing tools to help uncover the dynamics behind BMI, suggesting the application of causal loop diagrams, time delays, and stocks and flows [86].

3. Method

3.1. Research Methodology

As a research methodology, we conducted a multiple-case study, as this is considered a suitable research approach when the subject involves complex systems and organizational phenomena about which there is little knowledge [87,88]. In line with this study's objectives, multiple-case studies allow an in-depth and longitudinal analysis of cases, which could help us uncover and establish theories by assessing the similarities and differences between various companies, ensuring the reliability, validity, and relevance of the research [89,90]. Additionally, case studies provide a richness of data that is supportive of exploratory studies aiming at the creation of new theories, as was the case with this study [88].

3.2. Case Selection

Following Eisenhardt and Gräbner's [89] guidelines, we sought to build a theoretical sample. Moreover, we followed recommendations for critical [91,92] and longitudinal cases [88]. We delineated the following criteria: (1) we selected cases at least in the stage of pursuing the creation of new BMs through a BMI engine; (2) the selected companies displayed resilience and longevity in their BMI engines; (3) we selected large incumbents that were leading companies in their market segments; (4) the sample comprised at least one company in the manufacturing industry, one company in the ICT industry, and one company in the services industry; (5) the cases were not born digital and had existed for at least 20 years. The focus on large companies was based on the notion that larger and older companies tend to display a higher degree of systemic complementarity in their BMs [37,43], which leads to greater rigidity. This criterion rounded up our focus on critical cases, as the BMI literature highlights the challenge of changing existing BMs and moving from traditional business-as-usual to agile and exploratory organizations (for more details on agile organizations, see [93]).

The Selected Cases

Alpha is a 96-year-old leading incumbent in the Brazilian health diagnosis industry, offering a broad range of services. In 2014, the company started its renewal, in particular by reshaping and intensifying innovation activities, moving from traditional reactive medicine with diagnostic services to precision medicine. In the last three years, the company has created its first new BM and has been pursuing the creation of new startups to fill in the predictive and precision medicine value chain.

Beta is a global player and a leading incumbent in the personal care and cosmetics industry, with a long and successful history. The company was born with innovation at its core, as it is one of the only players in the world to leverage Brazil's extensive flora and fauna. The uniqueness of the products has placed R&D at the core of the company since its founding. Since 2012, the company has been rethinking its BM, especially due to digital transformation. In the last three years, it has been attempting to create new startups with a strong merger and acquisition strategy.

Gama is one of the ten largest incumbents in the field of R&D outsourcing in the Brazilian ICT industry, and recently it has become an international player with projects in North America and other countries in South America. Despite the company's core activity of operationalizing third-party R&D projects, it has displayed poor innovation performance since its founding. Considering its basis in information technology, the company had no specific technological focus, executing almost any kind of project. To tackle this issue, the company began its BMI journey in 2017 by narrowing its technological focuses to the most promising future technologies according to a foresight study (including 3D printing, data science, cognitive computing, industry 4.0, cybersecurity, and blockchain) and creating new BMs based on these technologies. In 2020, the company launched its first new startup, and it launched two more in 2021. Table 1 summarizes the cases in terms of their size, revenue, and employee count.

Table 1. A brief description of the cases, including the country of origin, age, industry, size, employee count, and revenue.

Case	Age (Years in 2021)	BMI Journey Beginning	Industry	Employee Count	Revenues (USD)
Alpha	96	2014	Health services	~13.000	>1 billion
Beta	53	2012	Personal care and cosmetics manufacturing	~17.500	>22 billion
Gama	21	2017	Software	~700	>100 million

We followed the Eurostat classification of company size based on persons employed: micro-enterprises with less than 10 persons, small enterprises with more than 10 and less than 49 persons, medium enterprises with 50 or more and less than 249 persons, and large companies with more than 249 persons.

3.3. Data Collection

For the data collection, we followed the literature's directives for multiple-case studies [87,88,90]. We developed a case-study protocol, considering data from semi-structured interviews with key informants and a longitudinal analysis of annual reports and public documents as secondary data. To ensure reliability and validity, we deployed triangulation techniques to cope with possible informant biases, especially stemming from the characteristics and judgments of our interviewees that may have led to a distortion of reality [94]. Considering the different realities of our case companies, we followed different triangulation and data-collection strategies. For Alpha and Beta, which are public companies, we took advantage of the availability of a large amount of documentary data, extensively using reports and documents to triangulate with the interviews. Thus, we first conducted an in-depth documentary analysis and then proceeded to the interviews. This allowed us to confront interviewees from Alpha and Beta with documentary data when contradicting information arose. For Gama, which is not public and thus did not provide such a richness of documentary data, we broadened the demographics of our interviewees by including persons from different backgrounds and managerial layers and conducted an internal document analysis.

We conducted 14 semi-structured interviews, with an average duration of 60 min, ranging from 15 to 75 min. We created transcripts of the interviews immediately following their completion. Considering the goal of understanding the systemic complementarities between the BMI engine and the current BM, focusing on the structural and strategic levels, we chose our key informants from the top management team of the companies, preferably at the CXO level and directly connected to the BMI engines. In the case of Gama, we included interviewees from other departments and levels, such as R&D and human resources, to make up for the lower amount of available data and facilitate a deeper analysis. Table 2 depicts the demographic data of the key informants in each case, the supplementary material used to triangulate, the number of interviews per case, and the duration of the interviews.

Table 2. Key informants, number of interviews, average duration, annual and managerial reports, and additional documents.

Case	Key Informants	Number of Interviews (Average Duration)	Managerial Reports Analyzed	Additional Sources
Alpha	CTO and innovation manager	3 (60 min)	7, from 2015 to 2021 (~200 pages)	Public data from social media, website, and informative documents.
Beta	Executive business director and CEO	2 (63 min)	7, from 2015 to 2021 (~750 pages)	Public data from website, social media, news, and mergers and acquisitions.
Gama	CEO, innovation director, HR director, R&D personnel	9 (15–75 min)	Not available	Internal strategic documents (strategic map evolution, strategic communication); public data from website, social media, and news.

3.4. Data Analysis

For the data analysis, we filed and documented the data into tables and revisited the interview transcriptions multiple times to analyze the gathered data. Then, we followed Strauss and Corbin's [95] recommendations. First, we conducted open coding, focusing on first analyzing each case separately. After understanding each case, we moved to axial coding, looking for similarities and differences between the cases and considering how they contributed to answering our research question. Finally, we conducted selective coding to derive relevant constructs and concepts from the cases [87]. We also employed one of the researchers as a devil's advocate to help reduce potential biases in the analysis [96]. Finally, the authors conducted data ideation and representation processes, contrasting the available data sources as the underlying triangulation method [97,98].

4. Results of the Case Studies

In this section, we present our study's core findings. First, we briefly present the BM of each of the studied cases, highlighting how it co-evolved with their BMI engines from the beginning of our analysis. Then, we investigate the system dynamics through which their structured approach to pursuing BM renewal led them to begin exploring more radical BMI. We then show how our case studies created integration mechanisms between their BMI engines and the core business model to sustain their exploratory efforts. Hence, through a system dynamics analytical lens, we present the inducted theory of how incumbents can create BMI capabilities to prepare themselves to respond to radical BMI.

4.1. Presentation of the Cases

4.1.1. Alpha

Alpha's initial BM was that of a health diagnostics service, operating via intermediates, in the B2B2C model or directly via the B2C model. The core value proposition was centered on high-quality tests and sample collection. Its value creation architecture was based on deploying a technical-oriented staff responsible for conducting R&D to create new tests or improve the existing ones. Alpha's position in the market was to attend all patient classes, with different layers of tests and exams and through different channels, focusing on service excellence to acquire and retain customers. Thus, innovation until 2015 was mostly directed toward technological advancements in medical techniques and analysis.

The BMI efforts in the company began in 2017 with the "genomic project", an initiative that aimed to leverage the power of digital technologies, particularly artificial intelligence, to pioneer predictive and precision medicine in the future (Alpha's annual reports, 2017, 2018, 2019, 2020; CEO interview). Alpha's modular BMI process was based on reframing its value proposition to focus on predictive and precision medicine, i.e., patient well-being. This materialized as modular differentiation from the reactive medicine practiced so far via the exams and tests offered by the company, based in discrete product innovations inside the BM (Alpha's new business director).

The evolution of such a practice led Alpha to a transformative change in its BM, rethinking its business model from a diagnostic services provider to a healthcare platform (Alpha's annual reports, 2020 and 2021). The value creation element of the new BM changed to incorporate the exploration of new businesses that could play a role in the predictive medicine ecosystem. In 2019, Alpha launched its first spin-off, a B2C BM platform that performed the functions of telemedicine marketing, genetic and lifestyle conditions monitoring, treatment and exam scheduling, and so on (Alpha's annual report, 2019 and 2020).

4.1.2. Beta

Beta's initial BM followed the traditional personal care and cosmetics manufacturing model. The company delivered value by deploying a large force of sales representatives that increased its sales and created value through R&D to provide product and process innovations that sustained the value proposition of well-being through differentiation. The company differentiated itself within the market by positioning itself as a sustainability-oriented company, exploiting the country's vast plant diversity without depleting it and creating value for neglected populations living in underexplored areas. In a manner, the company's demand was driven by its network of representatives, which sold the products through personal contacts to end customers. Thus, it could be understood as a B2B2C model.

Naturally, this network of representatives played a major role by shaping Beta's product mix, obtaining customer feedback that could inform R&D, and creating bonds with end customers to transmit the company's core values to society. This was, however, a largely analogical process that relied on suboptimal information flow and emphasized mouth-to-mouth mechanisms. Thus, Beta depended on its representatives' knowledge creation and sharing, whose effectiveness was perceived as low due to information loss (interviews with Beta's CIO and innovation manager). As such, Beta's BMI journey began by focusing on how to digitalize this highly analogical process, therefore improving its effectiveness. It is safe to say that this represented modular and incremental BM renewal.

The evolution of Beta's BMI journey followed the digitalization of its entire BM, with the precise goal of becoming a digital company (interview with Beta's CIO). For Beta, this meant implementing an agile culture to reduce lead times from innovation processes, and therefore the company moved forward to renew its value creation mechanisms through digitalizing the R&D process. Finally, Beta decided to explore the addition of new BMs, especially a service BM, to reinforce its value proposition through a BM exploration strategy. The company mainly adopted an acquisitions strategy to purchase fast-growing startups with BMs that were seen as complementary to the company's vision in order to create a well-being platform around its core BM.

4.1.3. Gama

As described by its CEO, Gama's initial BM was that of a "passive outsourcing of Information technology R&D" (interview with Gama's CEO). In this regard, Gama's value propositions were information technology competency and knowledge, with its value creation process being the application of knowledge to solve customers' problems. Under the initial model, the value delivery was achieved through the company's commercial department. Large IT companies found Gama due to its market reputation and asked for potential solutions to well-defined projects, which the companies were unwilling to conduct internally. Although offering R&D outsourcing solutions, Gama did not have its own R&D department and hired people ad hoc to solve demands as they arose (interviews with Gama's operations manager and CEO).

Gama's BMI journey began in 2017, when macroeconomic problems in Brazil led major IT companies to cut their R&D budgets, which had drastic consequences for Gama (interview with Gama's innovation director, internal strategic documents). The company needed new revenue sources to complement its main BM, as it was too dependent upon the external economic conditions. Gama first changed its value proposition by proactively searching for market problems and creating potential solutions in the form of minimum viable products (MVPs) or proofs of concepts (PoCs), which were implemented to improve the company's reputation in the market and gain a competitive advantage.

Following this, Gama created an R&D department responsible for anticipating the problems faced by large IT companies and building MVPs and PoCs encapsulating the resources needed to solve such problems. In doing so, the company transformed its BM from a passive R&D outsourcing BM to an active R&D outsourcing BM. The accumulation of such MVPs and PoCs, considered assets by the company, led it to explore novel BMs, launching its first startup in 2020 and three more in 2021. Gama's startups are still in the market creation stage.

4.2. From Business Model Renewal to Business Model Exploration

The BMI efforts of our studied cases arose due to the perceived threats stemming from digitalization, which created a feeling of needing to act among the companies' management. Alpha's journey began by repositioning its services toward high-end customer segments, with the focus of the improvements being on the value proposition (Alpha's annual report, 2015 and 2016). Then, it coupled this action with the genomic project, which combined the company's medical capabilities with novel bioinformatic and digital capabilities, targeting the creation of new business strands through novel service offerings complementary to the existing BM (annual reports, 2018 and 2019; CEO interview). Beta focused on its sales representatives network, which was highly personal and analogical, targeting its value delivery architecture to improve performance while creating means to extract value from customer data (CTO interview, Beta's annual report). Gama's target was the creation of new assets, such as prototypes, that could support its reputation and image in the market, thus reshaping its value proposition and value delivery by better segmenting its customers and sharpening its offerings (interviews with the CEO and innovation director).

The first step to achieving the outlined goals was to deploy a structured approach, changing the organization's design by: (1) either creating an innovation department at the top management level (Beta and Gama) or reframing a top-management-level department's role to focus on innovation (Alpha) and (2) assigning a champion to the innovation departments at an executive position. Alpha's choice was to reframe its new business department to embed digitalization at the core of the business (Alpha's annual report) through the deployment of IT personnel in the leadership:

> "We are an organization that we had a medical and technical board, and I was also part of it, where there is an R&D with all the doctors conducting innovation in tests and innovation in services. The doctor with the R&D team sets up this test. Now we have a new arm in business innovation. [. . .] And there is the whole IT part that has the traditional, infrastructure and systems and there is the all-digital part that looks after squads, whether in the traditional or in the new businesses." (Alpha's CEO)

Relevant to the evolution dynamics of the BMI efforts by the studied cases was the provision of limited resources coupled with a high degree of control and a need for results. Alpha had the most significant resources for its innovation department, as it reassigned part of the new business department, providing a dedicated innovation personnel and budget. However, the company understood the need to keep the department lean by building the innovation team transversal to the company, with employees from different departments participating in the innovation squads (CEO interview). Beta assigned to its newly created vice presidency of the business platform (Beta's annual report) a team of five members (interview with Beta's CIO). These groups were also deployed transversal to the organization through a matrixial structure, in which the projects were managed through squads (interviews with Beta's CIO and innovation manager).

> "In 2012, when digitalization actions began, the goal was the digitalization of the business, and not of internal specific departments. Hence, the challenge was to digitalize our representatives' network in the society." (Beta's innovation manager)

Similarly, Gama's approach was to entrust its innovation direction to its innovation director, with other team members being volunteers taking part in the innovation projects (interviews with CEO, innovation director, and R&D manager).

> "We had limited resources, and the department was comprised only by me. So, I had to create engagement and gather volunteers, which worked outside their hours." (Gama's innovation director)

Due to the combination of limited resources, a high degree of control, and the need to change, the innovation department focused on renewing the current BM, targeting solutions that consumed fewer resources and delivered more significant results. The innovation departments' actions grew from small modular changes in specific parts of the BM, i.e., digitalization, to architectural changes across the whole BM. In doing so, the companies experienced an increase in the performance of their current BMs. Alpha's revenue grew from around USD 500 million in 2015 to USD 1 billion in 2021 (Alpha's financial reports). Beta grew 175% from 2016 to 2021, along with an increase in net profits, in comparison to its growth of 43% in the period from 2011 to 2015, during which Beta shrunk its margins and net profits (Beta's financial reports). Gama's income grew 250% in the period between 2017 and 2021, and it swelled from around 250 employees in 2017 to more than 600 in 2021, again in high contrast to the period between 2014 to 2017, when the company reduced its size from around 300 to less than 200 employees and struggled to maintain its revenue size (Gama's internal documents). Table 3 provides more details on the companies' performance.

Table 3. Performance of Alpha, Beta, and Gama by year.

	Alpha		Beta		Gama	
Year	**Revenue Growth (% Compared to Previous Year)**	**Head Count**	**Revenue Growth (% Compared to Previous Year)**	**Head Count**	**Revenue Growth (% Compared to Previous Year)**	**Head Count**
2015	11.60%	8600	8.60%	6591	7.20%	291
2016	9.70%	8400	1.73%	6397	−5.91%	229
2017	12.40%	8700	25.09%	6311	−29.11%	181
2018	11.30%	9400	34.99%	6635	32.80%	188
2019	9.10%	10,000	6.17%	6820	36.53%	227
2020	2.10%	11,200	39.97%	6920	40.86%	399
2021	30.10%	13,000	7.64%	17,672	116.59%	600

Interestingly, whereas Alpha and Gama's growth was steady during the considered periods, Beta displayed an "accordion effect", whereby it recorded high growth in one year, followed by a stagnant period the next year. This phenomenon, which can be interpreted as a consequence of the company's acquisitions strategy, will be explored further below. Although limited, these performance indicators help partially translate the BM renewal in terms of the company's growth rate and employee count.

Despite the main result being a reduction in the need to change the current BMs, this growing evolutionary approach led to a set of relevant additional outcomes that we will explore in the next subsections: (1) increased openness to innovation among both the top management and the wider employee bases of the companies; (2) enhanced resource mobilization (human, budgetary, relational) and availability for innovation departments; and (3) an increase in BMI capabilities, with the teams focusing their learning efforts in this direction, enjoying greater freedom and growing resources.

This subsection examined how the conditions surrounding the emergence of BMI efforts in the incumbents played a vital role in the evolutionary dynamics of their BMI capabilities. This was because such conditions led the companies to deploy creative methods for gathering resources, coupled with an incremental and more chirurgical focus on Pareto solutions that consumed the least resources but led to higher returns. The achievement of performance gains through the renewal of the current BMs reduced the need to change the current BMs while creating a latent stock of BMI capabilities. We observed a growing set of resources for innovation departments and cultural changes related to increased openness to innovation. This created a tension (i.e., between growing BMI capabilities, openness to innovation, and available resources and a diminishing need to change the current BM) that led to a shift in focus from BM renewal to the exploration of new BMs. Figure 1 summarizes the system dynamics surmised from the multiple case studies, which we will explore further in the next subsections.

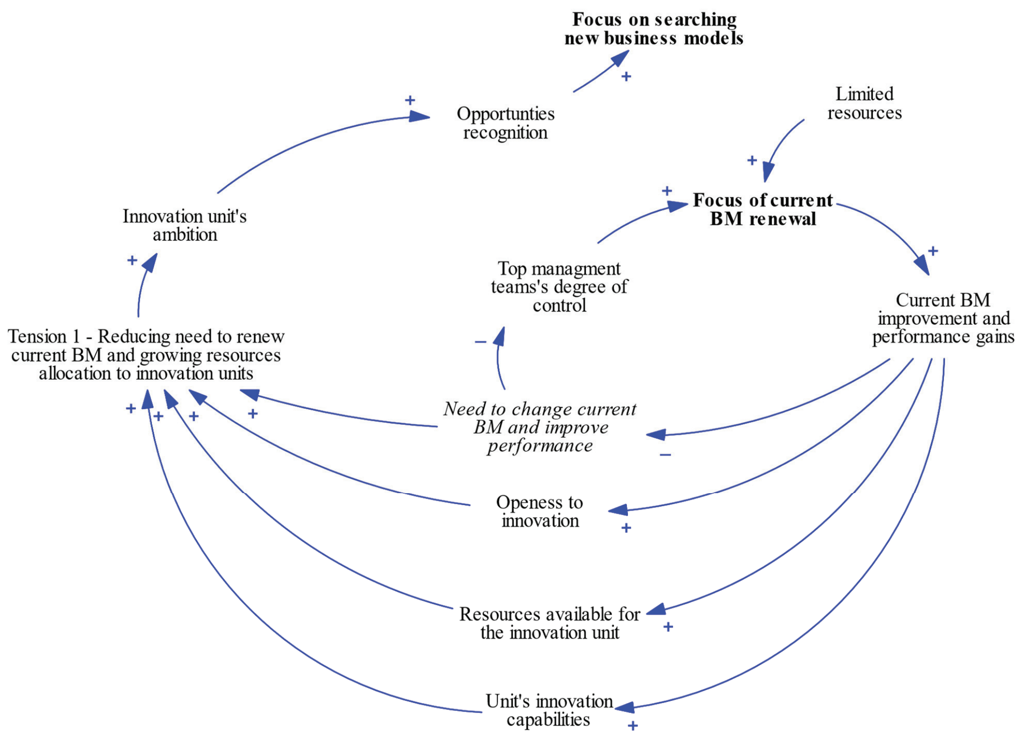

Figure 1. The system dynamics behind the evolution from BM renewal to BM exploration.

4.2.1. Openness to Innovation

We found that openness to innovation had its roots in three different mechanisms. The first was the integration mechanism of creating transversal agile teams, in which members from different departments took part. To unfreeze and change the organizational culture towards innovation, the companies chose the strategy of introducing BMI techniques and creating an innovation-friendly atmosphere to motivate and capacitate their personnel. Alpha and Beta introduced Spotify squads (Alpha's innovation manager; Beta's CIO) led by IT experts, with the particular aim of helping disseminate agile techniques. This action was conducive to engaging interested employees to take part in Hackathons, design thinking [99], and lean startup [100] events (Alpha CEO interview, Beta innovation manager interview, Gama CEO interview). One essential element cited in the interviews was the acceptance of failure, which was accompanied by events and a secure space to think outside the box.

> "But new capabilities as professionals who think about User Experience, digital, platform solutions, we didn't have. We bought [a] primary care startup. We set up a digital team, a team with young people with these other capabilities.

> We were making a mix, because in our view these people with new capabilities cannot be left alone in the organization" (Alpha's innovation director)

The second mechanism was the top management team's degree of control, the consequent autonomy of the innovation department, and the influential actions of the innovation department's leadership. The need to generate results with limited resources naturally pushed the leadership to act as a seller of ideas in pursuit of buy-in from the top management. The incremental growth from small wins to larger changes in the current BM increased the top management team's confidence in the department's ability to deliver results and make autonomous decisions for larger jumps. As Beta's CIO put it:

> "The CEO and the chairman were the biggest sponsors' of the projects. As we had successful small wins, we earned top management's interest and that allowed us to reach the current stage. [. . .]. So, we spent 2 years piloting a digital Business Model in which the digital was placed at the center. The first was in Campinas and ended up being rejected due to the view that the Value Proposition for consultants was still insufficient. The second pilot was in São José dos Campos, with adjustments to this value proposition, and already a slightly more open vision. This led to changes even in the organization's way of approving projects. In the past, to make a small change to the company's logo had to be approved by the Vice Presidents. In 2014, when the Business model was created, Natura started to provide a platform for the consultant, with all the necessary functionalities" (Beta's CIO)

The third mechanism stemmed from the managerial point of view. The structural change induced by the top management teams through creating specialized innovation departments transmitted an important message across the organization regarding the company deemed relevant. This induced a shift in cognition, with personnel believing that to fit into the organization it was essential to embrace innovation, triggering an evolution in the culture to one more open to innovation:

> "We transmitted a message for the employees that innovation was of utmost importance. We designed our open innovation funnel and how innovation would contribute for our core business, hired an experienced, yet forward thinking, innovation director." (Gama's CEO)

4.2.2. Resource Availability

We noticed a solid and constant growth in the number of employees involved in the innovation departments. Gama started with only the innovation director in 2017. In 2020, the company had more than 30 employees dedicated to the department, which increased to around 50 employees in 2022, accompanied by the creation of a formal R&D department (Gama's internal documents). Beta's vice presidency of business platforms started with five employees, i.e., the CIO, one product owner, one tech lead, one scrum master, and one user experience professional (Beta CIO interview). Subsequently, it grew and separated into two core subdivisions, the innovation lab and the business innovation department, and added a CTO to share the leadership with the CIO (interview with Beta's innovation manager). This represented an increase in resources and freedom to balance incremental and radical innovation. When asked about the size of the fixed team, the CIO answered as follows:

> "(Today) 50, my team practically does the leadership, who does it in practice is consulting (partnerships). In our squads, the Product Owners, Tech leads, scrum master and User Experience are all [Beta] employees. The remainder of the development and quality force is outsourced. There are more than 50 [outsourced] consulting partners." (Beta's CIO)

4.2.3. Innovation Capabilities

The accumulation of innovation capabilities stemmed from the combination of learning activities conducted by the innovation departments and the strategic and structural approach followed by the studied cases. The guiding thread that allowed the associated activities to create BMI capabilities was the attention devoted to searching for opportunities, designing changes to gather necessary resources, and the cultural and transformational actions necessary for change. The efforts to create an innovative culture and improve the quality of solutions led to a learning curve regarding BMI in the studied cases. Alpha's attempts to combine digital competencies and innovation capabilities with their core competence in medicine through the squads led to knowledge sharing regarding BMI and the spread of knowledge about its tools, practices, and processes (Alpha CEO interview). In measurable terms, Alpha increased from 66 implemented product and process innovations in 2015 to 430 in 2021 (Alpha's annual reports, 2015 and 2021). Gama's approach was to encourage its employees to use their working hours to study innovation and engage in events, including their own BMI-oriented event, which combined theoretical and practical knowledge as the basis for their BMI capability evolution.

> "In the first rounds of our open innovation event, we had many potential opportunities brought by our employees, but we noticed that they still lacked quality, and we could only create basic ideas that, despite serving our core BM well, had no potential to become new business models. After a few iterations we noticed an important improvement, and were able to create our first ideas that had true potential to become new BMs" (Gama's innovation director)

4.3. Sustaining Business Model Exploration through the Creation of a "Buffer"

Exploring new BMs is an uncertain and time-consuming activity, from initiation until the new BMs provide relevant returns to the incumbents. The exploration of new BMs is also a resource-intensive activity. This is further exacerbated for incumbents, which need to sustain growth to satisfy their shareholders' and stakeholders' interests. In systemic terms, this means that the resources committed lead to a momentaneous increase in exploratory behavior and experimentation to create novel BMs. Given the time and learning curves, such activity might lead to the generation of new business models. However, on the other hand, the time delay associated with this activity in terms of years tends to suppress the activities by unbalancing the resource allocation towards incremental BM renewal, suppressing radical BM exploration.

In our cases, Beta had the most significant barriers to the pursuit of exploratory BMI. Alpha and Gama followed a more organic and evolutionary path. One probable reason was that Beta, after achieving BM renewal and securing greater resources, attempted to separate its new business creation engine from the core business (interviews with Beta's CIO and innovation manager). Moreover, Beta's BM renewal was mostly incremental, with most innovation manifesting as a transformation from analogical to digital, but without changing the BM logic (Beta's reports, 2015–2021). On the other hand, Alpha and Gama pursued transformative BM renewal; Alpha rethought its business from a value proposition of diagnostic services towards fully predictive medicine (Alpha's reports, 2018–2021, and Alpha CEO interview), and Gama moved from responsively operating outsourced R&D activity to anticipating its customers' needs, offering projects with cutting-edge technology, coupled with the creation of innovative BMs based on digital technologies (interviews with Gama's innovation director, CEO, and R&D manager).

Such a situation emphasizes the need to create integration mechanisms between the exploratory BMI endeavors and the current BMs. Alpha and Gama took advantage of the evolutionary dynamics of their BMI engines to establish touchpoints between both. Hence, to avoid the suppression of exploratory behavior, it makes sense to create a "buffer" that sustains the long-term perspective. One possible path, followed by Alpha and Gama, was to assign to their BMI engine a significant role in the existing BM and to explore the creation of complementary parallel BMs. Figure 2 depicts the systemic model of the buffer as a bridge mechanism between the renewal of the current BM and the creation of a new business model in incumbents, allowing incumbents to develop the ability to respond to radical innovation. The next subsections explore the cases' "buffers".

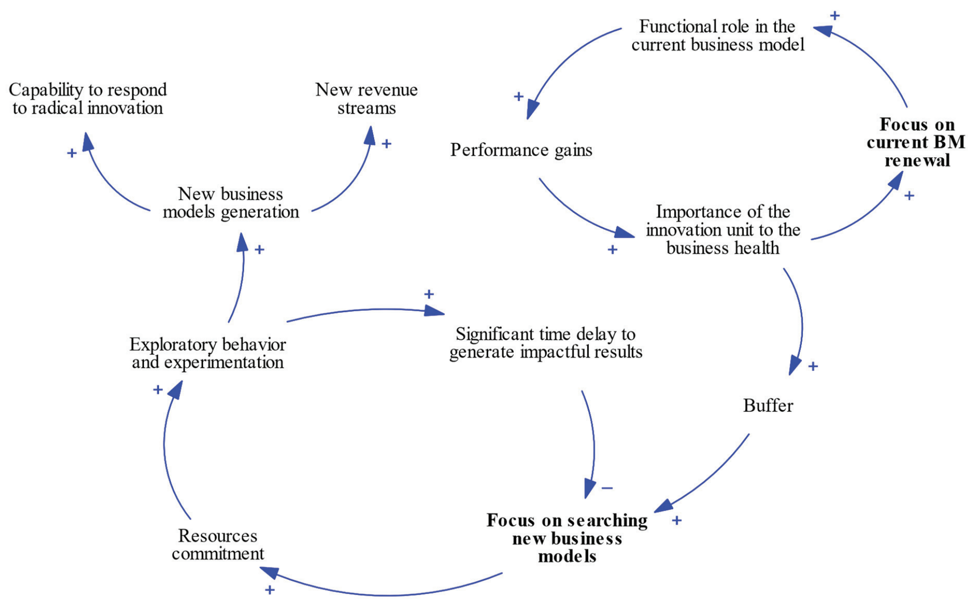

Figure 2. The "buffer" as a mechanism for sustaining exploratory BMI and bridging the dual goals of focusing on the core BM while exploring new BMs.

4.3.1. Alpha's Healthcare Platform Business Model as the Driver for Exploring New Business Models

Alpha had two core integration mechanisms. The first was the genomic project, in which the innovation department provided an inflow of high-value-added services for predictive and precision medicine to its customers, underpinning the company's differentiation strategy within the healthcare platform BM (annual report, 2021; CEO interview). This project formed the basis of mixing medical knowledge with data science and bioinformatics, comprising the core value proposition of the company's healthcare platform BM. The company defined this core as precision and predictive medicine based on patients' genomic, proteomic, and habit-related information, aimed at predicting future diseases and anticipating treatments.

> "In fact, the potential of using genomic information, behavioral and biological data from exams, has enormous potential. You can make a more predictive medicine. So how can we reduce patient health risk, do better follow-up to make an individualized and personalized health journey. Predictive medicine, such as using genomic, behavioral, and environmental data. So, the potential is very large and goes into analytics" (Alpha CEO interview)

Alpha promoted, through both mergers and acquisitions and internal startup development programs, the creation of new businesses that could orbit this central value proposition (Alpha's annual reports, 2019, 2020, 2021; CEO interview). Consequently, Alpha sought to fill multiple gaps in the predictive healthcare supply chain, delivering prediction services, treatment solutions, surgeries, habit and nutrition counseling, and services for digitalizing hospitals and nurseries. Therefore, although new businesses may take time to yield returns, Alpha's mixture of acquisitions and the creation of new BMs created a "constellation" of mutually reinforcing BMs. For example, its newly created BM, a B2C market platform, uses patients' data to promote their health and well-being. The platform has connections to the genomic project, as it provides predictive and preventive care for users, but it is also part of the marketplace for diagnosis, treatments, and so on, alongside Alpha's service and competitors. Additionally, Alpha took advantage of its access to data and large customer base to accelerate the growth of this new BM. The result is that this BM represents 5.2% of Alpha's revenue due to such linkages (Alpha's annual reports, 2020 and 2021).

4.3.2. Beta's Incremental Business Model Exploration to Improve Its Core Business Model

Beta rooted its BM exploration strategy in deploying startup challenges to (1) accelerate the resolution of current process bottlenecks and (2) solve large sustainability problems and, by exploring startups that offered services aligned with its core BM value proposition, strengthen its market position (interview with Beta's innovation manager). The idea was to create a BM constellation, to which the innovation department added, through acquisitions, fast-growing startups offering services that could potentialize their core business' product sales (CIO interview). Beta's innovation department, however, faced challenges when attempting to create its own new BMs:

> "What we have is an innovation machine that is not yet fully tuned. An incremental H1 type innovation is super easy. Now a more disruptive innovation is much more complex. We identify a cool startup that can speed up a process, the squads go there and promise that it will impact a certain indicator within a period of 4 months. The new business team does this pre-sale a lot, to raise funds. Everything that talks about innovation that is not connected with the core of the current business model is more complex" (Beta's CIO)

One explanation for Beta's struggle to sustain its BM exploration strategy lay in the fact that the company skipped radical (or transformative) BM renewal, moving directly to BM exploration. Despite the accumulation of favorable conditions, this did not create an effective buffer through renewing the company's value proposition, which remained the same after Beta's BM renewal. In this regard, Beta's deployment of acquisitions to accelerate the transformation and create new startups was conducted in order to gain buy-in from the top management and the company (Beta's CIO), leading to the observed accordion effect.

4.3.3. Gama's Competency "Encapsulation" and the Search for Pioneering Digital Technology Business Models

Gama's innovation department was at the root of their active R&D outsourcing BMs, whereby the R&D activity was focused on anticipating widespread customer trends and needs and creating highly customized and high-value-added offerings (interviews with Gama's CEO, innovation director, and R&D manager and Gama's strategic map). Similar to Alpha's approach, Gama's innovation department underlays the value creation at the core of its renewed BM's value proposition. To create the value of actively anticipating the widespread needs of IT customers, the company deployed its R&D team to explore well-defined technological platforms. This allowed them to play with novel solutions and create MVPs and PoCs (considered by the company as assets) that represented the cutting edge and tacit technological competencies in tangible terms (R&D manager interview).

> "We are a competencies seller. To have a competitive advantage in this market, we need to prove our skill to the clients, which is challenging because competencies are not tangible. What we do is anticipate our customers' needs by deeply studying what they will do in the future, build our experiments, transform into MVPs and PoCs and then enchant our customer. This is what differentiates us from our competitors in the market" (Gama's CEO)

As stressed by different members of the company (CEO, innovation director, R&D manager, new business manager) one of the greatest challenges for Gama when persuading customers to engage in R&D projects is to prove its competency. This is a task that the company is addressing through its innovation department in order to differentiate itself from other players in the market. The effective execution of plans and the achievement of meaningful results, such as growing from less than 200 employees in 2017 to more than 600 in 2021, were attributed by the company's management and employees to the innovation department (interviews with Gama's innovation director, CEO, R&D manager, and operations manager).

As a side-effect, Gama began accumulating such assets on its "shelf", which led the company to attempt to explore the natural creation of new BMs. Consequently, it was possible to observe a crescent-shaped growth in Gama's attempts to create new BMs. In 2019, Gama accumulated a set of 18 assets in the form of MVPs and PoCs, with no attempt to create a new BM. In 2020, Gama launched its first four startups in the market, and in 2021, two more were launched (Gama's internal documents).

In addition to the competency "encapsulation" integration mechanism, Gama has also followed the approach of linking the exploration of new BMs to a core strategic vision. Through this connection, the new BMs should follow the company's long-term goals regarding technological bases and market areas (Gama's internal documents). As such, the company can explore links between the core BM and newly created BMs by accelerating technological development and exploring its connections to facilitate market penetration (interviews with Gama's innovation director and new business manager). The impetus behind the technological alignment is not only the possibility for Gama to accelerate its nascent BMs' technological development and market penetration, but also the opportunity to create future clients who would also leverage Gama's R&D outsourcing BM.

> "My dream for the future of our innovation department is, that we will be creating our future clients." (Gama's innovation director)

5. Discussion and Conclusions

5.1. Theorethical Contributions

The innovator's dilemma [38] has provided a basis for understanding that well-managed and innovative incumbents tend to crumble in the face of radical innovation. This theory highlights the fact that incumbent BMs are structured not to promote innovation and the creation of novel BMs, but to be further improved [36,37]. However, incompatible with the current realities of businesses, digitalization, the increasing pace of technological development, and the growing pressures to achieve sustainable development goals have emphasized the need to solve this dilemma. The literature has reached a consensus that the ability to conduct core BM renewal and new BM exploration is vital [3,6,11,18,26]. Furthermore, creating parallel BMs is a potential path to building resilience and anticipating future disruptions [7,8]. The development of such resilience is, however, a significant challenge considering path-dependency issues [52–55], the cognitive and cultural barriers stemming from dominant logic and goal incompatibility [12,48,65], the possible adverse effects of adding new BMs to a portfolio [7,9], the time delays and challenges presented by new BMs before they can generate relevant results for the company, and the high resource mobilization required [11]. Thus, despite the wide recognition of the relevance of conducting both exploitative and exploratory BMI, the attempts to achieve the latter still suffer from high failure rates and poor results [7,11,17]. Our findings mirror exactly such phenomena, with the movement from BM renewal to BM exploration occurring in a semi-automatic fashion. The major problems arise when sustaining BM exploration efforts. We found that these are dependent upon a series of factors.

Bearing this in mind, by analyzing through a system dynamics lens the evolution over time of incumbents that developed systematic BMI processes though an integrated approach, we provided a series of contributions to understanding how incumbents can sustain their BM exploration efforts. More precisely, we depicted the existence of an evolutionary approach comprising a movement from BM renewal to the creation of favorable conditions for exploratory BMI. In line with the barriers identified by the literature (e.g., [8]), our findings also provide evidence that the discrepancy between the need to grow and the results obtained by BM exploration creates resistance from the top management and a tendency to move backwards to incrementalism. This vicious cycle has its roots in the fact that searching for new BMs is an activity that demands high resource allocation. Nevertheless, it presents long delays before providing noteworthy results, i.e., it is challenging and time-consuming to create a BM that generates results comparable to those achieved by incremental and short-term efforts. Thus, there is a paradoxical tension: exploring new BMs needs strategic alignment and a balance between incremental and radical innovations, which tends to favor incremental solutions over radical and exploratory ones. Our study, therefore, provides an initial contribution by showing that such a paradox is also a problem for integrated approaches. Beta's case precisely illustrates this paradox.

In contrast, our findings also provide evidence to support the idea that the integrated approach may have advantages in overcoming these barriers, especially through the creation of a buffer. Alpha and Gama's approach was to strategically assign to the BMI engines a vital role in contributing to the renewed BMs' value proposition and creation architecture. The companies thus relied on their BMI engines to create value and returns that satisfied the top management's requirements while creating integration mechanisms such as the transversal participation of the organizations' members in innovative activities. This pertains to the continuous pursuit of innovations within the core BM. An additional mechanism identified was the exploration of new BMs that are somehow complementary to the core BM, in line with the ambidexterity theory [21,22,24,25]. In this regard, our results provide evidence that both agrees with and contradicts the literature. In Beta's case, the strategic alignment between the core and the exploratory endeavors favored path-dependent behavior, while we found contradictory results for Alpha and Gama, whose buffers worked to foster radical innovation.

One explanation for this contradiction is that the problem did not seem to lie in the attempt to align the strategy of the innovation departments and the core BM, which, as the literature has highlighted, tends to unbalance attempts in favor of incremental innovation [11,12,48]. We suggest that when BM renewal is carried out with a long-term perspective in anticipation of disruptive BMs in a particular industry, this problem becomes a potential solution. Alpha's BM renewal began with the understanding that their present BM, focused on reactive medicine, would become obsolete when predictive and precision medicine became the new paradigm. Such a strategic vision led the company to carry out its BM renewal within this new paradigm, changing its BMs to those of a healthcare platform. Considering the possibility of pioneering this new paradigm and the existence of many "white spaces" [66,101], the exploration of new BMs turned out to be aligned with the company's strategic orientation and complementary to its vision. Likewise, Gama envisioned the future of R&D-outsourcing BMs as more collaborative, working with customers to anticipate the future, i.e., generating the demand from customers, rather than the customers outsourcing whatever R&D projects they are unwilling to conduct internally. With this approach, the company also changed its core BM into a pool from which many new BMs could be derived, creating mutual complementarities.

On the other hand, Beta stuck to its current BM's core logic, focusing on the digitalization of its analogical processes and targeting performance gains. In this case, the alignment did not lead directly to creating opportunity spaces for developing new BMs. Likewise, many of the abovementioned barriers stemmed from a scenario whereby the innovation departments were seen as a panacea, with the exploratory BMI able to diversify the company's revenue streams and save the company. One explanation for this is that in cases where no future envisioning takes place during the BM renewal, the dominant logic, with strong roots in the present state of the BMs, tends to win out over the exploratory behavior.

This theory also helps explain why the issue of managing parallel BMs does not arise in some cases of radical BMI by incumbents. For example, the exploration is seen to be segregated from the incumbent's core BM [11]; attempts are made to fit it into the present state of the core BM, as in the case of the Xerox spin-off [12]; or the exploration is carried out in random directions, which negatively affects the incumbent by increasing its managerial complexity [7]. It is reasonable to assume that diversifying the revenue stream through new BMs may be seen as unproductive in the short term by the top management, as the exploration takes time to produce results that represent significant returns. We argue that if this is the case, the tendency is for companies to attempt to gain buy-in by acquiring larger startups that can bring additional customers to the core BM, which can be understood as "incremental BM exploration".

Beta's example is particularly revealing. In the face of the top management team's reluctance to accept exploratory projects, the innovation department's managers began to map and purchase more mature startups to show the top management the power of adding novel BMs. The startups were aligned to the company's core BM, as they offered services that could encourage users to purchase Beta's products, thus improving the current BM and targeting lock-in effects. In sharp contrast, we observed that Alpha's spin-off encouraged patients to use not only Alpha's solution but also its competitors' solutions. Such a scenario highlights the fact that Alpha's buffer and BM constellation core were not aimed at further improving the initial BM but rather at contributing to the overarching future vision of predictive medicine benefiting patients' quality of life. Hence, with this case study, we provide the first evidence to complement the view presented in the literature that incumbents can sustain their exploratory BMI by following a transformative BM renewal strategy, attempting to anticipate possible disruptive paradigms for their respective BMs.

Finally, it is also noteworthy that of our three studied cases, the manufacturing company struggled the most to pursue transformative BM renewal. Although the focus of the study was not on conducting such a comparison, it should be mentioned. This difference may have been due to influences of higher sunk costs and a product-oriented mentality, which might have rendered the manufacturing company more rigid when it came to transformative BM renewal. Many cases presented in the literature, such as Kodak, Nokia, and Blockbuster, as well as those introduced by the innovator's dilemma, represent poor responses to radical innovation from manufacturing companies. Further investigation in this regard may be fruitful to broaden our understanding of the subject.

5.2. Managerial Implications

This study revealed relevant managerial implications. We sought to understand the process of BMI in incumbents, presenting a fine-grained consideration of different types of BM. Our results were in line with the literature's suggestion that incumbents should not abandon their focus on the core BM to explore new BMs randomly, and that a combination of both approaches can be fruitful for creating resilience when responding to radical innovation. In this regard, our system dynamics analysis of the evolution of BMI engines showed significant differences between the impacts of incremental and transformative BM renewal regarding the effectiveness of BM exploration, especially in relation to the creation of a strong "buffer". Thus, our study can assist the managerial audience in implementing BM renewal strategies that are future-oriented and transformative, targeting the anticipation of future disruptions. Although we recognize the challenges surrounding this process, innovation departments could assist in developing the necessary innovation capabilities to help overcome such issues. To this end, our studied cases followed the path of beginning with incremental changes, building capabilities, and advancing to a transformative BM renewal process. Then, leveraging conditions favorable to exploratory BMI, they moved forward to begin exploring new BMs in order to fill the gaps that existed inside the transformed value proposition.

5.3. Limitations

This study provided valuable insights into the system dynamics of BMI and the role of innovation departments in driving and managing this process. It is important to note that as qualitative research, this study's focus was not on validating or confirming a hypothesis. Instead, this paper offered important contributions to theory construction in the field of BMI. However, certain limitations of the present study should be pointed out. This research was based on multiple case studies, i.e., three Brazilian incumbents, which may not be representative of other companies or industries. We would have liked to address a wider range of technology and company types and, consequently, investigate different types of BMI. Comparing companies from different sectors could highlight the potential for cross-industry learning and the transferability of best practices. Nevertheless, comparing the BMI processes of similar companies, in terms of size and technology, could also lead us to new insights.

5.4. Future Research

Considering the abovementioned limitations and the results of this study, future studies could explore different areas. First, conducting a multiple-case study with a more representative organizational sample would be interesting. This would help to expand our knowledge regarding BMI and BM renewal processes. Second, a comparative analysis between similar companies, as mentioned previously, could also help to enhance our theoretical and practical understanding of this matter.

Furthermore, quantitative studies are essential to the development of this field, especially as they allow researchers to test hypotheses and evaluate the strength of relationships between identified variables. For instance, a future study could explore structural equation modeling (SEM) to examine the relationships between different variables that impact the success of business model innovation processes in incumbents. SEM would help identify the drivers of business model innovation and renewal and the mechanisms through which they operate in incumbents. Such a study could test hypotheses regarding the factors influencing the ability of companies to implement BMI effectively. Furthermore, studies could be conducted to provide empirical evidence regarding the relationship between transformative BM renewal and the performance of BM exploration endeavors in incumbents. Likewise, the effects and characteristics of top management teams could also be assessed to further elucidate the conditions that facilitate the pursuit of BM exploration.

Our findings highlighted an interesting connection between transformative BM renewal, from a future-based perspective of shaping the market and building avenues for planned opportunism, and BM exploration, which seeks to fill the consequent "white spaces" that emerge from such behavior. Thus, there is an opportunity to combine future studies on topics such as corporate foresight and BMI in incumbents. Such studies could provide better evidence regarding how companies can benefit from foresight activities and investigate whether certain forecasting practices negatively affect transformative BMI, shedding light on its barriers and opportunities. An analysis of top management teams could also be revealing in this regard. Finally, future studies could also investigate the long-term results of BMI processes, considering the impact on organizational sustainability. A combination of qualitative and quantitative approaches could help with this task.

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An Open System Understanding of Product Innovation: Attention Allocation, External Information Sources, and Absorptive Capacity

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Abstract: Product innovation is a key achievement by which a firm can not only build up its competitive advantages but also prolong its survival in the open market environment. By understanding the firm as a social system pursuing both efficiency and effectiveness, this study examines three key factors that independently enable product innovation through a theoretical lens of the open system approach: strategic attention, external information sources, and absorptive capacity. While we suggest that a focused set of strategic attentions functions as an internal means to enhance the likelihood of product innovation, we also propose that diverse external partners provide the firm with the relevant knowledge for product innovation. In addition, we argue that the absorptive capacity is a crucial factor that has a positive direct effect on product innovation and mediates the effects of the two variables on the product innovation, based on the organizational learning theory. We empirically examined our hypotheses with the reliable data collected systematically through the "Korean Innovation Survey 2020: Manufacturing Industry" and found support for all of our hypotheses. Finally, we discuss theoretical contributions and practical implications.

Keywords: open system approach; product innovation; attention allocation; strategic attentions; external information sources; absorptive capacity; organizational learning

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1. Introduction

In the contemporary business world, all firms are located in a highly competitive market environment and the firms are intensively required to build up their own unique means by which they can be distinguished from their competitors and prolong their survival in the market environment. Indeed, product innovation is considered as one of the most effective tools to properly respond to the rapidly changing customers' market needs and to look for the opportunities to take a solid market position on behalf of the firms. In a broader sense, a firm's successful innovation in its products is very likely to contribute to the economic and social environment where it belongs, as innovated or improved products that the firm introduces to the market will significantly expand the realm of the external environment [1]. However, more importantly, it is notable that product innovation, once successfully accomplished, is likely to improve the organizational structures and processes of a firm so that it can heighten the level of the fit between its internal characteristics and the external environment where it is located [2,3].

Nonetheless, many firms often experience difficulties in their efforts to achieve product innovation. The existing literature on strategic management and organization theory has pointed out that the failure in product innovation results mostly from the lack of a better understanding about the complex features of product innovation. Product innovation is not a simple project that a firm can accomplish only by paying attention to the technological side of products, but a complex one that requires a more holistic approach covering both the internal and external sides of the firm, such as the managerial, behavioral, organizational, or environmental aspects [4,5]. To overcome such problems derived from a technology-focused understanding about product innovation, this study aims to provide the policymakers of the firm with a more holistic perspective by which they can look into the managerial aspects involved in product innovation as well as the external environmental aspects. We particularly suggest that an open system approach can be a good solution to the problems that firms confront in their efforts of product innovation. In this study, we attempt to examine the relevance of the open system approach to the research area of product innovation by incorporating the ideas developed in organization theory, therefore suggesting a more holistic viewpoint that can effectively address the fundamental features of product innovation [6]. By adopting the open system approaches to the understanding of product innovation, this study aims to make contributions to the theoretical expansion of the literature on product innovation as well as the practical implications about product innovation.

To do so, we develop our theoretical framework about product innovation, based on organization theory, which has been greatly expanded upon as an academic discipline by inviting an open system approach, over the last seven decades or so [6–8]. As Katz and Kahn [6] suggest, the firm is best understood as an open social system in which various types of input, either internally or externally obtained, are transformed into the output under its managerial discretions along with the continuous transactions between the firm and the economic and social environment. Aligned with such solid research traditions, we further propose that a firm's efforts to enhance its product innovation is the major output and that based on certain features of its subsystems, our main variables that affect the effectiveness of product innovation are introduced: strategic attention, external information sources, and absorptive capacity.

In particular, we begin by proposing that at the center of a firm's managerial subsystems is how the firm allocates its strategic attentions to enable product innovation. Likewise, we also consider the characteristics of external information procurement as an important variable of the firm's supportive subsystems. We finally examine a firm's absorptive capacity as one of the core competencies that can effectively combine the inside resources with the resources located outside in the efforts to foster innovation in products, which is considered as an adaptive subsystem of a firm. In our proposed research hypotheses, we first argue that all of these three variables directly influence the effectiveness of product innovation. Next, we examine that the absorptive capacity, as a main component of a product innovation system, will mediate the effects of the strategic intention and external information sources on the effectiveness of product innovation.

In the following sections, we develop our hypotheses more specifically, based on the literature of organization theories relevant to our attempts to understand the structures and processes of product innovation. We then examine the hypotheses in the research context of Korean manufacturing industries from 2017 to 2019. This study contributes to the product innovation literature by suggesting a more holistic view in which the firm is regarded as an open social system and by promoting a better understanding of the firm's product innovation under such a view. Finally, we discuss some practical implications for the managerial practitioners and the firm decision-makers.

2. Theory and Hypotheses

2.1. Attention Allocation

As an open social system, the firm is composed of several different types of subsystems. Among the generic types of subsystems, suggested by Katz and Kahn [6], the managerial subsystem is one that takes the roles and functions of controlling, coordinating, and directing other subsystems in the firm. Usually, the top management is the very component of a firm's organizational structures and processes that develops and carries out the overall strategies about a broad range of organizational activities, given its authority and responsibilities.

According to the attention-based theory view [9,10], the firm is a system of structurally distributed attentions, and the attention of a firm is regarded as a crucial, but limited type of resource mostly due to the characteristics of the bounded rationality to which the firm is exposed [11,12]. Given a limited amount of attention resources, the top management of a firm has to deal with the attention allocating problems that may occur everywhere in the complex and complicated decision-making situations. That is, the main function of the top management is to figure out which issues are to be importantly dealt with in given situations and to select the issues that require the attention. Located in a highly competitive market environment, the firm has to find out which issue is mostly crucial for its prosperity, and even for its survival. However, the problem is that a variety of issues always compete with one another for the management's attentions within the boundaries of a firm [13]. In this regard, Ocasio [9,10] points out that the valuation and legitimization of issues are made by the cultural, social, and economic contexts of the organization and the issues with greater legitimacy, values, and relevance to the organization are likely to obtain more of the management's attention. In this governance procedure of allocation attentions, the top management of the firm, as the crucial decision-makers, should prioritize the issues according to the goals they pursue. That is, the selection of the issues in terms of attention allocation should be carried out by the top management along with their better understanding of the value and legitimacy of the issues.

Product innovation has long been recognized as an 'engine of organizational renewal' by which firms can survive and prosper in a competitive and dynamic market environment [14,15]. However, it is also regarded as a lengthy process that transforms a variety of resources into innovative products [16]. That is, production innovation is one of the most significant goals by which a firm can build long-lasting competencies in the market environment, so it necessarily requires the focal firm's attention to a great extent. However, the top management of the firm usually is situated to pursue diverse organizational goals simultaneously, and product innovation may be considered simply as one of the multiple goals that compete for sufficient attention from the management [10,17]. Therefore, we argue that the more organizational goals the top management attempts to achieve may seriously influence the effectiveness of product innovation.

In a rapidly changing and competitive environment, firms are challenged to accomplish multiple goals simultaneously. However, the literature about the multiple goals in organizations has well documented the problems of the concurrent pursuit of diverse goals (e.g., [18,19]). Aligned with this research line, we argue that the pursuit of diverse and multiple organizational goals not only leads the firm to generate various business strategies without careful managerial discretion, but also distracts the firm from properly choosing which specific strategy has to be given priority in terms of attention allocation [20]. When a firm has too many organizational goals and generates a broad range of business strategies to accomplish the diverse goals, it is unlikely to sustain its focus of attention correctly amongst the goals it attempts to achieve.

In this regard, we argue that pursuing a broader range of business strategies may result in the lack of sufficient managerial attention to product innovation which requires a selective set of managerial attentions comparatively over a lengthy time period in order to be successful. In other words, a firm in which the top management deals with diverse and multiple goals concurrently tends to experience more severely the conflicts in its attention allocation between the product innovation and other organizational goals. Given this, we conjecture that the product innovation may receive less attention when a firm faces such problems of allocating attentions to too many diverse organizational goals. Therefore, we propose that:

Hypothesis 1: *The concurrent pursuit of diverse and multiple business strategies is likely to prohibit a firm from enhancing the effectiveness of its efforts of product innovation.*

2.2. External Information Sources

Interestingly, the open system approach of organization theory emphasizes that a firm reside in a broader open environment in which it interacts with other organizations, in many ways [21]. To overcome the older formulation of system constructs that dealt with the closed system, the system theory suggests that a firm, which used to be considered as a self-contained structure, is more comprehensively understood by conceiving it as the one which is interdependent of external forces [6]. As an open social system, the firm often imports some form of available energy from the external environment and transforms it into other types of output [22,23]. According to the generic typology of subsystems suggested by Katz and Kahn [6], the procurement of the input through the transaction with the environment is a part of the supportive subsystem, and the information residing in the external domain is obtained by this supportive subsystem of the firm [24–26]. Based on this basic logic of the open system approach, we propose that to generate an output called production innovation, a firm needs to reach out to the external environment and obtain some important inputs. More specifically, the inputs are likely to be information and knowledge that may foster the product innovation within the firm's boundaries.

To generate a significant output in innovation-related activities, a firm cannot simply rely on the internal exploitation of its own information and knowledge [24]. As argued earlier in the previous section, product innovation is a project that requires a great number of resources under careful managerial attention [27]. Therefore, it is necessary that a firm reaches out for the information and knowledge that may reside beyond its boundaries to accomplish its goal of product innovation. In this regard, the literature of social networks in the research field of organization theory has consistently emphasized that building relationships with other external organizations may function as a key to innovation-related activities [28–30]. In particular, the exchange relationships with external partners will provide a relevant set of information and knowledge that are relevant specifically to product innovation.

Among the many characteristics of the networks that a firm may build beyond its boundaries, the connections to various types of other organizations will function as a conduit through which new knowledge and other relevant information flow into the focal firm. It means that a various set of external partners are likely to help the firm enhance the effectiveness of production innovation as external information sources. The recent literature of knowledge management also highlights the importance of the diverse external information sources in organizations' innovation performances [31–33]. Similarly, the literature points out that by having diverse external partners, not only does this expand the width of knowledge but it also encourages firms to recognize the importance of production innovation. More specifically, the social network literature points out that the external relationships with various types of organizations will provide more diverse information and knowledge than the relationships with the partners in a narrower scope (e.g., [34,35]). It means that other things being equal, establishing relationships with more diverse types of partners will facilitate a firm's capabilities in the activities of product innovation because novel and non-redundant knowledge can be obtained through diverse channels. Taken together, we propose our hypothesis regarding the effects of external information sources as follows:

Hypothesis 2: *A diverse set of external information sources is likely to help a firm enhance the effectiveness of its efforts of product innovation.*

2.3. Absorptive Capacity

As an open social system, the firm is constantly responding to the changing environment for its survival. Rather than simply maintaining the subsystems that concentrate relatively on the inward efficiency, a firm must develop an adaptive subsystem by which it senses the changes in the outward environments and translates the meaning of the changes for its purposes [6]. From a viewpoint of innovation-related activities, firms are required to constantly pay attention to the development of capabilities of incorporating the external demands and fostering a relevant set of innovation-related information and knowledge. That is, at the center of the adaptive subsystems are new skills and competencies that enable the firm to acquire, assimilate, and exploit new knowledge [36]. The organizational learning literature therefore suggests an internal mechanism to absorb various types of knowledge for the innovation purposes and names its absorptive capacity [37].

Absorptive capacity refers to "the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends [37]." However, from a perspective of organizational learning, absorptive capacity is an innovation-focused capability that tends to be built in a long process of accumulating learning experiences. Such a capability greatly requires the top management's managerial attentions along with a rich set of pre-existing knowledge that has been obtained through the various types of organizational routines and activities. The learning experiences accumulated within the firm's boundaries are prerequisite for the absorptive capacity toward innovation outcomes, and such learning experiences tend to reside in every kind of R&D related investments. Prior knowledge obtained from in-house R&D efforts becomes the main feedstock for a firm's absorptive capacity [38]. That is, the absorptive capacity, starting from the inward learning efforts, expands a firm's scope towards outward learning beyond the firm's boundaries.

Product innovation can be effectively facilitated not only by the inward learning processes but also by the external learning efforts that respond to the market demands. It is fundamentally pushed forward by the firm's efforts to improve the internal innovation-related mechanisms. Furthermore, a successful product innovation is possible when the firm correctly understands the market needs and makes a proper access to the knowledge beyond the boundary. Considering this feature of product innovation, we argue that as a knowledge synthesizing mechanism, absorptive capacity is a crucial part of the function of effective product innovation. To support our arguments, the product innovation literature consistently reports the positive effects of the absorptive capacity on the performance of product innovation by considering it as the core component of successful product innovation (e.g., [39–41]). Therefore, we propose our hypothesis regarding the effect of the absorptive capacity on product innovation as follows:

Hypothesis 3: *Absorptive capacity of a firm is likely to enhance the effectiveness of its efforts of product innovation.*

By paying attention particularly to the roles of absorptive capacity that synthesize the inward learning experiences and the outward learning efforts, we now examine how absorptive capacity mediates the effects of attention allocation and external information sources on the performance of product innovation. We first begin by proposing that absorptive capacity mediates the relationship between the diversity of attention allocation and product innovation. As mentioned earlier, absorptive capacity is a core component of adaptive subsystems of a firm that has been established by incorporating a long managerial effort over a broad range of organizational activities [37,38]. In particular, the literature highlights that the top management's pursuit of diverse organizational goals tends to be embodied in its absorptive capacity when the goals are innovation focused [37,38,42]. As a main function of absorptive capacity is to interpret and comprehend the firm's organizational goals regarding innovation-related activities, it is where the diverse organizational goals are collected and cognitively processed into purposeful actions [42,43]. As Todorova and Durisin [43] suggest, a firm's strategic intentions towards innovation activities are reformulated by its absorptive capacity in terms of the strategic values it pursues. By focusing on the inward learning aspect of the absorptive capacity, therefore we argue that the absorptive capacity shows its mediating functions in linking the top management's attention allocations to the product innovation outcomes, so proposing our hypothesis as follows:

Hypothesis 4: *Absorptive capacity of a firm mediates the relationship between its attention allocation and the product innovation.*

As argued in the Section 2.2, exploring the diverse external partners provides the firm with new and valuable information and knowledge. However, for the firms, having diverse external information sources is different from interpreting and realizing the real values of the incoming information and knowledge. Unless a firm has built capabilities of assimilating and transforming the knowledge obtained from the external partners, it may be distracted from generating meaningful outcomes in its efforts to enhance the effectiveness of product innovation. Given such conditions, the absorptive capacity will likely function as a mechanism of processing the external information into the purposed innovation outcomes. As the literature on absorptive capacity shows, absorptive capacity takes a crucial mediating role in the process of integrating both internal and external knowledge sources into the creation of valuable outcomes (e.g., [44,45]). Therefore, we argue that the absorptive capacity of a firm will mediate the relationship between the external information sources and the product innovation, so proposing our hypothesis as follows:

Hypothesis 5: *Absorptive capacity of a firm mediates the relationship between the external information sources and product innovation.*

3. Methods

3.1. Data

To test our hypotheses, we use the "Korean Innovation Survey (KIS) 2020: Manufacturing Industry," which is systematically collected by the Science and Technology Policy Institute (STEPI), a Korean government-operated research institute, every two years. The questionnaire was developed originally according to the Organization for Economic Co-operation and Development's (OECD) *Oslo Manual*. The manual also serves as a set of guidelines for the development of the European Statistical Office's (EUROSTAT) "Community Innovation Survey (CIS), therefore the questionnaire design of the KIS is almost equivalent to that of the CIS except for some questions reflecting the Korea-specific context. Like the CIS in the European Union (EU), the KIS is used as a reliable data source by which the Korean government not only monitors firms' innovation-related actions and capabilities but also develops national policies regarding innovation in its country. Because the data is publicly open, many innovation-related empirical studies have used this data (e.g., [20,27,46–49]). Following the existing studies that have used this data, we also decided to use it in our analysis.

The population of the "Korean Innovation Survey 2020: Manufacturing Industry" is defined by the following two criteria: First, only the manufacturing companies that have more than 10 regular employees and that are registered in the "Korean Statistical Business Register (KSBR)" as of the end of 2019, are included in the population. Second, in order to identify whether the company is classified as a manufacturing industry, only those that fall under the categories 10 to 34 of the Korea Standard Industry Classification (KSIC) (2 digit), are included. Based on these criteria, the size of the population was identified as 50,785. The sample of the survey was drawn from this population through the stratified sampling scheme, and the final sample size was 4000. In our analysis, we used the same sample, so the number of our sample is also 4000.

3.2. Variables

3.2.1. Dependent Variable: Product Innovation

To measure the performance of product innovation, we used the answer to the KIS question, "During the three years 2017 to 2019, has your firm introduced any new or improved products to the market?" As described in the question item, the definition of product innovation in our measurement includes both the introduction of completely new products to the market and the achievement of significant improvement to existing products. That is, our measure of product innovation considers both the incremental and radical innovation of products. Among the 4000 firms in the sample, 951 firms were identified as having introduced new or improved products to the market (approximately 24%). Based on the answer, we constructed the production innovation variable as a binary variable.

3.2.2. Independent Variable: Attention Allocation

To measure the extent to which a firm focuses upon diverse business strategies, we used the KIS question, "During the three years 2017 to 2019, how important were the following strategies to the economic performance of your enterprise?" To answer this question, 10 different types of business strategies were provided: (1) focus on improving your existing goods or services, (2) focus on introducing new goods or services, (3) focus on low-price (price leadership), (4) focus on high-quality (quality leadership), (5) focus on a broad range of goods or services, (6) focus on one or a small number of key goods or services, (7) focus on satisfying established customer groups, (8) focus on reaching out to new customer groups, (9) focus on standardized goods or services, and (10) focus on customer-specific solutions. [50] To each business strategy, the respondents were asked to answer the question using a scale from "never (=0)" to "very important (=5)." Based on the answers, we constructed the variable as Blau's heterogeneity index, as follows [51]:

$$Diversity\ of\ business\ strateges = 1 - \sum_{i}^{10} p_i^2, \tag{1}$$

where i refers to each category of the business strategies, and p refers to the proportion of a weighted importance of a business strategy to those of all business strategies [50].

3.2.3. Independent Variable: External Information Sources

To measure the diversity of the external information sources a firm relies upon in its efforts for product innovation, we used the KIS 2020 question, "During the three years 2017 to 2019, how often did your firm cooperate with the following types of external partners as an external information source?" To answer this question, eight different types of partners were listed: (1) sister companies within your enterprise group, (2) other private companies, (3) other public companies, (4) universities or other higher education institutions, (5) private research institutes, (6) public research institutes, (7) governmental agencies, and (8) non-profit organizations. The respondents were asked to answer the question according to an interval scale from "never (=0)" to "very often (=5)." Using the answers to the question, we constructed the measure of the variable as Blau's heterogeneity index, as follows [51]:

$$Diversity\ of\ external\ information\ sources = 1 - \sum_{i}^{8} p_i^2, \tag{2}$$

where i refers to each category of the information sources, and p refers to the proportion of a weighted importance of an external information source to those of all information external sources.

3.2.4. Independent and Mediating Variable: Absorptive Capacities

To measure the absorptive capacity, we adopted an integrative approach suggested by the existing literature [52,53]. In particular, we constructed an indicator of the absorptive capacity as the principal components of the following variables: (1) the enterprise's internal R&D expenditure, (2) the number of employees specializing in R&D, (3) a dummy indicating whether the enterprise establishes and operates a fully staffed R&D department, (4) a dummy indicating whether the firm engages in in-house R&D activities, (5) a dummy indicating whether the firm collaborates with others for their R&D purposes, (6) a dummy indicating whether the firm contracts out their R&D activities, and (7) the number of funding methods for R&D purposes. This composite proxy measure is considered to include the key features for the conceptualization and measurement for the absorptive capacity because it is based mainly on the R&D features of the enterprise and R&D is accepted as a reliable proxy for the enterprise's capabilities that compose its absorptive capacity [37].

3.2.5. Control Variables

We controlled for other factors that may affect the performance of product innovation, in our analysis. First, we included the industry dummies by considering the fact that the extent to which a firm achieves product innovation may vary in different industrial contexts. According to the Korean Standard Industry Code (KSIC), we included 24 industry dummy variables, based on the 2 digit KSIC categories (KSIC 11 to 34). Second, we controlled for the firm's age. The firm's age is measured as the number of years from its foundation year to 2019 by following the existing studies [20,27,30,50]. Third, we included a dummy variable indicating whether the firm was classified as a small-and-medium-sized enterprise (SME), according to the Korean legal system. In the Korean legal system, the Small and Medium Enterprises Promotion Act is currently enforced, and the standards specifying the SMEs are based on the total assets and the average sales over the last three years. To be officially registered as a SME in Korea, the total assets must not exceed KRW 500 billion and the standards of the three-year average sales vary from KRW 80 billion to 150 billion, according to the industry category. In our sample, about 79 % of the firms were identified as SMEs. Finally, we also controlled for the firm's size by the number of employees as of 2019, by following the existing studies [20,27,28,30,50].

4. Results

In Table 1, we report the descriptive statistics of the variables included in the analysis. As mentioned earlier, out of 4000 firms in our sample, 951 firms (24%) introduced new or improved products to the market where they belong during the observation period from 2017 to 2019. Table 2 shows the pairwise correlations between the variables included in the analysis. While 24 industry code dummy variables are included in the analysis, the results of the pairwise correlation analysis are not reported in Table 2, due to space limitation.

Table 1. Descriptive Statistics.

Variables	Mean	S.D.	Min.	Max
Product innovation *(binary variable)*	0.24	0.43	0	1
Small and medium sized company *(dummy)*	0.79	0.41	0	1
Firm age *(in Year)*	22.75	13.12	5	95
Firm size *(number of employees)*	227.69	1270.93	10	66,468
Diversity of strategic attentions	0.75	0.21	0	0.90
Diversity of external information sources	0.15	0.29	0	0.88
Absorptive capacity	0.00	1.63	−1.73	27.31

Notes: N = 4000; industry dummies are not reported due to the space limitations.

As our dependent variable is constructed as a binary variable, the hypotheses proposing the independent direct effects of each independent variable are all tested using the logistic regression analysis. Table 3 shows the results of these logistic regression analyses in which all of the proposed effects on the product innovation are carefully examined. Due to the space limitations and minor research interests, all of the coefficients of each of the industry dummies, which we include in the analyses as the control variables, are not reported in Table 3. Model 1 includes all of the control variables as the baseline model.

Table 2. Pairwise correlations.

Variables	1	2	3	4	5	6
1. Product innovation						
2. Small and medium sized company *(dummy)*	−0.24 **					
3. Firm age *(in year)*	0.15 **	−0.37 **				
4. Firm size *(number of employees)*	0.11 **	−0.25 **	0.14 **			
5. Diversity of strategic attentions	−0.09 **	−0.13 **	0.11 **	0.07 **		
6. Diversity of external information sources	0.27 **	−0.31**	0.22 **	0.15 **	0.21 **	
7. Absorptive capacity	0.46 **	−0.41 **	0.28 **	0.40**	0.19 **	0.58 **

Notes: $N = 4000$; ** $p < 0.01$; industry dummies are not reported due to the space limitations.

Table 3. Results of the logistic regression.

Variables	Model 1	Model 2	Model 3	Model 4
(constant)	−0.93 **	0.54 **	−1.07 **	−1.09 **
	(0.20)	(0.25)	(0.20)	(0.21)
Small and medium sized company *(dummy)*	−0.94 **	−1.03 **	−0.77 **	−0.30 **
	(0.10)	(0.11)	(0.11)	(0.11)
Firm age *(in year)*	0.01 **	0.02 **	0.01 **	0.00 **
	(0.00)	(0.00)	(0.00)	(0.00)
Firm size *(number of employees)*	0.00 **	0.00 **	0.00 **	−0.00 **
	(0.00)	(0.00)	(0.00)	(0.00)
Diversity of strategic attentions		−1.83 **		
		(0.19)		
Diversity of external information sources			1.45 **	
			(0.14)	
Absorptive capacity				0.87 **
				(0.04)
Log Likelihood	−1985.85	−1940.59	−1931.58	−1658.65

Notes: $N = 4000$; ** $p < 0.01$; standard errors are in parentheses; industry dummies are not reported due to the space limitations.

In Model 2, we add the diversity of strategic attentions to the baseline model (Model 1). The findings show that the variable has a negative and significant effect on the product innovation. Because a larger magnitude of the diversity of strategic attentions implies the firm implements of a broader range of business strategies to the economic performances, the negative sign of the coefficient indicates that the firm may be hampered to generate its product innovation when it uses an unfocused set of business strategies. That is, Model 2 supports Hypothesis 1.

To test Hypothesis 2, Model 3 adds the variable of the diversity of external information sources to the baseline model (Model 1). The result shows that the coefficient of the variable turns out to be positive and significant. It indicates that the more diverse a firm interacts with external information sources, the more likely it will accomplish the product innovation. Thus, our hypothesis regarding the positive effect of the external information sources is supported.

Model 4 adds the variable of the absorptive capacity to the baseline model (Model 1). Model 4 tests Hypothesis 3, regarding the positive effect of the absorptive capacity on the product innovation. The coefficient of the absorptive capacity is positive and significant, and it confirms that a firm with a sufficient level of absorptive capacity is more likely to facilitate the product innovation. Therefore, Hypothesis 3 is also supported by the analysis.

Table 4 presents the results of the test of the mediating effects of the absorptive capacity on the relationship between the diversity of the strategic attentions and the product innovation. To analyze the mediating effect, we adopt the three-step analysis suggested by the existing literature [54–56]. The first step is to examine whether the diversity of the strategic attentions affects the product innovation, which is supported in Model 2, as reported both in Tables 3 and 4. The second step is to demonstrate that the diversity of the strategic attentions influences the absorptive capacity and the mediating variable. This step is supported in Model 5, in which the absorptive capacity is regressed on the diversity of strategic attentions along with the control variables. The diversity of strategic attentions has a positive and significant relationship with the absorptive capacity (beta = 0.78, $p < 0.01$). In the last step, which is reported in Model 6, the findings show that the absorptive capacity affects the product innovation at a significant level (beta = 1.00, $p < 0.01$), after controlling for the diversity of strategic attentions. Because the absorptive capacity and the diversity of strategic attentions are both significant in their effects on product innovation, a partial mediation effect is confirmed. Thus, Hypothesis 4 is supported in our mediation analysis.

Table 4. Mediation of the absorptive capacity between the strategic attentions and product innovation.

	Dependent Variable		
	Product Innovation (Logistic)	**Absorptive Capacity (OLS)**	**Product Innovation (Logistic)**
Variables	**Model 2**	**Model 5**	**Model 6**
(constant)	0.54 **	−0.66 **	1.52 **
	(0.25)	(0.14)	(0.28)
Small and medium sized company *(dummy)*	−1.03 **	−1.00 **	−0.37 **
	(0.11)	(0.06)	(0.12)
Firm age *(in year)*	0.02 **	0.02 **	0.01
	(0.00)	(0.00)	(0.00)
Firm size *(number of employees)*	0.00 **	0.00 **	−0.00
	(0.00)	(0.00)	(0.00)
Diversity of strategic attentions	−1.83 **	0.78 **	−3.27 **
	(0.19)	(0.11)	(0.23)
Absorptive capacity			1.00 **
			(0.04)
R-square		0.36	
Log Likelihood	−1940.59		−1554.86

Notes: $N = 4000$; ** $p < 0.01$; standard errors are in parentheses; industry dummies are not reported due to the space limitations.

As a robust check, we also conduct an additional mediation analysis based on a bias-corrected bootstrapping approach [57]. It is known that the bootstrapping approach effectively overcomes the limitations of Baron and Kenny's three step methods as well as the over-reliance on the normality assumption of the Sobel test [58]. In the bootstrapping test, the exclusion of zero in confidence interval (CI) is accepted to confirm the mediation effect [59]. Using 300 bootstrap samples and 95% CIs, we found a significant indirect effect of the diversity of the strategic attentions on the product innovation through the mediation of the absorptive capacity. The estimation of the indirect effect is 0.12 (CI = [0.09, 0.5], $p < 0.001$), which also supports Hypothesis 4.

Similar to Tables 4 and 5 reports the mediation test of the absorptive capacity on the relationship between the diversity of the external information sources and the product innovation based on Baron and Kenny's mediation test. As the first step, Model 3 shows that the diversity of the external information sources directly influences the product innovation. The second step is reported in Model 7, in which the absorptive capacity is regressed on the diversity of the external information sources along with the control variables. The findings show that the diversity of the external information sources has a positive and significant relationship with the absorptive capacity and the mediating variable (beta = 2.56, $p < 0.01$). Model 8, which reports the last step, presents that the absorptive capacity positively affects the product innovation at a significant level (beta = 0.92, $p < 0.01$), with the independent variable controlled. As both the mediating variable and the independent variable have significant effects in Model 8, the partial mediation effect of the absorptive capacity is confirmed.

Table 5. Mediation of the absorptive capacity between the external information sources and product innovation.

	Dependent Variable		
	Product Innovation (Logistic)	Absorptive Capacity (OLS)	Product Innovation (Logistic)
Variables	**Model 3**	**Model 7**	**Model 8**
(constant)	−1.07 **	−0.32 **	−1.07 **
	(0.20)	(0.09)	(0.21)
Small and medium sized company *(dummy)*	−0.77 **	−0.64 **	−0.32 **
	(0.11)	(0.05)	(0.11)
Firm age *(in year)*	0.01 **	0.01 **	0.00
	(0.00)	(0.00)	(0.00)
Firm size *(number of employees)*	0.00 **	0.00 **	−0.00
	(0.00)	(0.00)	(0.00)
Diversity of external information sources	1.45 **	2.56 **	−0.46 **
	(0.14)	(0.07)	(0.17)
Absorptive capacity			0.92 **
			(0.05)
R-square		0.51	
Log Likelihood	−1931.58		−1654.93

Notes: $N = 4000$; ** $p < 0.01$; standard errors are in parentheses; industry dummies are not reported due to the space limitations.

In a separate mediation test, using the bootstrapping approach, it is found that the absorptive capacity also has a significant indirect effect on the relationship between the external information sources and the product innovation, by using a 300-bootstrapping sample. The estimation of the indirect effect is 0.39 (CI = [0.35,0.43] $p < 0.001$). Therefore, Hypothesis 5 is also supported.

Figure 1 depicts the findings of our analysis, in which the diversity of the strategic attentions, the diversity of the external information sources, and the absorptive capacity, all influence directly product innovation; and the absorptive capacity mediates both the relationship between the diversity of the strategic attentions and product innovation and the relationship between the diversity of the external information sources and product innovation.

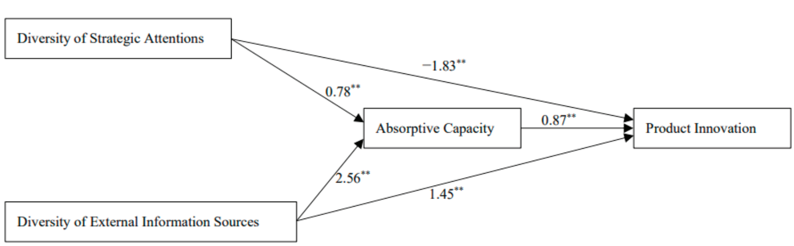

Figure 1. The diagram of the findings. ** $p < 0.01$.

5. Discussion

Building upon the open system approach to organization studies [6–8], this paper proposes that a firm's efforts to enhance its product innovation is best understood when the firm is considered as an open social system in which the managerial subsystem of the attention allocation, the supportive subsystem of procuring external information sources, and the adaptive subsystem of building the absorptive capacity function collaboratively to accomplish the product innovation outcomes. We therefore suggest that the product innovation is a complex and complicated task that requires more holistic arrangements of subsystems encompassing both internal and external aspects of an organization than simple improvements of technological competencies. By using the data set of the "Korean Innovation Survey 2020: Manufacturing Industry", we empirically examined all of our hypotheses we developed, based on the open system approach, and our empirical findings support all five hypotheses.

Our findings contribute to the product innovation literature by providing a more holistic and comprehensive explanation on how to successfully overcome myopic strategies that hasten for immediate visible outcomes of product innovation. While the existing studies about product innovation tend to focus mostly on the technological side of products, our findings highlight the importance of long-term managerial considerations, which incorporate a more focused distribution of attentions to the goal of product innovation [1–3]. Unless the top management carefully pours more focused attention into the firm's efforts of product innovation, it is unlikely that the firm will achieve the goal of product innovation. Additionally, the findings show that the firm must expand the range of external information sources diversely in order to obtain the relevant information and knowledge for its efforts of product innovation. More importantly, this study found that building up the absorptive capacity is a crucial step to synthetically combine the internal strategic attentions with the external information and knowledge for its purposes of product innovation. In sum, we believe that our findings guide the firm pursuing the product innovation to a more holistic viewpoint based on the open system approach.

Our study also contributes to the system theory by expanding its theoretical perspectives to the realm of organization studies. Since the system theory was first introduced, the expansion of the theory has been attempted in many other disciplines, and the research area of organization studies is one of those disciplines. By understanding the organizations through the lens of the open system theory [6–8], we suggested in this study that the efforts to enhance the product innovation is better understood as an organic combination of various subsystems residing in the organizational structures and processes. Rather, a simple sum of independent subsystems within the organizational boundaries, the organizational goals can be accomplished more effectively when the firm is considered as a total sum of interactively communicating subsystems that encompass both internal and external aspects of the whole system. All three subsystems included in our hypotheses do not separately function, but closely interact with one another to generate the purposed outcomes. Thus, the empirical findings of this study not only confirm the theoretical relevance of the open system theory to the understanding of the firm's actions of achieving its goals but also expands the scope of the theory.

6. Conclusions

This study provides some important practical implications, especially to the firms that attempt to generate considerable outcomes in product innovation. First, it highlights the importance of the proper allocation of managerial attentions. While a firm faces diverse goals concurrently, it must build up managerial competencies to overcome the potential distraction derived from diverse and multiple goals. Based on the attention-based view of the organizations, we argued that the pursuit of multiple goals may result in the dispersion of limited attention resources, which can be detrimental to the relatively complex and complicated goals that require prioritized attentions, such as product innovation, in our case [9,10,20]. As our findings show, the failure of prioritizing the attention resources is very likely to hamper the firm in the accomplishment of its important strategic tasks. To build the competencies of choosing which goals need more attention resources, the top management of the firm must pay attention especially to the features of the given tasks in terms of the values of various goals, and prioritizing groups of the goals.

Second, based on the findings of this study, we emphasize the importance of reaching out to for information and knowledge through the external networks of various types of external organizations. As product innovation is a task that requires a broad range of information and knowledge, the firms pursuing this goal are likely to obtain the knowledge resources that may not grow within the firm boundaries. The knowledge for product innovation is not limited to the technological kinds, but may include institutional or legal kinds. Establishing good relationships with various types of external partners will therefore function as the reliable inflowing channel of the knowledge that resides in the external environments [34,35]. Thus, it is very important that the policymakers should find ways to establish reliable relationships with other organizations.

Lastly, our findings guide the policymakers to build the absorptive capacity within their firms in order to enhance the effectiveness of product innovation. As argued earlier, the absorptive capacity is a crucial component of the innovation-related activities, especially because it connects the external knowledge with the internal competencies. From a viewpoint of organizational design, it is known that the absorptive capacity is structurally positioned in an independent department specializing in research and development. Likewise, maintaining the professional workforce with research skills and knowledge also functions as a crucial part of the firm's absorptive capacity. The top management of a firm must consistently invest in establishing knowledge-intensive routines and mechanisms within the boundary, and such efforts will consequently lay a solid ground for building the firm's absorptive capacity.

Despite some critical contributions and practical implications, this study has some limitations that deserve future study, in terms of the data. As the dataset used in this study is constructed by a survey method, one may raise a question particularly about the data. It is often addressed that a survey method may be subject to some issues about the reliability of responses, which may lead to response biases such as the self-enhancement bias. While the Korean Innovation Survey has been conducted by an authoritative, government-funded research institute, following the global standard, and thus considered as a reliable data source by prior studies (e.g., [20,27,46,47]), future studies would benefit from a more objective measure to rule out such restrictions. Another limitation may be pointed out in terms of generalizability of our findings. Our research context of Korean manufacturing industries may have some institutional, cultural, and economic features. Therefore our findings need to be validated in other contexts, for example, by using the Community Innovation Survey (CIS) that encompasses the member nations of the European Union. We believe that these limitations will be effectively addressed by future research.

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systems

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Start-Ups as Adaptable Stable Systems Based on Synchronous Business Models

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Abstract: Business models have been a popular topic in research and practice for more than twenty years. During this time, frameworks for formulating business models have been developed, such as the business model canvas. Moreover, different business model frameworks have been proposed for different sectors. Yet, these frameworks have the fundamental shortcoming of not addressing directly and persistently the primary objective of start-ups: to survive in changing environments. The aim of the action research reported in this paper is to overcome that fundamental shortcoming. This is an important topic because the majority of start-ups do not survive. In this paper, first principles for survival in changing environments are related to business models. In particular, action research to reframe start-ups as adaptable stable systems based on synchronous business models is reported. The paper provides three principal contributions. The contribution to business model theory building is to relate survival first principles revealed through natural science research to business models. Reference to first principles highlight that survival depends on maintaining both external adaptability and internal stability through synchronization with changing environments. The second contribution is to business model practice through describing a simple business modeling method that is based on the scientific first principles. The third contribution is to provide an example that bridges the rigor–relevance gap between scientific research and business practice.

Keywords: adaptability; business model; ecological fitness; entropy; environment; growth; stability; start-ups; survival; synchronous

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1. Introduction

It has been argued that nature-based methods can contribute to increasing the resilience of human organizations in a changing world [1,2]. First principles include basic propositions about nature that have been revealed through scientific research [3]. For example, first principles of how organisms survive in changing environments. One basic proposition is that survival in changing environments depends upon balancing adaptability and stability [4–8]. Organisms that are well-adapted with their environments can be described as having high ecological fitness [9]. In other words, they have a good fit with their environment. Organisms that are best adapted with their environments can survive with least action and have surplus energy available to enable their growth [10]. For organisms to be well-adapted to their environments, they need to have reciprocal back-and-forth exchanges of learning and development with their environments [11]: ideally, synchronous exchanges of learning and development. This involves organisms having internal models of how they will survive in environments. Internal models are shaped by open boundaries and survival parameters. Organisms that do not continue to develop their internal models through learning with their environments will not survive [12]. For example, without understanding of their environments, they will experience high information uncertainty, much physical disorder, and useless energy expenditure lost in unproductive actions: all of which can undermine their internal stability [13].

In this paper, action research [14,15] is reported that involved survival first principles being applied in a simple business modeling method. The action research is reported in the remaining five sections of the paper. Next, in Section 2, the action research methodology is explained. In Section 3, literature review, internal model formulation and operation are explained in terms of first principles. In addition, survival is explained in terms of synchronization for adaptable stability. In Section 4, implementation of first principles in the new method is described. In Section 5, the method is related to different stages of start-ups lifecycles, and to other methods for business modeling. In conclusion, in Section 6, principal contributions are stated, and directions for future research are proposed. By providing survival first principles for changing environments, the paper goes beyond extant business model theory and practice that is based on organizational studies [16,17]. Furthermore, this paper goes beyond business model studies that have framed interaction between businesses and environments in terms of open innovation [18,19], and beyond studies that have advocated for consideration of ecological sustainability in business models [20,21]. By contrast, the focus here is on fundamental principles for survival that have been revealed by natural sciences research [22,23]. The aim of the paper is to address the fundamental shortcoming of extant business model methods that do not address directly and persistently the primary objective of start-ups: to survive in changing environments. Nonetheless, it is not intended to suggest that the business modeling method explained in this paper should replace existing methods. Rather, that the method presented here could complement existing methods.

2. Action Research Methodology

Action research adds change to the traditional research objectives of improving description, explanation, and prediction of complex phenomena. Action research is appropriate when complex phenomena can be improved through change [14,15]. Apropos, the survival rate of start-ups is very low. Moreover, evaluating which start-ups will be successful is so difficult that it can be more effective to allocate start-up funding randomly rather than on the basis of analyzing start-ups' plans [24,25]. Hence, new business model methods are needed to facilitate start-ups' survival and growth. The action research involved iterations of review of natural science findings concerned with survival in changing environments; formulation of the new method; and obtaining feedback on the new method from start-up experts. Feedback was obtained through meetings during which the latest version of the new method was discussed with experts. In addition, experts provided feedback via emails. Experts opined that natural science first principles are relevant to their own organizations and to the start-ups that they support through their programmes. Their feedback provided suggestions for improving the usability of the method.

3. Literature Review

3.1. Internal Models

Natural science research indicates that the formulation of an internal model involves establishing boundaries and parameters. In particular, organisms construct their own constraining boundary conditions in order to be able to do the work needed to survive. Work has been described as the constrained release of energy into a few degrees of freedom [26]. If the release of energy is not constrained, most of the energy would be dissipated rapidly as entropy. For practical purposes, entropy can be considered to be information uncertainty that leads to physical disorder, which entails useless energy expenditure that is lost in unproductive actions. By contrast, constraining the release of energy enables more work to be done with the same amount of energy. Establishing constraining boundary conditions enables organisms to differentiate themselves from the environment while being open to exchanges of information, matter, and energy with the environment [27].

For example, a hunter–gatherer band distinguishes itself from other hunter–gatherer bands and other species. Such differentiation is essential to survival in deciding what will be hunted/gathered, and in the arrangement of work for efficient hunting and gathering that provides an energy surplus. For hunter–gatherer bands and for business organizations, the positioning of boundaries can depend upon comparison of differences between the transaction costs of doing work internally versus buying work done in the environment—for example, whether to construct a shelter or to occupy a cave; whether to make inside a business or to buy from the market [28].

Organisms and organizations can shape their boundaries and how they will release energy to do work through a bricolage process, which involves choosing what is most useful from whatever existing things happen to be available. Bricolage with existing things can be directed towards creating new things that involve new interactions between work, energy, and entropy. This, in turn, can lead to exponential growth in opportunities for new things as more existing things become available for bricolage. For example, the potential uses of one existing thing can be combined in many different ways with the many potential uses of other existing things. Potential uses of existing things can include many new uses that are different to their original uses [29,30]. This can lead to the creation of complements and substitutes for existing things. What is created emerges unpredictably from different organisms' and different organizations' different perspectives [31,32].

Exchanges with the environment take place on what can be described as survival parameters. Consider, for example, a band of hunter–gatherers that is well-adapted to its environment. To survive, they need water, food, and shelter. As the hunter–gatherer band is well-adapted with its environment, its members know exactly how to obtain water, food, and shelter close by. Hence, they can obtain water, food, and shelter with the least action and minimal energy expenditure, which leaves them with surplus energy that they can use to grow the size of their hunter–gatherer band. For the hunter–gatherer band, water, food, and shelter can be considered to be three survival parameters around which many everyday activities are arranged. Energy availability can be considered to be their controlling survival parameter. This is because while there may be some flexibility on individual survival parameters, such as how long they can survive without water or food or shelter, they cannot survive without having at least some energy available to try to obtain water, food, and shelter. Together, the four parameters provide the basis for the hunter–gatherer band's internal model of how it will survive in the world. Such parameter-based structuring can be applied to many phenomena [33].

Internals models provide the basis for generating patterns of interaction with the world. In particular, iterations of predictions and actions are made on survival parameters with the overall goal of minimizing uncertainty about how to survive. For example, three survival parameters for businesses can be customer base, product sales, and user experience. Their control parameter can be cash flow. This is because while there may be some flexibility in individual survival parameters, they cannot survive without having positive cash flow to pay for the many activities involved in growing a customer base, making product sales, and achieving positive user experience.

Businesses will make predictions about how many sales they expect on their product sales survival parameter. There will be no prediction error on the product sales survival parameter if sales forecasts are matched by actual sales. However, all survival parameters must be considered together when seeking to minimize uncertainty about how to survive. For example, there can be high uncertainty about survival even if sales forecast is matched by actual sales, but if user experience of the sold products is very bad. Then, the customer base could shrink and cash flow could be negative because of costs such as product recalls.

Maintaining synchronization with the environment involves making predictions about what will happen in interactions with the environment and addressing prediction errors between what is expected to happen and what does happen. Natural science research indicates that three types of actions can be taken iteratively to reduce prediction errors: i.e., to reduce differences between what is expected to happen and what actually happens—updating beliefs, shifting focus, or changing work [13,34]. Actions can be updating beliefs about how to survive, such as updating beliefs about how wide a range of products to offer. Actions can include shifting focus of attention in trying to survive, such as paying more attention to existing customers from whom sales are low. Actions can involve changing work done in order to survive, such as improving invoicing procedures to improve cash flow. Each individual action can contribute to changing business and/or environment to maintain synchrony and improve fit between business and environment.

As summarized in Figure 1, updating beliefs, shifting focus, and changing work can be directed towards improving capabilities to compete, to cooperate, and/or to construct in the environment. Construct refers to processes by which an organism alters local environment and/or undertakes wider ecosystem engineering in order to increase potential for survival by making more of the kind of space it needs for itself. In particular, construction can increase the flows of information, matter, and energy for the organism [9]. Construction may be carried in competition against others or in cooperation with others as necessary to improve fitness [35].

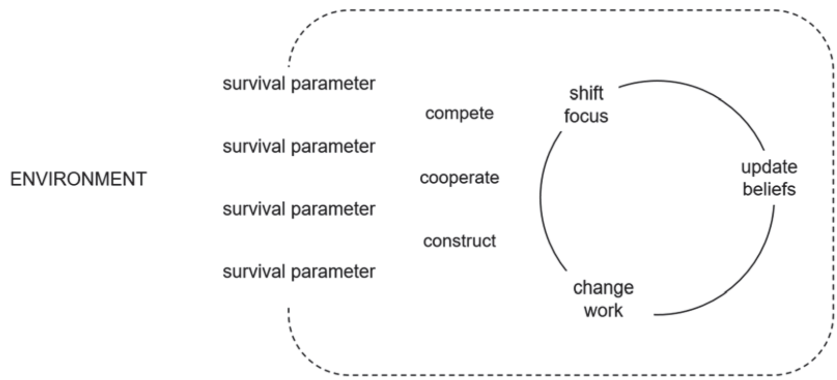

Figure 1. Internal model comprising open boundaries and survival parameters that synchronizes with the environment by updating beliefs, shifting focus and/or changing work.

3.2. Synchronization for Adaptable Stability

Overall, long-term survival depends upon synchronous back-and-forth reciprocal exchanges of organism–environment learning and development. Such synchronous systems can be described in terms of rhythmogenesis. That is the generation of rhythms found in biological systems in which coupling provides feedback [36]. This corresponds with the notion of the so called dance of change, which involves organizations making external changes and internal changes in order to survive [37]. If businesses' internal models are well-adapted to their environments, they will not experience information uncertainty on their survival parameters that leads to physical disorder and entails unproductive energy expenditure, which can undermine internal stability [38]. For example, they can have adequate customer base, product sales, and user experience with minimal energy expenditure, which leaves them with surplus energy that they can use to grow their businesses.

However, survival depends upon neither overfitting nor underfitting internal models through iterations of actions during back-and-forth exchanges with the environment [39]. Rather, internal models need to resemble the environment [40]. Overfitting can involve an internal model becoming too complicated because it is changed in response to every unexpected small sensory input from the environment. This can happen because sensory input from the environment is inherently noisy. Conversely, underfitting can occur when an internal model does not adequately resemble the environment in which an organization intends to survive. Overfitting can lead to internal models being too complicated, but under-fitting can lead to internal models being too simple. Both of which can increase risks from interactions with the environment.

Survival risks are increased if the internal model is not aligned with the causes of sensory inputs from the environment. For example, a nonlinear internal model will tend to have poor predictive performance when a business is trying to survive in a linear environment (i.e., overfitting) or vice versa (i.e., underfitting). Also, there can be ambiguous sensory inputs if iterations of actions lead to there being imprecise alignment between internal model and external environment. This can hinder accuracy in predictions about what is expected to happen and accuracy in perception of what has happened [41,42].

As well as an internal model losing synchrony with the environment through overfitting or underfitting, there can be loss of model synchrony because iterations of predictions and actions come to be focused on the past rather than on the changing present. This phenomenon can be found at the level of microbiology [43] and can be considered as an organism becoming stubborn [12]. From the point of view of business, this phenomenon can be referred to as lock-in where businesses base their current actions on entrenched paths of past actions [44], even when there is increasing evidence that actions are failing [45].

Such rigidity can be more likely when an organism or an organization considers itself to be threatened [46]. This can be because internal models provide the basis for generating perceptions. In particular, perceptions about the world are made through combination of sensory stimuli coming from the world, such as light coming to the eyes, and internal representations built through prior experience [47,48]. This can be summed up with phrases such as, 'we don't see things as they are but as we are' [49]. Internal representations can have a determining influence over what we would like to see in the environment [41] and over how we interpret sensory inputs from the environment [42]: neither of which necessarily provides accurate information about the environment. This may be because humans evolved as hunter–gatherers to emphasize memories of knowledge considered most important for survival [50].

When an internal model is not synchronous with the environment, prediction errors on individual survival parameters and overall uncertainty about how to survive can increase until a business fails. For example, a business can be uncertain why product sales do not meet its sales forecast when it believes that its new product range has a variation for every possible customer's every possible taste (i.e., overfitting) or that its one new product is best for all customers (i.e., underfitting) or that there is no need to change its products because they have been market leaders in the past (i.e., no fitting). In any case, this can lead to physical disorder in rushed actions such as crisis product campaigns and haphazard cash raising, which undermines internal stability. This disorder entails unproductive energy expenditure that can leave little energy remaining for productive work actions. If this continues, a business will lose resources, and organizational stress can increase until the business fails [51,52]. Thus, as summarized in Table 1, survival depends upon avoiding over fitting, under fitting, or no-fitting the internal model with the environment.

Table 1. Internal Model Adaptation for Synchrony with the Environment.

Maladaptation	Adaptation
Underfitting	Increase survival parameters and inter-relationships between them
Overfitting	Reduce survival parameters and inter-relationships between them
No fitting	Change boundaries, survival parameters, and inter-relationships

On the one hand, adaptive fitness depends on being efficient enough to survive with least action and thus have surplus energy available to enable growth. On the other hand, focusing only on efficiency, for example through underfitting, can lead to organisms and organizations being too efficient for their own good. This is because they can become too brittle to deal with environmental disturbances [53,54]. Hence, adaptive fitness also depends upon not overfitting but having a wide-enough variety of internal states to be able to adapt with changing external environments [55,56]. Accordingly, internal models need to be open to cycles of expansion and reduction [57], and as summarized in Table 1, internal model maladaptation needs to be addressed through internal model adaptation.

4. Results

Figure 2 shows a screenshot of the whole Excel sheet for the simple business model method, which is based on the first principles explained in the preceding sections.

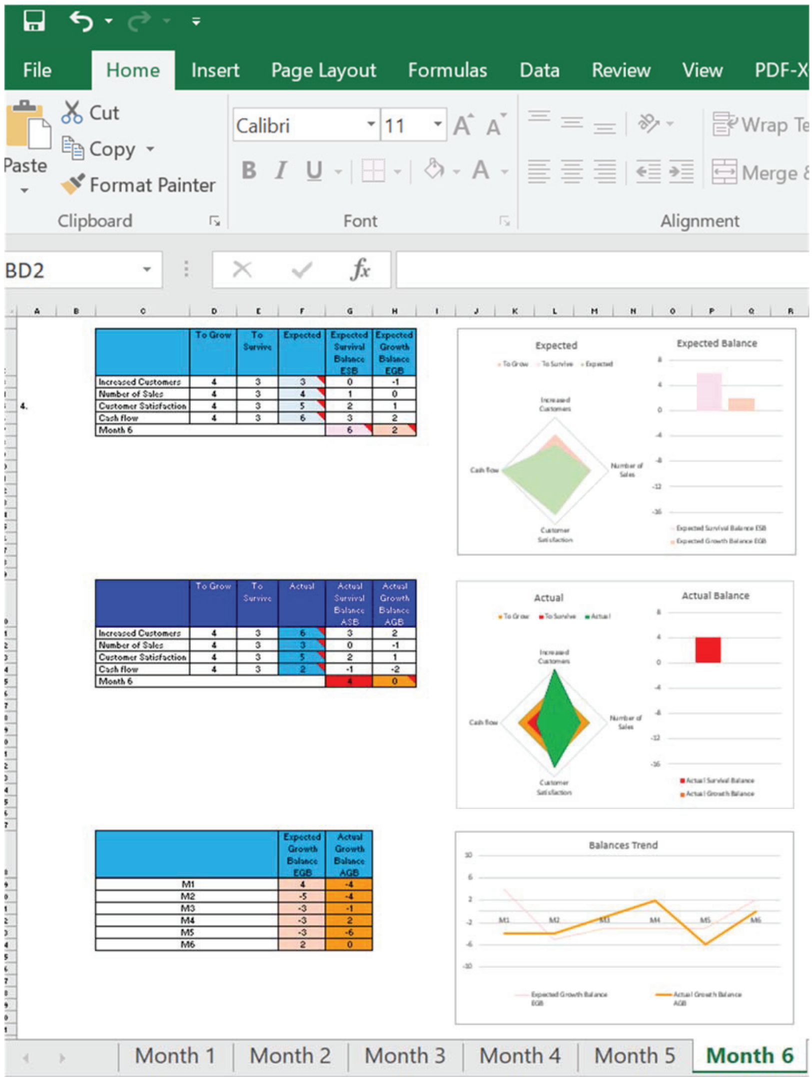

Figure 2. Business modeling method based on survival first principles.

To frame is to address certain aspects of a topic. Framing affects evaluations and decisions [58,59]. The framing of the simple method addresses directly and persistently the need to achieve at least survival performance on survival parameters. In particular, users make predictions on survival parameters and take actions to correct prediction errors on survival parameters. This is essential for maintaining synchronization with changing environments that is necessary for ecological fitness. Start-ups must be adaptive to address prediction errors on survival parameters arising from changes in the environment. At the same time, minimizing prediction errors on survival parameters can facilitate start-ups' internal stability. Figure 3 shows an example of radar charts and bar charts generated when using the simple method.

Figure 3. Expected performance compared to actual performance on survival parameters.

Figure 3 shows an example of radar charts and bars charts that are generated by entering 1, 2, 3 or 4 for performance on survival parameters: customer base, product sales, user experience, and cash flow. Figure 3 shows that the start-up has prediction errors. In particular, start-ups' expectations about customer base were not achieved, but actual product sales and actual user experience were better than expected. Figure 3 shows the quartile representations used in the method in which 4 represents enough for growth, 3 represents enough for survival, 2 represents not enough for survival over more than one prediction period, and 1 represents not enough for survival within one prediction period. For example, if cash flow of 78 thousand is needed for growth that month, entering 4 represents 78 thousand, entering 3 represents 58.5 thousand, entering 2 represents 39 thousand, entering 1 represents 19.5 thousands; 1, 2, 3, 4 are quartile representations, which can be applied to all survival parameters irrespective of measurement units. For example, customer base can be measured in terms of number of customers, product sales can be measured in terms of number of sales, user experience can be measured in terms of experience ratings, and cash flow can be measured in terms of currency units. Here, quartile representations are heuristic representations, that is rule-of-thumb representations, which have been developed during human evolution and are still effective today [60,61].

Figure 4 shows variations over six months between what is expected to happen and what actually happens. Such varying prediction errors can be commonplace as organizations seek to maintain synchronization with environments that are changing continually.

	Expected Growth Balance EGB	Actual Growth Balance AGB
M1	-2	-3
M2	-5	-4
M3	-3	-1
M4	-3	2
M5	-3	-6
M6	2	0

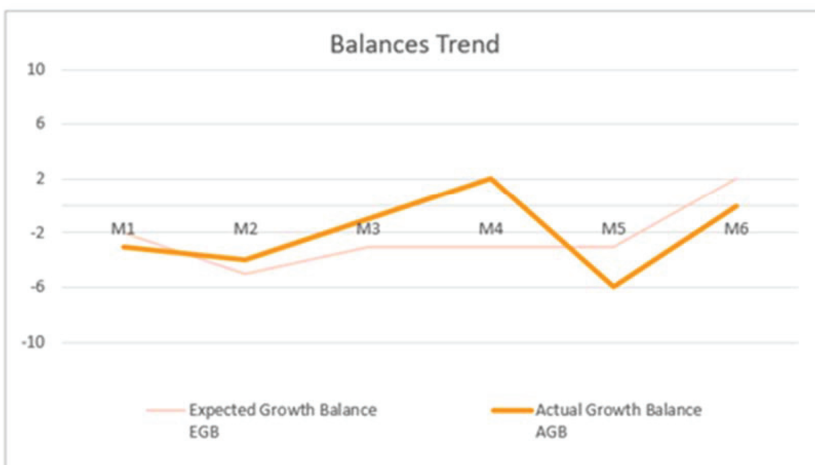

Figure 4. Trend in differences between expected performance compared to actual performance.

The tables and charts in this business modeling method may seem to be simplistic. However, simplicity is preferable in nature [62], in science [63], and in practice [64]. Moreover, the tables and charts in the simple method are consistent with human perception having evolved to be focused on ecological fitness that is necessary for survival [65]. Furthermore, the simple representations used in the method are consistent with communication science that has revealed the importance of matching format to task [66], and with the use of visual representations to improve the relevance of science to practice [67].

As shown in Figure 5, in accordance with first principles, the interactive training slides that accompany the simple method provide advice on the three options for addressing prediction errors: updating beliefs, shifting focus, and/or changing method of work. This is done with practical examples—in particular, Update Business Model: for example, expand or reduce the scope of the business model in terms of survival parameters for customer base, product sales, user experience, and cash flow; Shift Focus: for example, shift focus to pay more attention to those existing customers from who sales are low or to pay more attention to a new market segment of customers; Change Method of Work: for example, improve delivery procedures to improve customer satisfaction and/or improve invoicing procedures in order to improve cash flow. The use of different examples in the interactive training slides is in accordance with the use of contrasting cases during instruction in order to improve learning [68].

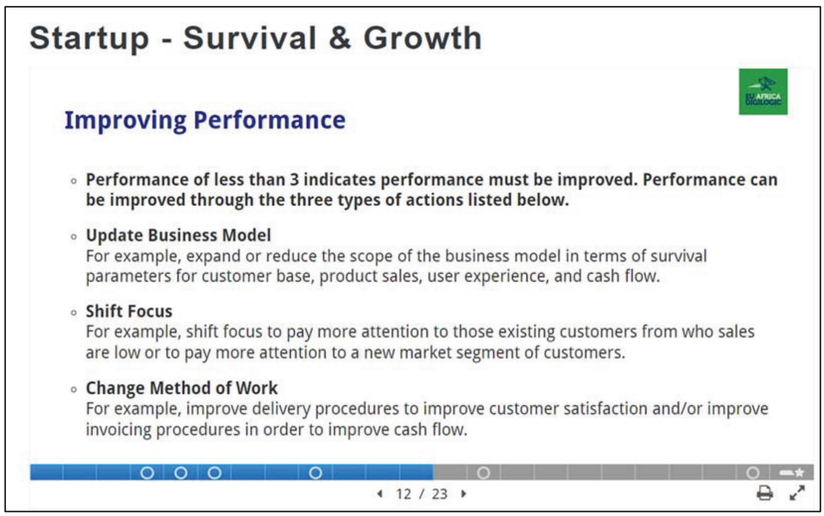

Figure 5. Interactive training slides: Actions to achieve synchrony by addressing prediction errors.

In accordance with first principles, as shown in Figure 6, the interactive training slides that accompany the simple method provide advice on the need to avoid underfitting, overfitting, and no fitting. For practical understanding, this is done without using the fitting terminology. Instead, users are advised that updating the business model should not lead to there being too few or too many survival parameters; that focus should be on alignment with the current environment not on the business' past boundaries, past survival parameters, and/or past activities; and that changing methods should not lead to there being too few or too many activities involved in work to achieve performance on survival parameters.

As shown in Figure 7, the interactive training slides include questions to test learning about the method. Correct answers are indicated with green highlighting, a green tick and plus one. Incorrect answers are indicated by red highlighting, a red cross, and minus one. Incorrect are accompanied by this statement: Please reread the slides to learn correct answers and try again. The interactive training slides can be navigated one-by-one by use of the backwards arrow and the forwards arrow as necessary. Alternatively, users can be move between the sections of the interactive training slides by use of the circles on the bar above the backwards and forwards arrows.

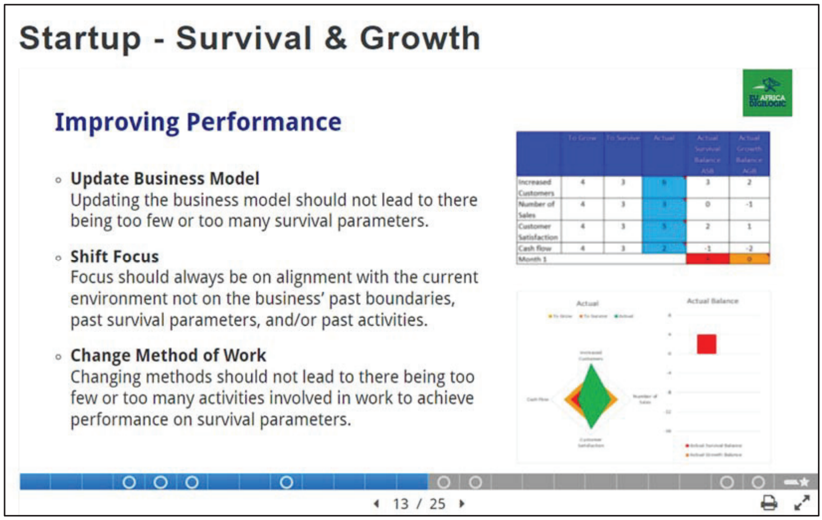

Figure 6. Interactive training slides: Practical steps to avoid underfitting, overfitting, and no fitting of business model.

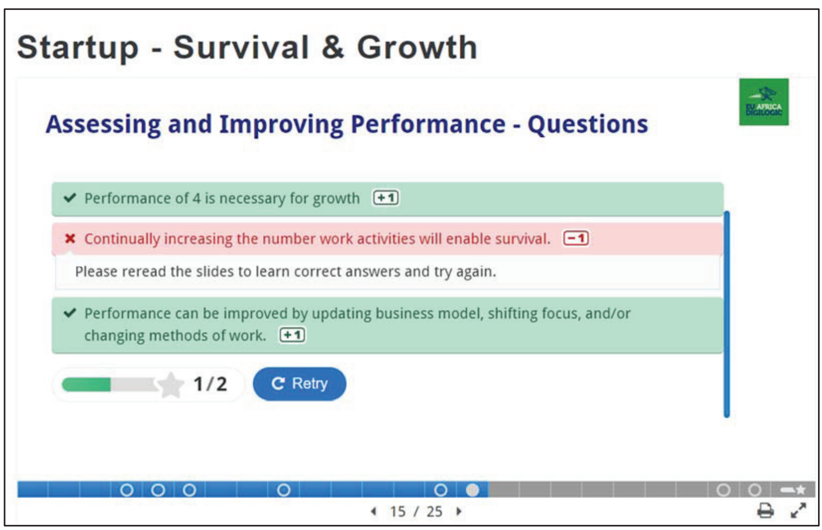

Figure 7. Interactive training slides: Example of question slide.

5. Discussion

In terms of first principles, the lifecycle of a start-up can be framed in terms of arrival of the fittest and survival of the fittest [9,69]. From the point-of-view of organizational studies concerned with start-up lifecycles stages [70], arrival of the fittest can be related to ideation stage and transition stage. Survival of the fittest can be related to the subsequent stages of scaling and exit [71]. For a start-up, arrival in a competitive environment with a higher level of fitness than other organizations can involve several activities, including formulating a business model and identifying customers to enabling iterative testing of the business model as the start-up endeavors to transition towards scaling [72]. When seeking to arrive as the fittest in a competitive market, existing business modeling methods such as the business model canvas can be used iteratively to define value proposition, cost structure, revenue streams, key partners, key resources, key activities, customer segments, customer relationships, and distribution channels [19]. Such definition can involve ideation with a variety of techniques, such as the use of visualizations that can clarify market systems [73] and others that can reduce the influence of preconceptions that can limit innovation [74].

Despite the many strengths of the business model canvas, it does not facilitate performance measurement [75]. Instead, start-ups can define a multitude of key performance indicators (KPIs) [76]. This can correspond with overfitting an internal model to the external state of a changing environment [39]. Alternatively, start-ups can use a standard balanced scorecard with only a few summary criteria, but which can still involve a multitude of performance measurements [77]. By contrast, the simple method explained here is intended to facilitate measurement of performance on those parameters that are fundamental to survival. This is done on individual survival parameters, such as customer base, product sales, user experience, and cash flow. However, the overall measurement, through the charts shown in Figures 3 and 4 is of synchrony with the environment. Thus, although the method is simple, it goes beyond the well-established practice of start-ups measuring their activities in terms of many KPIs, which do not immediately indicate the extent of synchrony with its environment.

As start-ups seek to survive as the fittest during scaling towards the exit stage of initial public share offering, private sales, etc., they may move from informal structure to formal structure. In doing so, there can be crises of bureaucracy amidst change from founding generalists taking ad hoc actions to specialists being employed to follow documented procedures [71], for example within quality management systems [78]. This change from informal to formal can involve change from a business model being founders' mental model to the business model being a simplified representation of the start-up's activities or even a detailed explanation of how business is conducted [79]. The simple method shown here is not in conflict with such changes from informal to formal. This is because it is focused on performance on survival parameters, rather than on the activities that are carried out to achieve performance on survival parameters.

Furthermore, the relevance of the simple method shown here is not restricted by any size of start-up from ideation to exit. This is because it is based on first principles that are applicable from the level of particles to organizations [56,80]. In particular, prediction errors on survival parameters arise from information uncertainty about how to survive, for example uncertainty about how to achieve sufficient product sales to survive. Irrespective of start-up stage or size, information uncertainty about how to survive will lead to physical disorder, which entails useless energy expenditure lost in unproductive actions. If prediction errors are not reduced through updating beliefs, shifting focus, or changing work, organizations of any stage or size can be overwhelmed by what has been described in the system dynamics literature as firefighting [81]—in other words, by becoming trapped in a quagmire of deadline pressure, overtime working and energy depletion.

In the most fundamental terms, making prediction errors on survival parameters indicates that living things, here start-ups, do not know how to counteract locally the universal trend towards maximum entropy [26]. Information uncertainty about how to survive can be stated in terms of information-theoretic entropy as defined by Claude Shannon in the 1940s [82]. For example, if there is an information-theoretic entropy of 2.58 bits, there is the statistical mechanics entropy of physical disorder from there being six equiprobable but different ways in which work could be carried out. If only one of those six different ways of carrying out the work is correct, there will be the thermodynamic entropy of potentially useful thermodynamic energy becoming practically useless thermodynamic energy as it is lost in five failed attempts out of six attempts to carry out the work. Statistical mechanics entropy describes the disorder of a system, with entropy increasing as the number of states available to the system increases [83]. Statistical mechanics entropy was defined by Ludwig Boltzmann in the 1870s and Max Planck in the 1900s. This was preceded by definition of thermodynamic entropy by Rudolf Clausius in the 1860s based on observations that much energy is lost due to dissipation and cannot be converted into useful work. Thermodynamic entropy can be regarded as a measure of chaos in a thermodynamic system [84]. Irrespective of the stage of evolution or size of a living thing, it cannot survive dissipation into the environment of the energy it needs to do work necessary for its survival. Rather, living things need to have boundaries that are open to the environment but constrain their release of energy into a few degrees of freedom [26,27]. This is necessary to be able to adapt to external changes while maintaining sufficient internal stability to make most efficient use of energy through least action [10,85,86].

A further fundamental reason why the simple method shown here is relevant to start-ups of any stage or size is that the stage or size of a start-up cannot lead to constant synchrony with the competitive market in which it intends to survive and grow. This is because competitive markets are environments that will change unpredictably. Competition in markets will change unpredictably because the potential uses of existing things can be combined in many different ways with the many potential uses of other existing things. Potential uses of existing things can include many new uses that are different to their original uses [29,30]. This leads to the creation of complements and substitutes for existing things. What is created emerges unpredictably from different organizations' different perspectives [31,32]. Hence, it is not realistic to anticipate that start-ups will initially make prediction errors on survival parameters but then come to have no information uncertainty about how to survive. Rather, new sources of information uncertainty will arise from changing competition. Moreover, it will arise from increasingly widespread climate-related environmental changes [87–92]. Accordingly, start-ups will continue to need to address prediction errors on survival parameters throughout their lifecycles by updating beliefs, shifting focus, or changing work.

6. Conclusions

Living systems can facilitate their survival by balancing adaptability and stability through synchronization with environments. This paper reports action research that involved survival first principles being applied in a simple business modeling method, which can support start-ups in being adaptable stable systems that are synchronous with their environments. In particular, synchrony involves the use of business models to predict performance on survival parameters and taking actions to address prediction errors of actual performance not matching expected performance.

The paper provides three principal contributions. The contribution to business model theory building is to relate survival first principles to business models. Referring to survival first principles revealed through natural sciences research is apposite as organizational research has not ameliorated the persistently high failure rate of start-ups around the world. Furthermore, it is timely as start-ups experience increasing unpredictability around them due to climate-related environmental changes. Accordingly, it is now more important than ever to recognize that survival and growth depends upon synchrony with changing environments. The contribution to business practice is to describe a simple business modeling method that is based on the scientific first principles. As the simple method uses standard basic software and is easily explained through a few slides, it is accessible throughout start-up lifecycles to a wide range of potential users in any sector. This is important in order to address directly and persistently the primary objective of start-ups: to survive in changing environments. The third contribution is to provide an example that bridges the rigor–relevance gap between scientific research and business practice. It is an example that encompasses basic research, e.g., [22,23] use-inspired basic research [40,57] and pure applied research, which illustrates the value of fundamental research and the unpredictability of how it will eventually come to be useful.

The reported study is limited by the simple method not having been combined with existing methods. Apropos, future research could investigate potential for existing methods to inform definition of open boundaries, survival parameters, and activities to achieve necessary performance on survival parameters. Subsequently, research could investigate the potential for existing methods to support shifting focus and/or changing methods of work. Such research could investigate potential for relating the sparse representations of the business modeling method explained in this paper with the rich picture technique and other existing methods that can facilitate shared visualization of start-ups' interactions with changing environments.

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The Blitz Canvas: A Business Model Innovation Framework for Software Startups

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Abstract: Software startups are temporary organizations created with the purpose of bringing a profitable business idea to life. In the initial stages, the commercial viability of any product concept is yet to be proven and until the startup can generate revenue, resources are always in short supply. To this end, this research proposes a process-oriented, competition-aware, metric-driven business model development and innovation framework. The proposed framework is designed to aid this process, by supporting the creation and validation of the business model. A web-based tool is created to demonstrate the working of the proposed model and validation is performed using survey data collected from the usage experience of participants. The data is used to evaluate the research questions and the ability of the proposed framework to overcome the shortcomings of the business model canvas. The results showed that the tool (and by extension, the framework) made the task of business model creation a quick and easy process, while at the same time covering all the required areas to create a holistic business model. The framework contributes to startup success by creating a structured approach to business development, helping to visualize the avenues for product differentiation and planning growth.

Keywords: business model innovation; blitz canvas; process-driven business models; business model canvas; lean startups

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1. Introduction

A startup can be defined as a temporary organization in search of a repeatable and scalable business model, which it finds can work [1]. Startups are important to both their immediate stakeholders and the economy in general, as they are seen as engines of job creation and economic growth [2]. It has been estimated that in the span of 20 years between 1980 and 1999, entrepreneurs created 95% of the new wealth generated during that time period and added 34 million new jobs to the economy [3,4]. Fast-forward to the next couple of decades, and startups added 2.5 million jobs to the United States economy in the year 2015 alone, and 1.7 million in 2017 [5]. In Australia, jobs created by startups accounted for almost all the 1.6 million jobs created in the economy between 2003 and 2014 [6]. However, startups also have a very high rate of failure, with some estimates placing this number between 70 and 90% [7–9]. A study conducted by CB Insights [10] revealed that among startups that manage to stay afloat for over a year and go on to acquire some level of venture backing, 70% of startups in the technology field failed within a span of 20 months after raising their first round of financing. When looking at the startup failure rate according to industry type, the category with the highest failure rate (at 63%) was the information technology industry [11]. These are not insignificant numbers and identifying the reasons for this failure merits more attention.

The traditional business model planning structure provides a "roadmap" for startup founders, which can be used to define objectives and goals, measure progress, and work on milestones [12]. However, the suitability and relevance of this framework in current market conditions has been debated elsewhere [13,14]. This is primarily due to the reason that business models and products developed using such structures do not verify or validate whether the solution being created will indeed cater to the user's needs or if the product has the potential to be monetized [15]. This provides context for the top reason why startups fail, as discussed earlier in this section, which is that startups fail because they create products that do not have sufficient market demand. The concept of the business model canvas (BMC) was introduced by Osterwalder and Pigneur [16] to overcome some of the shortcomings of the traditional approach since it provided a quicker and easier alternative to traditional business model planning. However, it still had many of the same shortcomings, which included some of the key reasons for startup failures discussed so far, such as a failure to consider the competition and to take into account the core competencies within the startup, among others. This provides the opportunity for a framework to be introduced that will improve the chances of startup success. Such a framework would ideally be based on an agile philosophy (which incorporates validation as part of its core structure), one which takes into account the critical factors for software startup success and overcomes the shortcomings of most business modeling frameworks.

To this end, the current body of work proposes the blitz canvas (BC), which is a process-based, innovation-focused, market/competition-aware, foundationally strong, synergistic and growth-oriented framework for business model development and innovation. Being process-driven, the framework is designed to provide an easy pathway for creating a business model around a product/solution concept quickly, while effectively managing the startup capital (costs) and ensuring differentiation in the offering. The framework is called the "blitz canvas" due to its focus on the speed of development (of the business model).

The blitz canvas also aids in the process of business model innovation (BMI), which is in essence the search for novel means to generate and/or capture value for the involved stakeholders [17]. The approach taken by the BC to achieve this end is by supporting the creation, visualization, and validation of the business model via a process-based mechanism. The process-based mechanism of business model creation and visualization plays a pivotal role here, considering the importance of the BMI in conferring a reliable form of competitive advantage that needs to be explicitly supported and reliably managed [18].

It needs to be highlighted that the target audience of this framework is inexperienced entrepreneurs and first-time start-up teams who are working in the software arena. One of the primary goals of the blitz canvas is to lower the barriers of entry by allowing inexperienced entrepreneurs and first-time startup teams in the field of software development to participate in the startup economy by providing them with a process-driven and end-to-end framework for startup development. Most business modeling frameworks were created to cater for tangible products rather than intangible offerings such as software. The dynamics of creating and monetizing software products can involve a different set of challenges and opportunities. The organizational characteristics that are unique to software startups may include:

- The ability to prototype and test out concepts quickly.
- The ability to change direction quickly with evolving business scope/user problems.
- The ability to accommodate and handle sudden growth.
- A low barrier to entry—not many resources are required besides manpower, computer systems and internet connectivity.
- The ability to leverage SaaS business models to get a product or service up and running quickly.
- The ability to make changes to the product after it has been shipped, based on user feedback.

The next few sections of this work are structured as follows: in Section 2, the groundwork is established by reviewing the related work and providing the potential for this research. Section 3 provides an outline of the research methodology employed for this work. Section 4 proposes an outline of the blitz model and provides a description of each of the model's stages. Section 5 details the validation of the proposed model via analysis of survey data collected from participants who interacted with an online tool, created based on the proposed model. This is followed by a discussion of the model and a summary of the key contributions of the model in Section 6. Lastly, Section 7 outlines our conclusions and notes the limitations of the current work, suggesting possible directions for future research.

2. Related Work

Business model development is a crucial area of focus for the success of any startup. It should come as no surprise that much literature has been dedicated to understanding this area. This section discusses the relevant literature in the business model development field, starting with understanding the concept of business models and then investigating the BMC framework. The shortcomings of the BMC are also studied, along with the rationale for our proposal of the BC.

2.1. Business Models

Business models have been around for as long as businesses have had the capacity to remain profitable for their investors. As a general understanding of the term, business models can be thought of as a hypothesis developed by a startup's management with the purpose of structuring the organization, in order to determine the requirements or problems of their target customer, how they might want a solution delivered to them, and how much they might be likely to pay to acquire this solution [19]. From another perspective, a business model can be described as "the logic of the firm, the way it operates and how it creates value for its stakeholders" [20]. If we consider the basic concept of the business model at its most fundamental level, a business model is how an organization generates revenue and makes a profit [21]. The typical business model will touch upon a number of concepts in order to demonstrate how it will eventually generate revenue and become profitable, including but not limited to matters regarding the operating mechanisms [20,22], pricing structures [19,20], customer segmentation and how the product generates value for the customer [19,23], among other details.

It must be noted that developments in the field of ICT have majorly contributed to the renewed interest in innovation pertaining to the concept of business models [20]. A subsequent shift has also taken place to adopt methodologies such as the lean startup, which can efficiently aid startup organizations in creating better business models (Hokkanen and Väänänen-Vainio-Mattila, 2015; Ries, 2011). Although relatively new, development philosophies such as the lean methodology have great appeal due to the fact that this inherently reduces waste, in the form of both time and resources.

2.2. The Business Model Canvas (BMC)

The BMC was introduced by Osterwalder and Pigneur [16] as a means to provide structure to the business modeling process. The BMC provides the ability for users to map their ideas onto a base structure of business model elements that is divided into nine segments (see Figure 1). The BMC is perceived differently based on the user profile and its purpose of usage [24]. To add to this framework, there are many variations on how the BMC is used to create new business models, although a common approach is to start from the customer segment, by identifying the target customer for whom the startup intends to create the value proposition [25]. The next segment is value proposition, which describes the solution or overall offering that the startup can provide to the customer, with the intention of adding a certain amount of value for the customer. This offering would be provided to the customer via certain distribution channels. At the same time, the business will need to evaluate how it should maintain its customer relationships so that it can attract new customers, retain its acquired customers, and grow its existing customer base. The key activities segment comprises the critical activities that need to be performed for the smooth functioning of the startup, while the key resources segment represents the critical assets, those that the startup already has and those that the startup will need to possess for the functioning of the business. In the initial stages, most startups might not have all the necessary resources at their disposal or might not be able to perform the required activities to successfully execute the planned business idea. Hence, these startups can choose to collaborate with key partners to acquire the resources needed and work on critical activities that they might not be able to accomplish on their own at that point in time. Planning the various segments of the BMC can give the startup an idea of the required cost structure to get the business model to work and evaluate the possible options for revenue streams, for generating revenue based on the business idea.

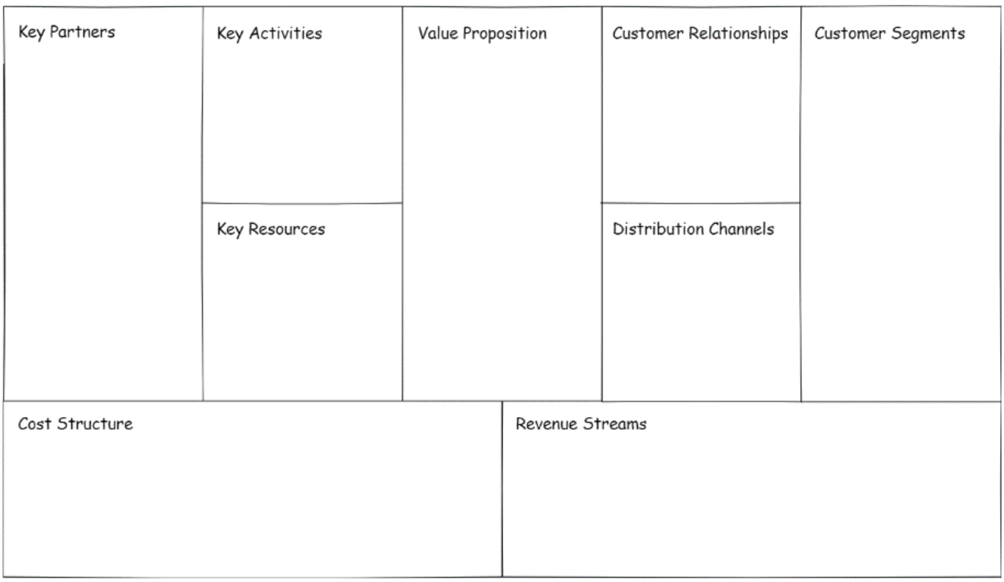

Figure 1. A reconstruction of the Business Model Canvas (BMC) adapted from the works of Osterwalder and Pigneur (2010) [16].

2.3. Shortcomings of the BMC

The BMC serves as a basis for startup teams to build their business model around their conceived product ideas and concepts. It is frequently cited as a good example of great design, mixed with great science, to produce a practical tool for entrepreneurs to work with [26]. While the BMC does a good job of covering important segments of business model planning, it is not without its shortcomings. Fauvel [27] has outlined many of the shortcomings of the BMC, which are summarized in Table 1. Startups who intend to use the BMC as a practical tool to develop their business model will need to further investigate these shortcomings beforehand.

Table 1. Shortcomings of the BMC.

Shortcomings	Source(s)
Consideration of competing entities from the market	(Kraaijenbrink, 2012 [28])
Establishment of the unique selling proposition (USP)	(Maurya, 2010 [29])
Taking into account performance measurement, using metrics such as KPIs	(Spanz, 2012 [30]; Maurya, 2010 [29])
Consideration of synergies within the BMC	(Spanz, 2012 [30])
Formulation of strategic goals or objectives of the startup	(Kraaijenbrink, 2012 [28]; Spanz, 2012 [30])
Consideration of competence for solution development	(Spanz, 2012 [30])

One frequently noted shortcoming of the BMC approach to business model planning is that the study of competing entities is not included as part of the conventional BMC structure [28]. Even though the purpose of this exclusion might evidently have been to simplify the business model development process, it is vital that the competing forces be taken into consideration during product and business model development and innovation, in terms of product differentiation and analysis for synergies among competing players in the market. Another area where the BMC falls short is the lack of consideration of a differentiation factor in general and the unique selling proposition (USP) in particular for product offerings [29]. From the perspective of startups, getting product visibility among consumers in the modern and highly competitive market can be a hard task. To this end, the presence of differentiation can help provide visibility to the current planned offering and highlight the feature(s) that make the offering unique.

The BMC also does not (at its core) take into account any kind of measurement of performance in the startup's journey to success. The identification of metrics/key performance indicators (KPIs), which can help to monitor if the startup is on the right track to reach its intended goal [29,30], is not a part of the conventional BMC structure. Spanz [30] further points out that business model planning using the BMC does not explicitly involve stating and subsequently tracking goals for startups. This argument is supported by the fact that the BMC excludes from its structure the requirement to mandatorily consider the strategic purpose (including its mission, vision or goals) of the startup [28]. Aside from this, Spanz [30] also argues that the BMC does not check if the startup has the required (core) competence to execute its proposed concept/idea or innovation.

2.4. Rationale for the Blitz Canvas

Although there are many frameworks for business model development and innovation, very few frameworks aid in the planning and creation of the conditions required for success among startups. The BC aims to provide such a base to help develop business models while improving the chances of success for software startups. The BC's framework does not intend to replace but rather extend the BMC model by addressing the key issues (as cited in Section 2.3) with its BMC structure, including the lack of awareness of competing entities and the need for a good foundation, synergy and growth-orientation. In addition, the BC provides a "process-flow" structure for business model development and innovation, with the intent of creating an easy-to-traverse pathway for inexperienced entrepreneurs to follow.

In essence, this involves retaining the strong points of the BMC, such as its simplicity and its ability to create a business model around a product idea, while at the same time tackling many of the shortcomings. One instance of managing the BMC's shortcomings is the introduction of a foundational base that includes the determination of the mission, vision and goals for the startup as part of the business model. Such a consideration can help guide the product and business decisions of the software startup under uncertain circumstances [31,32].

One of the central aims of the BC, as the name suggests, is to get the products in the hands of the customers as quickly as possible. As most startups do not have resources in abundance, unlike established enterprises [33], they may not have the time and money to compete in the field of marketing campaigns in the same manner as their established competitors. Instead, the startup would stand a better chance if they were to outpace the competition by bringing the product to the market before the competition has the chance to develop a competing offering. Other benefits of early time-to-market have been found to include a higher degree of customer loyalty, an increase in the market share for the product, and a reduction in total product development costs [34–36].

In keeping with the best practices from an agile philosophy, the BC considers the customer as a co-innovator of the product, since the startup would consult with the customer during the validation stages. This kind of "co-innovation" improves product/solution acceptability and, therefore, improves the chances of business success [37]. Continuous improvement is at the center of such a validation cycle, ensuring that the evolving product always caters to the customer's needs.

3. Research Methodology

The goal of this research work is to present a process-driven, easy-to-use approach to business model development and innovation with a focus on key success factors (as defined by the triple cornerstone framework), one that overcomes the shortcomings of previous lean-based business modeling frameworks. The research methodology can be outlined as shown in Figure 2. Many lean-based business development frameworks have been proposed, such as the lean startup framework by Ries [15] and the BMC by Osterwalder and Pigneur [16], to guide startups in their business model development journey. As part of this work, the existing literature was reviewed to uncover the challenges faced when using these lean-based frameworks, with the aim of business model development and innovation for software startups. Some of the challenges include the lack of certain elements, such as a strategic foundation for startups, the establishment of a unique selling proposition (USP), taking into account competing entities as part of the business model development and innovation process, the consideration of synergies of the various segments of the business model and the benefits of identifying and using metrics as part of business model development. The reviewed literature is also used to design a new framework for business model development and innovation, with the aim of overcoming the shortcomings of existing frameworks. The proposed framework takes into account key success factors (identified as a part of the triple-cornerstone framework) to ensure that the focus of the framework is directed toward ensuring the success of the software startup. To test out the validity of the framework, a software application or tool is designed and prototyped with the aim of gathering feedback from users. The feedback is collected in the form of end-user surveys and the model is assessed using the (quantitative) data collected as the outcome of these surveys.

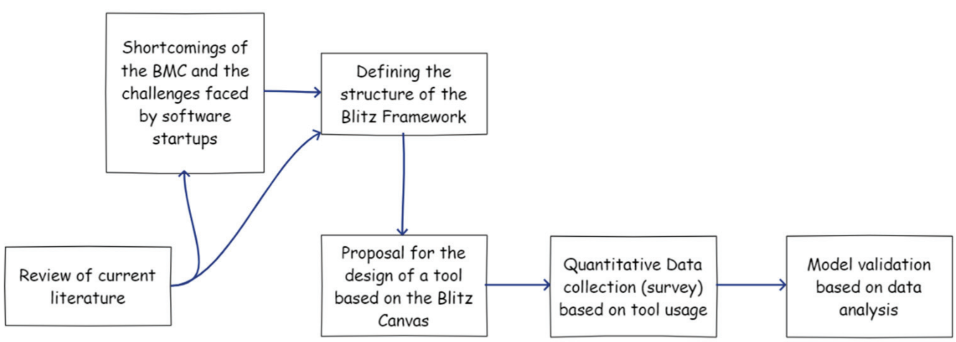

Figure 2. The research methodology.

The major questions that this research work attempts to answer are:

- RQ1: Could an easy-to-use, process-driven framework be proposed to aid in business model development and innovation for software startups around a product concept?
- RQ2: Would the resultant framework provide a foundation for the rapid development of the business model for a clearly differentiated value proposition, while keeping in mind the management of startup capital?
- RQ3: Could the proposed framework be designed to address the shortcomings of the business model canvas outlined in Section 2.3 of this work?

4. The Blitz Canvas—A Proposal

This research proposes the blitz canvas (BC) framework as a model to overcome many of the shortcomings outlined in Section 2.3 of this work. The framework places a focus on the foundation of the startup by identifying the key strategic elements, as part of the early sections of its structure. The framework provides a more holistic perspective for a conception of the value proposition by contrasting the proposed offering with that of competing entities in the market and the establishment of key differentiator(s). This approach stands in contrast to the siloed approach of most product and business development frameworks. As part of its structure, the proposed framework encourages the identification of key metrics to track various aspects of the product and business development process. The overall framework provides a synergistic and process-driven approach to business development.

By design and intent, the BC is structured to help the user focus on a single perspective in the business development process at any one point in time, at the same time maintaining focus on the broader perspective. The idea is not unlike the one used in *Six Thinking Hats* by Edward de Bono [38]. When one perspective is worked on, all considerations are seen only from that particular perspective. A high-level, conceptual view of the perspectives is shown in Figure 3. The process-driven nature of the BC helps the user to keep track of the current state of progress of business model development and innovation, while at the same time providing context to the development activities with regard to the overall purpose of the business.

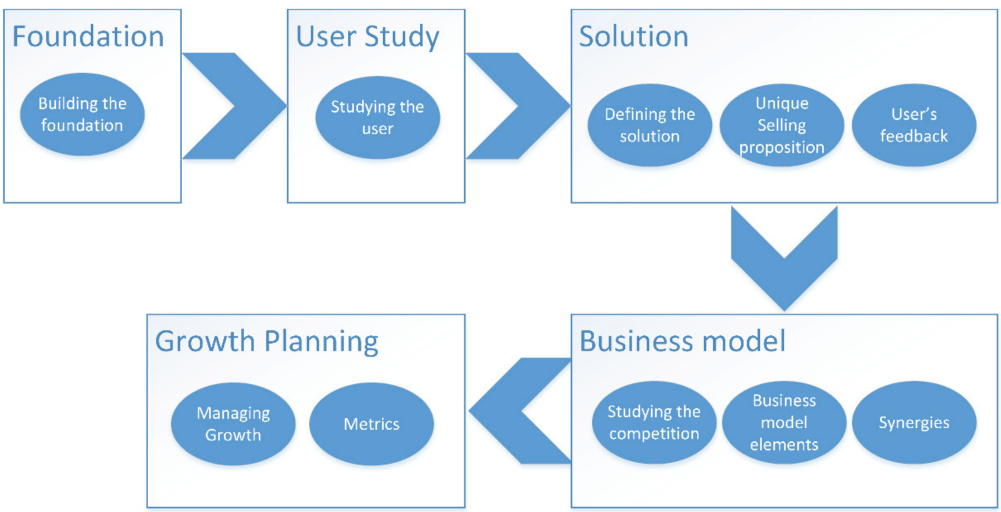

Figure 3. The stages of the blitz canvas framework.

The high-level conceptual view is further broken down into ten stages. This is performed in order to guide the user through the process of business model development while making sure that the complexity associated with the process is reduced by including smaller, numbered steps as part of any single stage. Each stage is divided into sequential steps that the user can follow to complete each stage and begin the next. The sequence of steps primarily serves as a guideline rather than a strict protocol. Hence, the user adopting the framework is encouraged to modify the suggested sequence of steps in the framework to suit their own needs and workflow.

4.1. Stage 1: Building the Foundation

The foundation of an organization begins with establishing the purpose of its inception and continued existence. The first stage, therefore, involves the formulation of the strategic purpose for the startup. The stage starts with the establishment of a mission and vision statement. As a part of the strategic planning process, the mission is considered to be the first step [39]. A clear definition of the term "mission" was provided by Alt and Zimmerman [40], who described it as follows: "a high-level understanding of the overall vision, strategic goals and the value proposition including the basic product or service features". The mission helps the startup group understand why it exists, while the vision conveys what the startup wants to achieve in a finite duration of time. Maurya [41] highlights the importance of the vision from the perspective of the overall business and suggests that steps should be taken by the business to identify and establish it. Breaking down the vision into individual goals can make it easier to achieve. Goals provide insight into what needs to be done to achieve the vision, after starting out with the establishment of the mission. In fact, defining one or more clear goals along with clear time frames can make it easier for businesses to achieve their vision [42]. These foundational elements are deliberated upon since they provide a general direction for the value delivered to the customer and the growth to be expected in that market [43].

The foundation layer also describes the core culture of the startup, which outlines how tasks are accomplished, with an emphasis on best practices. This is because of how the startup functions; the nature and quality of the outcome and its general evolution are impacted by the organizational culture, which is determined and established during the initial phases of the startup [44]. Lastly, the core competencies of the startup team are also noted during this phase, since identifying these can be vital for the startup's success [45,46]. This would involve listing what skills are needed to accomplish key goals (along with the overall vision) and outlining which skills the startup currently has. Core competence can be a good indicator of which tasks the organization can perform in-house and which tasks the organization can consider outsourcing [47]. As an instance of this, Apple has claimed that its core competence of good design has provided it with a competitive advantage [48]. The identification of core competencies can translate into becoming a sustainable competitive advantage for organizations [49], and certain competencies could be particularly relevant during the early stages of the startup's journey [50]. Establishing these details before delving into the business model can provide much-needed direction for the business in times of uncertainty (such as market turbulence) and help guide the development of future products. As part of this stage, these details are discussed and noted. The elements of this stage are presented in Figure 4.

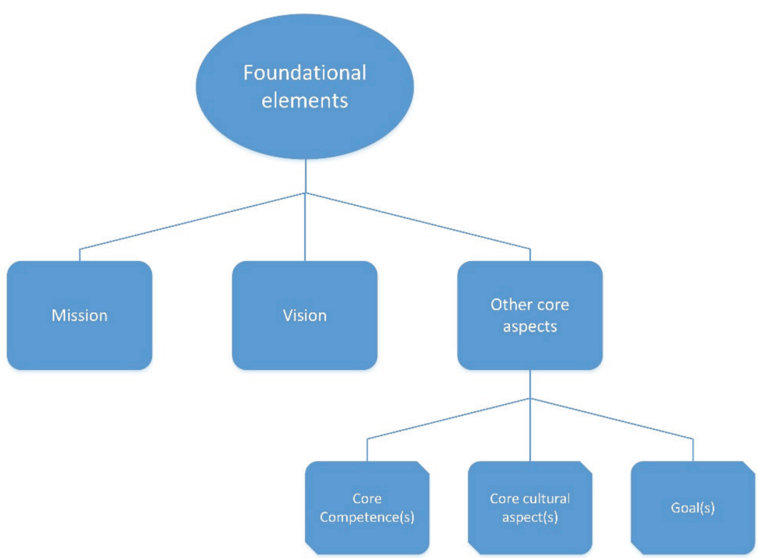

Figure 4. Blitz canvas—foundational elements.

4.2. Stage 2: Studying the User

The establishment of the foundation is followed by a study of the user, who they are and what are their goals, frustrations, and motivations. These details can be outlined by working on a user persona, as applied in the lean approach. In essence, a persona includes a detailed, articulate description of a fictional customer, along with a fictional narrative of that customer, who is seen as a representation of the target customer base [51]. The description can include demographic, behavioral and psychographic details, along with the needs of the user [52]. Other details include goals, frustrations, and motivations along with their personality traits, etc. The details that go into the persona are derived from user interviews and observations of the user's interactions with the system [53]. A user persona is used primarily because startup organizations and small teams rarely have the resources required to commit to large-scale user studies. In such cases, the focus on one or a few fictitious individuals (derived from user research) who can represent the user base and possess common character traits of that user base can prove to be more effective in any study of the user.

The user can also be the subject of study during the phase when requirements are captured. A common methodology for requirement capture is the user stories technique that was popularized by Cohn [54], since it enables businesses to work collaboratively with the customer. User stories are also popular, owing to their ability to capture requirements in a simple non-technical format and their flexible nature [55]. As outlined by Cohn [54], the essential details of the requirements that are captured include who has a requirement, what features the user expects from the solution and why this requirement is considered necessary or important by the user. Owing to this format, user stories can also provide valuable information on the user's goals and their role in the system of which they are a part. They also detail the functions or features that the user would anticipate will be included in the value proposition provided to them. Establishing user personas beforehand can reduce rework when working on user stories since the goals of the user are clearly defined as part of the user persona. A high-level perspective of the user study stage is shown in Figure 5.

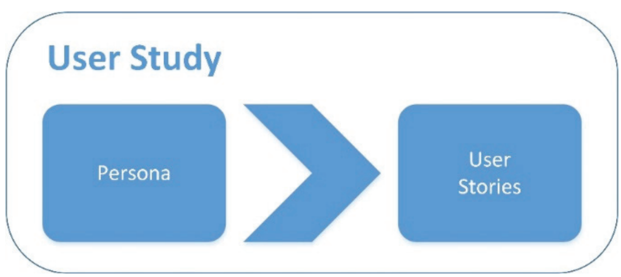

Figure 5. Blitz canvas—user study.

4.3. Stage 3: Defining the Solution

The product goals are then defined for the solution concept, based on the study of the user. As outlined by Betta et al. [56], a successful outcome for product development undertakings becomes more likely when the goals are defined clearly. The defining of goals is also outlined as a best practice in the product development literature [57,58]. The primary purpose is to ensure that the goals of the product are in line with the mission, vision and goals of the organization, as suggested by Barczak and Kahn [57]. Alongside the product goals, product features are determined. The user stories from the previous stage can serve as good indicators for identifying the desired features. This is because at least one feature is captured as a part of every user story [59]. User stories, owing to their simplistic format of requirements capture, have sometimes been accused of lacking contextual clarity [60]. To overcome this, a description of the product feature can be captured alongside the feature itself. The defined features are also prioritized using MoSCoW analysis, which is a commonly adopted technique in the agile school of methodologies [61,62]. As part of this prioritization technique, the feature sets are classified based on "Must-have", "Should-have", "Could-have" and "Won't-have" features. The prioritization and decision-making process to determine which features need to be included when working with an iterative development methodology is known to be a challenging task [63]. Handling this as part of this stage could allow the development team to prioritize the features optimally for the development process.

A wireframe-based prototype of the solution is created based on the shortlisted set of features. The wireframe itself should initially be low-fidelity in nature and iteratively evolves into high-fidelity wireframes [64]. This is because low-fidelity wireframes are essentially devoid of graphics and resemble simple pencil sketches of a working application, which are important for initial user feedback. The lack of graphics or colors will ensure that the focus of user interaction and feedback remains on the workflow of the application [65]. With this approach, the feedback collected will be related to this workflow, rather than users rejecting the application, for instance, because they did not like the color scheme.

However, since this framework deals with business model development and innovation of the product concept, it is assumed that the product has already undergone an evolution from low to high fidelity and, therefore, will use the evolved high-fidelity prototype for the purpose of gathering user feedback. High-fidelity prototypes possess similar visual traits to the intended completed product [65], which can provide the users with a "hands-on" feel for the completed product and can help with the gathering of relevant feedback. The wireframes are created with the purpose of collecting feedback from potential end-users during the later stages of this framework.

4.4. Stage 4: Unique Selling Proposition

Any proposed solution has a greater chance of standing out, gaining customer interest, and capturing market share when there is a defined, unique selling proposition (USP) associated with the product. A USP can serve as a product differentiator, which is considered one of the most critical success factors for a given product [66], and, in turn, can impact the success of a startup. Maurya [41] acknowledges the need for an unfair advantage, which he defines as one of the structural elements of the lean canvas, as either an asset or feature that competing providers will not easily be able to replicate. The consideration, identification and inclusion of a USP or unfair advantage can provide a form of defense against the competition and new entrants to the field [67].

The key customer touchpoint is also determined during this stage so that the solution concept can identify the most critical interaction, wherein the introduction of a solution can resolve the user's primary pain point. As the development of the value proposition (in the form of the solution) is an ever-evolving process, the needs of the users can be studied during various stages of the product development life cycle. As part of that effort, the various points of interaction when a user comes into contact with the solution can provide valuable insight to the team regarding the needs of the user [68]. These are known as touchpoints and can inform the development team on how the product is being used, along with details that can serve as inputs to the evolving design and development process [69]. This stage encourages the development team to highlight how the solution will help leverage the customer touchpoint and what the anticipated impact of such an intervention might turn out to be.

4.5. Stage 5: The User's Feedback

The solution concept, which was formalized as a wireframe in stage three of this framework, is validated via the collection of user feedback. Potential and prospective users are provided with the interactive wireframe sequence and their feedback when using the solution concept is recorded. The recorded data that is collected is qualitative in nature and is collected with the aim of informing the development team of the usefulness of the current application. Blank and Dorf [31] recommend the gathering of qualitative feedback first, as it provides more clarity regarding the perceptions of the user regarding the product. Furr and Ahlstrom [70] support this approach and recommend the gathering of quantitative data after qualitative feedback. The collected feedback also assists the development team in the decision-making process [71], such as prioritization for the next set of planned features for future iterations of the product. The process from stages three to five is represented in Figure 6.

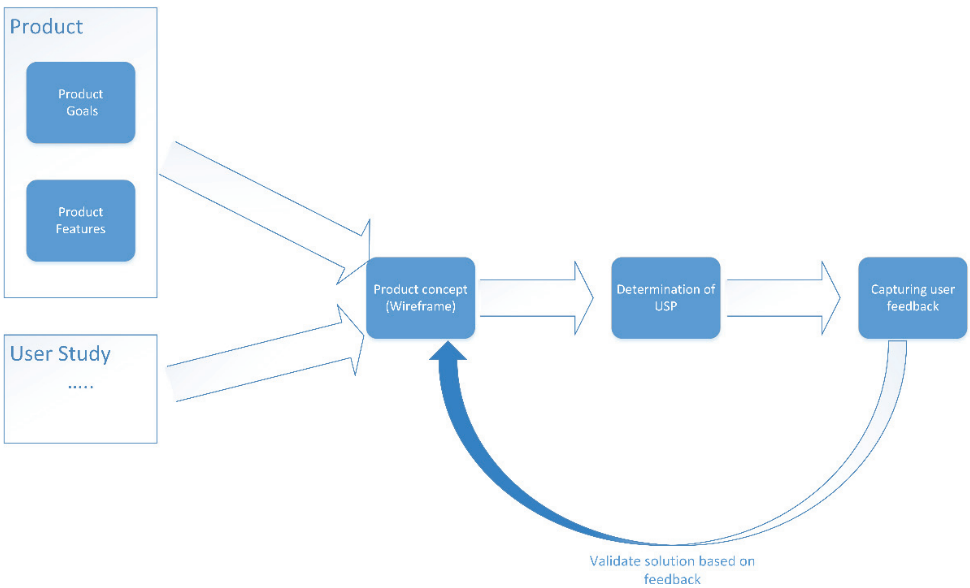

Figure 6. An overview of the solution development process.

4.6. Stage 6: Studying the Competition

A study of the current competition is performed to identify how the market offerings cater to the pain points of the users. Although it is not utilized very often and is a comparatively newer process, the study of competing entities can provide insight into user needs [72] and can contribute to developing better products in a number of ways. Firstly, they can point to the status quo and the features that can help differentiate the startup's offering from that of the competition [41]. In certain cases, a study of the competition can serve as a good starting point for the conception of solutions [72]. A study of the competition can also help the startup to recognize the best time to perform a pivot [73], as well as potential partnerships into which they can enter [74]. However, in the current context, the central aim of this study of the competition is to contrast the current offerings with that of the competition, to improve the current offering by determining the base set of features and establishing a relevant USP.

4.7. Stage 7: Business Model Elements

In this stage, the business model elements are added to the framework. The business model elements included in this section are structured as per the BMC framework. Accordingly, a business model is developed based on a working product concept by creating a value proposition around the target customer segment(s). In order to eventually deliver the products to the customers, the startup gains the help of distribution channel(s). The acquiring, retaining and growth of the customers are planned to achieve this as a part of the customer relationship segment. Revenue streams are designed to monetize the business model, which is developed as a result of planned BMC. The key resources to help build the business are identified. Key partners are chosen to substitute for resources that are not available to the startup. However, the market in general, and potential customers in particular, need to be made aware of the existence of the solution developed by the business.

Key activities are also planned to raise awareness among potential customers via organizing or participating in events or conferences relating to the domain of the solution. The cost structure is built accordingly, taking into consideration all the expenses incurred in the remaining segments and the revenue streams. The segments until this point are congruent to the original BMC, as shown in Figure 1. The BMC framework was the preferred base for the selection of the business model elements, due to its structural simplicity and speed. Although certain shortcomings of the BMC have been identified earlier in Section 2.3 of this work, the BC framework is designed to overcome many of these shortcomings.

In addition to the BMC elements, intellectual property (IP) assets that can be protected by the business are identified. Securing their IP assets enables startups to maximize the value captured from the solutions and products that they develop [75], and the strategic utilization of these assets can serve as a competitive advantage to the organization [76]. Although many startups cannot afford to apply for certain IP assets, such as patents, they might still benefit from protecting other IP, such as copyright or trade secrets. There is evidence to back up the claim that IP assets (other than patents) such as trademarks, trade secrets and copyright have been found to be useful to manage competition in the present-day markets [77]. Identifying such assets at an early stage can help startups to protect their intellectual property and improve their perceived market value, making them more attractive to potential investors.

Apart from IP, startups can also benefit from identifying "As a Service" offerings, such as "Infrastructure as a Service" (IaaS), "Platform as a Service" (PaaS), or "Software as a Service" (SaaS), which can reduce costs and speed up the pace of product development. A decade ago, most software startups would have been required to build their own backend infrastructure if they wanted to offer certain useful features in their applications, such as user authentication or cloud storage. However, the advent of newer innovations, spurred on as a result of market demands, have created offerings that can provide a completely managed platform for the creation and delivery of software-based solution offerings [78]. These include service-based solutions, such as Microsoft Azure, Amazon AWS and Google's Firebase. These services can dramatically lower development costs, decrease the time-to-market for products, and allow the development team to focus on building better user experiences rather than focus on the creation and maintenance of backend infrastructure [79]. SaaS offerings, such as Canva, can lower the barriers of entry for startups by allowing the startup teams to access valuable resources via more economical one-time or monthly costs [80]. Identifying these at the early stages can significantly improve the chances of success for startups since quicker development and deployment can result in faster instances of validated learning [81]. An overview of the business model stage (stage 7) for the BC is shown in Figure 7.

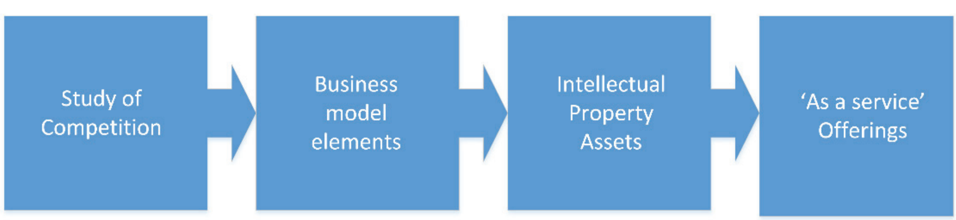

Figure 7. An overview of the business model stage.

4.8. Stage 8: Synergies

One of the identified shortcomings of the BMC was that the model did not have a provision for the identification of synergies between the various segments of the business model [30]. The business model development process is a complex phenomenon, with interdependencies within its various elements or sections [82]. Synergies involve two or more sections of the business model working together to provide more benefits to the business than they could offer on their own to the startup. The identification of synergies can lead to a reduction in costs and a simplification of workflow [83]. For instance, the customer relationship segment can use the data from publicly provided customer reviews of the product to inform the future development of the value proposition. As part of this stage, the synergies are noted for implementation as part of the business process.

4.9. Stage 9: Managing Growth

After the solution concept has been validated by the customer and the solution is developed in an iterative manner, the planning phase should focus on handling the growth (and related aspects) of usage of the services associated with the product. Planning in advance how this growth will be handled can be beneficial to the development team. The customer development methodology by Blank [1] states that startups are in a state of "search" for a business model that works and that will remain in that state until they find one that can scale and is repeatable and profitable. The lean startup methodology, on the other hand, recommends going for scale only after the product-market fit has been identified [15]. Potential strategies for handling growth, however, are noted as part of this section, in anticipation of the product's eventual growth in adoption and usage.

Along with the management of the growth of the existing solution, additional complementary offerings (to the core offering) can be initiated by the startup to create product ecosystems. Organizations can garner significant benefits from either creating or becoming a part of such ecosystems [84]. The idea of additional complementary offerings is that at some point of iterative solution development, some user stories may be vital to resolving key pain points but may not fall within the scope of the current solution. In such a case, based on the success of the core offering, it would be ideal to develop newer solution offerings that can provide features complementary to the core solution [85], offering a seamless user experience. This can potentially lead to multiple product concepts forming an ecosystem of complementary product offerings, which could also serve as a source of competitive advantage [86].

Having multiple product concepts around the core product offering provides the startup with another advantage in the form of multiple potential directions to explore, should the core product concept fail the test of validation with the customer. As pointed out by Steve Blank [1], few value propositions or business models survive the first contact with the customer. Hence, identifying multiple potential product concepts can provide the team with additional ideas to test out, and to quickly change direction if the core product concept fails to provide enough value to its intended audience, while at the same time working within the user's problem field (as guided by the mission). As part of this stage, a list of such potential solution concepts is brainstormed for review and possible future development efforts. A high-level view of the areas of growth in focus is shown in Figure 8.

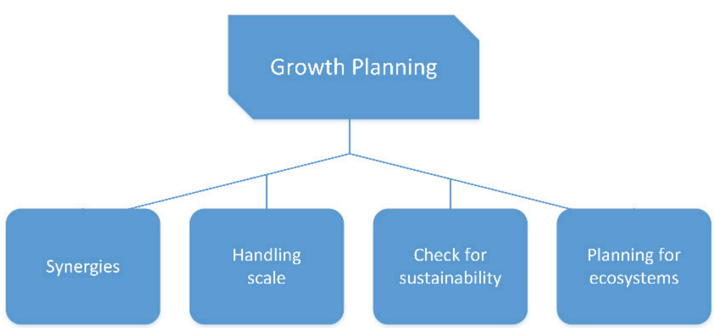

Figure 8. An overview of the business model phase.

4.10. Stage 10: Metrics

Metrics are identified in this section of the framework to track the performance and progress of the various sections of the business. However, gathering metrics that are indeed useful for the intended purpose of measurement to track progress can be tricky, as there are many situations where the team can track incorrect and vanity metrics [87]. These metrics will not provide sufficient information to suggest actionable steps and, therefore, might not be useful to the startup. There are many metric frameworks that provide a basis for collecting metrics at a general level, such as Google's HEART framework, GSM and lean analytics [88,89]. The issue with most frameworks, however, is that they place emphasis on growth and the related aspects of startups. The product and business development fields are not the subject of focus in most frameworks.

The BC primarily identifies one north-star metric, which is intended to serve as a single-point guide for startups. The idea is that since most startups do not have enormous resources, they will benefit if they focus on trying to impact a single critical metric rather than trying to move multiple non-critical ones [90]. In addition, the startup can choose to identify a range of additional metrics for the purpose of tracking performance and quality. To provide a holistic structure to achieve this, the MESOPS model for metric determination, developed by Shanbhag and Pardede [91], was integrated with this section, owing to its consideration of the multiple aspects of both product and business development. The MESOPS model encourages the identification of metrics for the problem and solution spaces, evangelism, scale, evolution and ecosystem aspects of the product and business models (dimensions presented in Figure 9). The MESOPS model, therefore, takes an end-to-end perspective of the metric identification process, which covers a wide range of areas to determine the useful metrics to track and measure.

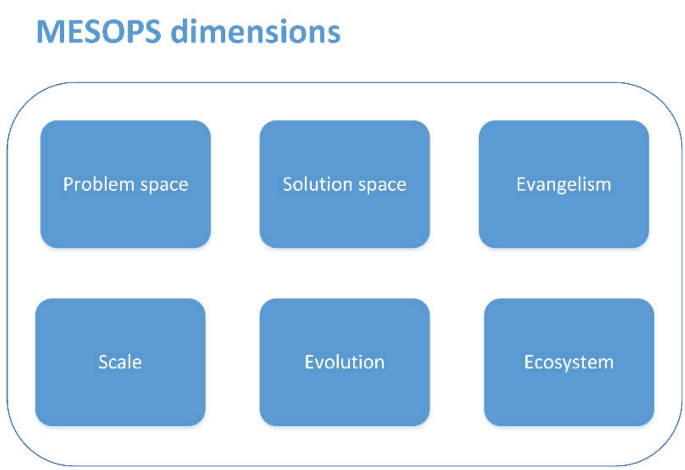

Figure 9. Dimensions for the determination of metrics as per the MESOPS framework.

5. Analysis and Evaluation

This research reviews the usefulness and effectiveness of the proposed BC framework through the use of an online survey instrument. For the purpose of evaluation of the model's effectiveness, a web-based tool named iVenture (link to the iVenture app prototype used for the purpose of concept validation survey: https://iventure-v1.web.app/Bcprocessmodel, accessed on 1 February 2022) was created to take the participants through the ten stages and then present the business model in the form of a dashboard. A survey was conducted based on the interactions with this tool. To reduce the cognitive load of the participants, a business model was created around a fictional to-do list product called "MyToDo", which is aimed at helping users to improve their productivity by improving their task-management skills. The participants are taken through the process of business model development using the tool and are then requested to answer the questions put forward in the survey. Essentially, the tool presents the users with a pre-built business model for them to interact with and lets the users get a feel for the process of business model development and innovation, using the framework step-by-step through its various stages. Figure 10 shows an overview of the process that the framework uses to develop the business model. From this screen, the participants will need to traverse through the various stages, guided by an application interface, upon completion of which process they will be presented with the business dashboard. Figure 11 shows the developed business model, presented in the form of a dashboard.

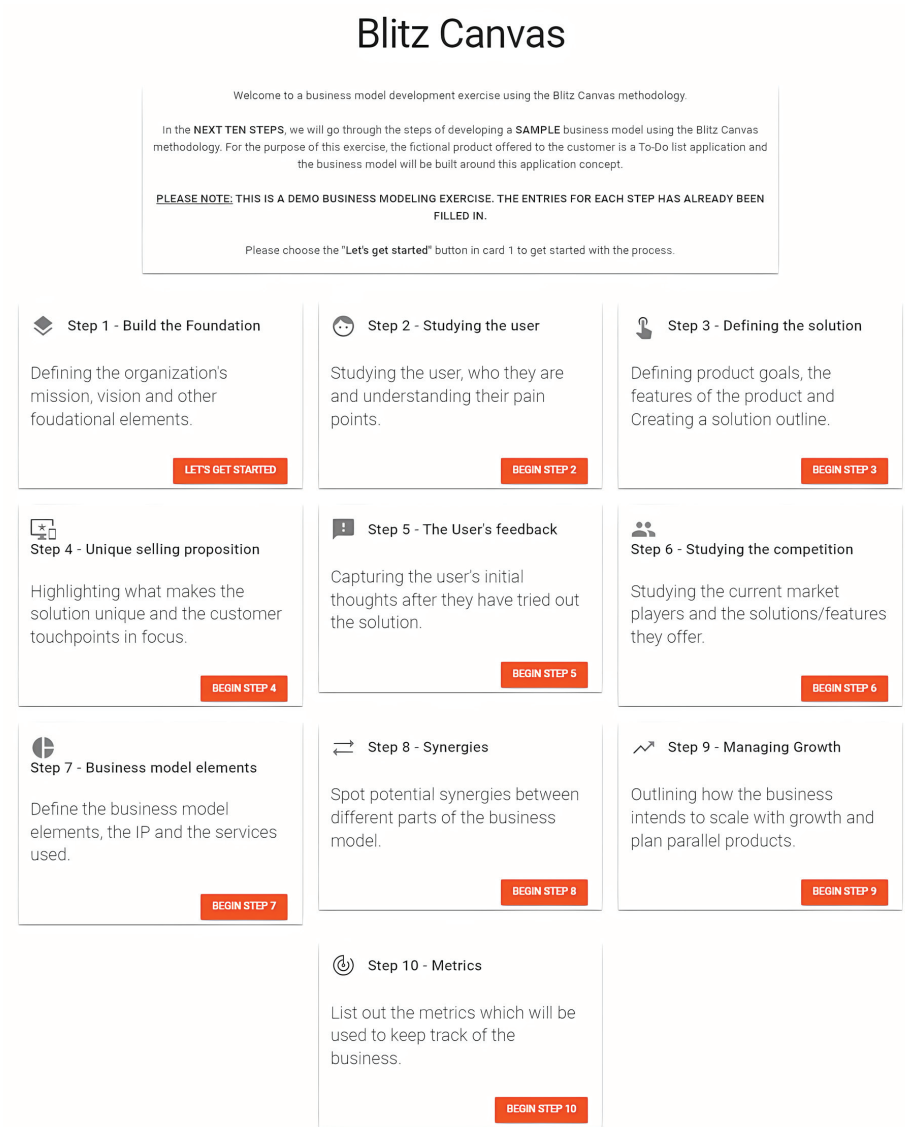

Figure 10. Process flow for the web tool, based on the blitz canvas.

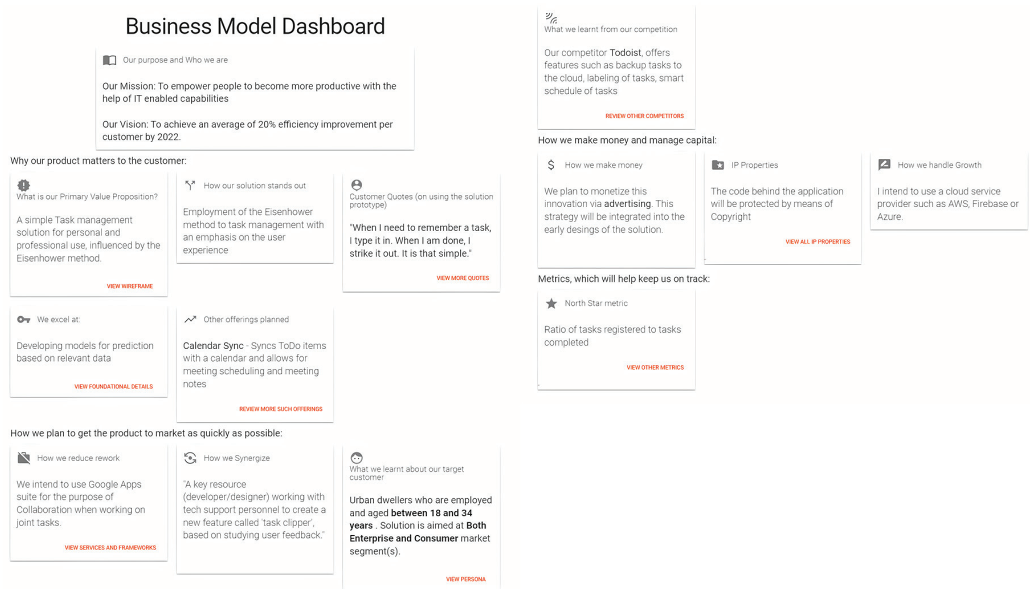

Figure 11. The developed business model, presented as a dashboard.

5.1. Exploratory Analysis of Survey Data (Evaluation)

This section discusses the results of the survey conducted as part of the evaluation of the proposed BC model. The respondents of this survey included students enrolled in a course with entrepreneurship being one of the subjects at La Trobe University and recent graduates from the professional social networking website, LinkedIn. As the target audience of the proposed framework is inexperienced entrepreneurs and first-time startup teams, students and graduates who enrolled in this course and thereby expressed an interest in venturing on the entrepreneurial journey were identified as the ideal audience for the validation efforts of the framework. The survey instrument was developed using the Qualtrics tool and was sent to the students via email, then shared with the recent graduates via LinkedIn. The survey was conducted after being granted permission from the Human Research Ethics committee at La Trobe University.

5.2. Survey Structure

The survey structure contained 10 questions and was distributed in two sections. A URL of the hosted web tool was shared with the participants. The first page of the web tool contained an overview of the tool and instructions on how to access the survey, after going through the tool's functions. The questions included in Section 1 addressed the queries relating to startup success factors (time-to-market, product differentiation and the optimal usage of startup capital) and the shortcomings of the BMC. Section 2 validated the speed and ease of use of the process-driven nature of the tool, using which method the business model was developed. For Section 1 (Q1_1 through Q2_5), the questions were structured as statements and the user was asked for their level of either agreement or disagreement with the statement made. For the single question in Section 2 (Q3_1), the question was worded as a question rather than a statement. For both sections, the options provided a range from strong agreement to strong disagreement. The options presented in the seven-point Likert scale include Strongly Agree, Agree, Somewhat Agree, Neither Agree nor Disagree, Somewhat Disagree, Disagree, and Strongly Disagree. Any value between Strongly Agree and Somewhat Agree is considered to be a valid positive response. The relationship between the research goals and the questions presented in the survey are discussed in Table 2, while the shortcomings of the BMC mapped to the survey questions are shown in Table 3. The survey questions, along with the pertinent descriptive statistics, are presented in Table 4.

Table 2. Relationship between the aims of this research to the SQs.

Research Questions (RQ)	Corresponding SQ
Could an easy-to-use, process-driven framework be proposed to aid in business model development and innovation for software startups around a product concept?	SQ1_1, SQ3_1
Would the resultant framework provide a foundation for rapid development of the business model for a clearly differentiated value proposition, while keeping in mind the management of startup capital?	SQ1_2, SQ2_2, SQ2_4, SQ1_3, SQ3_1, SQ1_4
Could the proposed framework be designed to address the shortcomings of the business model canvas outlined in Section 2.3 of this work?	Addressed in Table 3

Table 3. Mapping the shortcomings of the BMC to the corresponding SQs.

Shortcomings of the BMC	Corresponding SQ
Formulation of strategic goals or objectives of the startup (Kraaijenbrink, 2012 [28]; Spanz, 2012 [30]), consideration of competence for solution development (Spanz, 2012 [30])	SQ2_1
Establishment of USP (Maurya, 2010 [29])	SQ2_2
Consideration of competing entities from the market (Kraaijenbrink, 2012 [28])	SQ2_4
Consideration of synergies within the BMC (Spanz, 2012 [30])	SQ2_5
Taking into account performance measurement using metrics such as KPIs (Spanz, 2012 [30]; Maurya, 2010 [41])	SQ2_3

Table 4. Survey questions and corresponding descriptive statistics for all sections of the survey.

Survey Question (SQ)		N	Min	Max	Mean	Std. Dev
SQ1_1	The tool provided a step-by-step pathway for the startup to create a business model from start to completion around their product idea.	174	1	7	6.14	0.91
SQ1_2	The dashboard clearly presented the information, with a focus on why the product should matter to the customer/end-user.	174	1	7	5.94	1.06
SQ1_3	The dashboard clearly presented the information, with a focus on getting the product to market quickly.	175	1	7	5.82	1.14
SQ1_4	The tool covered the required areas needed to build a good business model.	174	1	7	6.01	1
SQ2_1	The tool helped gather information regarding the strategic aspects of a startup, such as the mission of the startup.	175	1	7	6.04	1.04
SQ2_2	The tool clearly highlighted the unique selling proposition (USP) of the product.	175	1	7	5.88	1.08
SQ2_3	The tool helped collect metrics to measure various aspects such as the growth of the startup.	173	1	7	5.91	1.02
SQ2_4	This tool made it easy to gather information regarding competing products and study them.	174	1	7	5.82	1.13

Table 4. *Cont.*

	Survey Question (SQ)	N	Min	Max	Mean	Std. Dev
SQ2_5	Using the tool, synergies between business segments could be captured.	174	1	7	5.88	1.04
SQ3_1	Creating the business model using the tool was a quick and easy process.	173	1	7	6.02	0.9

5.3. Responses and Survey-to-Research Question Mapping

Overall, the survey request was accepted by 209 respondents. After preprocessing and filtering out incomplete survey responses, 175 responses were retained and used in the analysis process. Python and Orange data-mining software were used to carry out the analysis process. Table 2 presents the corresponding survey question/statement (SQ) for each of the research questions (RQs), while Table 3 presents the mapping of the SQs to the shortcomings of the BMC, as listed in Section 2 of this work. The response of each participant, based on the frequency (count) for each option, is presented in Table 4.

Table 4 presents the descriptive statistical information pertaining to the responses collected to the survey questions. Survey questions SQ1_1 and SQ3_1 assess the process-driven nature and the ease of use of the framework, along with its effectiveness in developing the business model from start to completion. Around 94.86% of the respondents (with a mean score of 6.14) agreed that the tool provided a step-by-step pathway for startups to create a business model, from start to completion, around their product idea, while 94.83% of the respondents (with a mean score of 6.02) agreed that creating a business model using the tool (and by extension, the framework) was a quick and easy process.

Survey question SQ1_2 assessed the ability of the tool to clearly define the differentiator for the value proposition. In total, 91.53% of the respondents (with a mean score of 5.94) agreed that the dashboard produced by the tool clearly outlined why the product should matter to the user, which implied the direct indication of a product differentiator. Additionally, survey questions SQ2_2 and SQ2_4 also highlighted additional information regarding the product differentiation aspect of the product and business model. In fact, 89.15% of the respondents (with a mean score of 5.88) agreed that the tool clearly highlighted the USP of the product or value proposition. Around 86.78% of respondents (with a mean score of 5.82) agreed that the tool made it easy to gather information about competing products and study them.

The aspect of making a quicker time to market part of the framework was assessed by survey question SQ3_1, where 94.83% of respondents (with a mean score of 6.02) agreed that creating a business model using the tool (and, by extension, the framework) was a quick and easy process. The optimal usage of capital was assessed by question SQ1_4, to which 92.53% of respondents (with a mean score of 6.00) agreed that the tool covered all the required areas to build a good business model. This assessment directly relates to capital because a good business model converts acquired capital into economic value [19], irrespective of whether the type of capital being referred to is financial, physical or intellectual [92]. In fact, a business model demonstrates how it makes use of these different forms of capital to generate value [92]. Hence, a good business model is a good indicator of the optimal usage of the said capital.

The tools addressing the shortcomings of the BMC were assessed by questions SQ2_1, SQ2_2, SQ2_3, SQ2_4 and SQ2_5. One of the shortcomings of the BMC (noted in Section 2.3 of this work) was the absence of strategic goals/objectives or considerations of competencies being formulated as part of the core BMC structure. SQ2_1 assessed this ability of the tool, with 92.61% of respondents (with a mean score of 6.04) agreeing that the tool helped gather information regarding the strategic aspects of the startup. SQ2_2 assessed the ability of the tool to clearly highlight the unique selling proposition, with 89.15% of the respondents (with a mean score of 5.88) agreeing that it did so. In total, 86.78% of the respondents (with a mean score of 5.82) agreed that the tool made it easy to gather information about competing products and to study them (question SQ2_4). Similarly, 88.51% of respondents (with a mean score of 5.88) agreed that when using the tool, synergies between business segments could be captured (question SQ2_5). Finally, question SQ2_3 assessed the ability of the tool to identify metrics to measure various aspects of the startup, such as growth, wherein 89.01% of the respondents agreed that it did (with a mean score of 5.91). The graphical representations of the SQs can be seen in Figures 12–14.

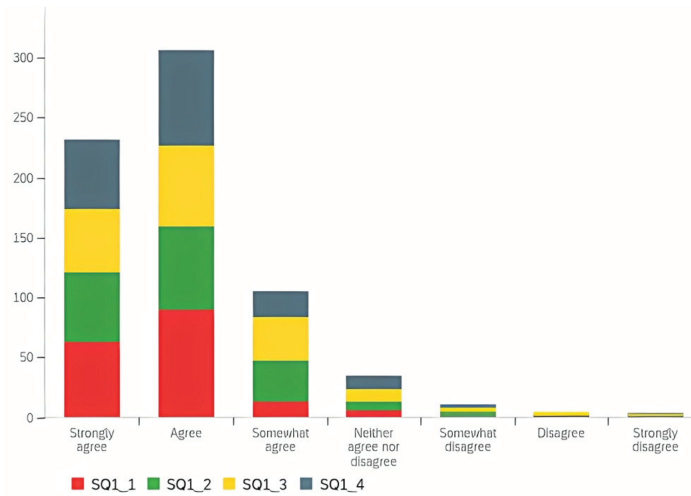

Figure 12. Graphical representation of the survey results for Section 1.

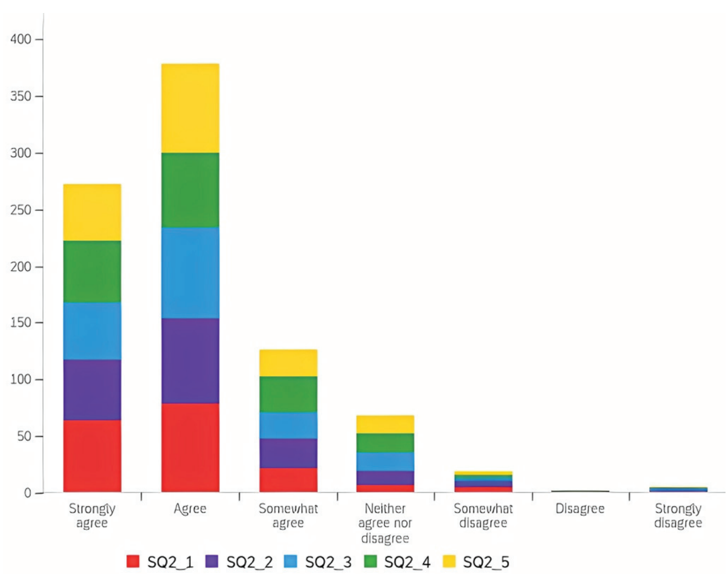

Figure 13. Graphical representation of the survey results for Section 2.

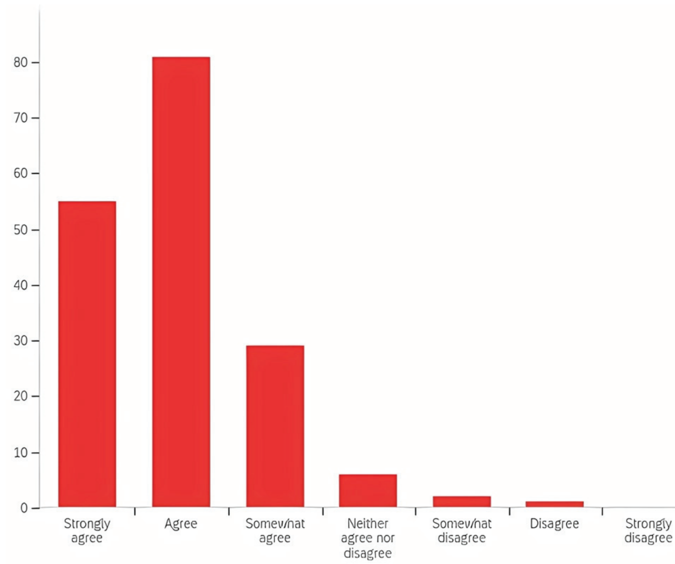

Figure 14. Graphical representation of the survey results for SQ3_1.

On the subject of mean and standard deviations for the survey areas, most of the questions elicited a standard deviation scoring of between 0.9 and 1.14, which would imply that most respondents had opinions similar to one another, with a high level of agreement persisting among the respondents. As per the presented results in the previous sections, it can be clearly stated that the tool and, by extension, the BC framework, provided an easy-to-use, process-driven framework for business model development and innovation for aspiring software startups, which addresses the shortcomings identified in the BMC framework. It also indicates that the BC framework takes into account critical success factors defined in the triple cornerstones model (the presence of product differentiation, quicker time to market and the optimal usage of startup capital).

6. Literature Analysis on the Contributions of BC

Much of the research conducted in this domain has focused on vertical in-depth aspects of individual core dimensions of startups. Instances of this can be seen in work performed from the process perspective, such as agile-based processes for developing products or the business perspective for developing the overall business models [15,87]. This includes research leads with a technical or product-related viewpoint. Most such research undertakings do not provide a clear pathway for startups to go from conception to the realization of the startup idea. The current work proposes a high-level process-driven framework with which entrepreneurs can take their product ideas from the concept to business model realization.

The blitz canvas is structured to overcome the shortcomings listed in Table 1 and in Section 2.3 of this work. In stage 1, the business objectives are established and the goals are listed, which accounts for the formulation of the strategic goals of the startup [28,30]. The potential synergies are identified in stage 8, which accounts for the consideration of synergies within segments of the canvas, which was another shortcoming noted by Spanz [30]. These synergies can serve as a trigger for identifying avenues for further product and/or service innovations. The key metrics listed as part of stage 10 provide an avenue for performance measurement using metrics, as noted by Maurya [41]. Maurya [41] also mentioned the establishment of a USP as a missing element from the original BMC, which is covered as part of stage 4. The key differentiators are identified in part when studying the competing offerings in stage 6 of the blitz canvas, the consideration of which was noted as a shortcoming by Kraaijenbrink [28]. The study of the competition can further help the organization with a better market positioning of the product and value proposition. Innovation competence, which is noted as another area that needs improvement in the BMC by Spanz [30], is handled in multiple stages of the blitz canvas, starting right at the beginning of stage 1. The identification of core competencies lists the skills available to the startup at inception, and "As a Service" products are sought out in areas where skills or competencies are lacking.

Another central aspect of the blitz canvas is its embedded focus on the important aspects of startup success, such as time to market [36] and product differentiation [93]. The importance of being early to market cannot be understated for startups, as startups do not have the financial or marketing resources to compete with established players [94,95] who have resources in abundance. In such cases where the startup manages to get products out early to the market, resources that would otherwise be spent on marketing (or other activities that raise customer awareness of the product) can now be spent on creating better products or to improve the services built around the existing product. This is because, at an earlier timeframe, there is a higher probability that there is little to no competition in the market for the startup, which creates one of the most optimal circumstances for a product's success.

As discussed earlier, most startups do not have the resources to compete with established players in the market [94,95]. In such scenarios, apart from an early time to market, the best way to distinguish their offerings from that of the competition is to have clear product differentiation. In such cases, the startup positions its offering so as to not be in direct competition with presently established players and, therefore, allows customers to clearly see the differences in the value propositions between competing offerings and its own offering. The blitz canvas is structured in such a way that these factors are identified when working through the framework. For instance, the identification of USP during stage 4 is aimed at helping the startup to differentiate its offering from that of the competition. The selection of "As a service" products and components are leveraged to reduce the time it takes for the product to be built and for it to be released on the market. PaaS services can save startups an immense amount of time and work, as these services handle the technical details of the backend. The prototypes built based on low-/high-fidelity wireframes, along with user feedback (as part of stage 5) help to validate the assumptions that go into the product concepts so that the startup team can subsequently start developing the business model around the product.

The blitz canvas can also serve as a validation tool for the technical and business sections of the startup. The importance of validation has already been well established in both the product and business spheres [15,87]. Not performing validation at any stage would have a domino effect on the subsequent stages in the nascent phases of any startup. For instance, when considering a scenario where the context establishment for a product idea was not validated early on before development commenced, it would subsequently move into development and then the business model would be built around it. This would cost the startup far more to rework the idea at such a late stage, should it find that the developed product does not cater to the customer pain points. It would be far more cost-effective to spot inconsistencies and rectify the gap in the understanding of customer needs early on. In keeping with this finding, the blitz canvas focuses on the validation of the product concept before moving on to the development of the business model.

From the viewpoint of a skeptical investor, the startup is expected to show the progress of the business goals at regular intervals that are consistent with available funds [96]. The blitz canvas can also be adapted to support a goal-based approach to business model development (in the form of iterative business model development), on which the investor can assess the work done and measure it against defined goals (as part of stage 1 or the foundation stage). This can make it easier for the startup as well as potential investors to evaluate, over time, the progress that the startup is making toward reaching its established goals. This can help investors to make informed decisions regarding the startup, based on data. The research contributions of the blitz canvas include:

- The proposal of a process-driven model that serves as a roadmap for startups in its business model development and innovation efforts.
- The integration of the study of competing market forces as part of the business model development and innovation process, which can help with product positioning in the market.
- The creation of a foundational base for the startup by establishing, as part of the BM process, the entity's mission, vision, values and core competencies.
- Planning for potential synergies within business segments and future growth as part of the core business model innovation process, which can provide a platform for newer innovations in the form of products and services.
- The integration of metrics identification for tracking performance as part of the business model innovation process.
- A data-backed proof-of-concept to present the business model's planning details, with a focus on critical success factors, as defined by the triple-cornerstone framework by Shanbhag and Pardede [66].
- A demonstration of overcoming the noted shortcomings of the business model canvas for business model development and innovation, while ensuring a quick process for said development.

The scientific contributions of this work include:

- The traditional approach meets speed requirements and minimizes cost expenditure. In essence, this research explores the rediscovery of the usefulness offered by a more traditional approach to business model development, while at the same time mitigating its downsides, such as a delayed time to market and the higher costs associated with business model realization. The intent is to have a better understanding of and evaluate the advantages of a holistic approach to business model development rather than a lean approach, in the context of the usability of business modeling frameworks aimed at inexperienced or first-time entrepreneurs.
- The specialization of business model development toward a single industry sector. This research explores the potential to develop a business model development framework to better leverage the qualities of the software market. As indicated in the response to a previous question by a reviewer of this paper, most business model development frameworks are designed to be generic and are applicable across a wide variety of industries. While this can make it useful in many areas from manufacturing to healthcare, it comes with the cost of not leveraging the unique qualities of any one sector and helping the aspiring startup team to reach its potential by making use of key resources. Some examples of these qualities include the ability to quickly change direction by testing product concepts relatively fast, when compared to sectors such as transportation, manufacturing or healthcare, the ability to enter newer geographic market locations with a relatively small amount of effort and the ability to scale and capture a larger user-base by simply increasing the server bandwidth capacity.
- The encouragement of data-driven business model development. In addition to the previously mentioned points, business model development efforts are encouraged from a data-driven foundation. The question of the usefulness of leveraging data to guide decision-making in the business model development world has been discussed for many years. However, very few frameworks explicitly encourage their users to actively use metrics to help with such data-driven efforts. This research explores how a framework that leverages metrics to guide decision-making based on data would function. Besides the outlined contributions, this research evaluates the usefulness of a process-based approach vs. an open-canvas approach to business model development.

In addition to its research and scientific contributions, the proposed framework was created to adapt to the needs and the unique qualities of software start-ups, which were listed in the introductory section of this work. The corresponding stages of the framework that address the challenges/opportunities (as listed in the Introduction) include:

- Stage 3: Defining the solution, and Stage 5: User's feedback—These stages help guide the team's efforts toward rapid validation of the product concept by first creating an easily testable prototype, using low-fidelity wireframes (as part of stage 3), then collecting feedback from users based on their usage of these prototypes (as part of stage 5).
- Stage 5: User's feedback—At the end of the same stage, when feedback is collected from users, the startup team has the option to change direction if the feedback from the users indicates that the created solution does not solve the user's problem, or if the users generally do not see enough value in the solution that it might not be commercially viable to continue the development process.
- Step 9—Managing growth—The framework encourages the startup team to list possible steps that they can take to ensure they are prepared for growth and how they would manage a sudden increase in the number of users interested in the product offering.
- Step 4: Unique selling proposition, Step 6: Studying the competition, and Step 7: Business model elements—Since the barriers to entry in the software target market can be relatively low, identifying a unique value proposition can help software startups go a long way to retaining acquired and activated customers. Besides this finding, a study of the existing players in the market can also help to plan better strategies to develop and monetize the current product development efforts, along with saving resources by not having to "reinvent the wheel". Lastly, step 7 of the framework helps startup teams to identify possible intellectual property assets that they can leverage to gain an edge over the competition.
- Step 7: Business model elements—to help get the product to the market and into the hands of customers as quickly as possible, the blitz canvas framework encourages the usage of SaaS products that could include third-party components, "Software as a Service" products and rapid application development frameworks, to reduce the time taken to develop the product in question. This is a unique trait of the software target market and one that is leveraged by few business model development frameworks to achieve a quicker time to market, which, in turn, can be important to the success of the product and, in turn, that of the business model.
- Step 10: Metrics—The identification and the usage of metrics in monitoring the relevance of the solution to solving the customers' problems is crucial to the success of software products, as they can be modified after an initial version has been shipped to the customer. Identifying and using the right metrics to keep the solution relevant and useful to the customers can result in the continued success of the product; the blitz canvas framework helps software startups achieve this by incorporating metric identification as part of the core framework.

7. Conclusions and Future Work

The proposed framework provides an avenue for business model innovation for software startups by guiding the entrepreneur through a step-by-step process to realize their business model, along with the validation of the said model. The web-based tool created to help apply the framework assisted with the visualization of the business model, which, in turn, served as a platform by which to study the evolution of the customer problem, get the product to market quickly and plan for growth. Being competition-aware by nature, the framework helped identify key differentiators for the core value proposition, which could help in marketing efforts quickly and more efficiently. The consideration of synergies across business model segments and the identification of metrics supported the business model innovation process.

As indicated by the first research question (RQ1), the proposed model (BC) has been designed to integrate business model development and innovation around the product (concept) to create a seamless process-driven approach for generating business models for software startups. As reflected in the results of our analysis of the data (from questions SQ1_1, SQ3_1), the proposed framework holds its ground and shows promise of being an easy-to-use and process-driven business model development instrument that software startups can use to base their product concepts on.

When looking at the second research question (RQ2), the results of the analysis (SQ1_2, SQ2_2, SQ2_4) suggest that the tool (and, by extension, the framework) helped differentiate the offering with a focus on why the product in development should matter to the user, highlighting its USP when comparing it to the competition. The analysis (SQ1_3, SQ3_1) also suggested that the process of business model creation was quick and easy when performed using the tool and that the developed business model covered all the required areas (SQ1_4). Lastly, the results of the analysis (SQ2_1, SQ2_2, SQ2_3, SQ2_4, SQ2_5) outlined how the structure of the proposed framework addressed the shortcomings of the BMC (RQ3), which are outlined in Section 2.3 of this work.

This study contributes to the existing body of literature by providing a high-level process-driven framework for startups to develop a solution concept from an idea to a business model in the form of the blitz canvas. Aiding the process of business model innovation, the framework is based on a process-driven structure, with the provision to iterate as required. As part of the process-driven structure, practical and hands-on activities are proposed, such as creating wireframes, prototypes and validations. These are introduced at certain intervals at each stage of the model or framework. A tool was designed based on this proposed framework. The framework was then validated based on the analysis of the usage data of this tool, which was collected using a survey.

Another foundational consideration when developing the BC was that of certain success factors, such as the time to market and product differentiation. Multiple segments within the BC address these success factors, owing to the nature of their importance from the standpoint of startups. The BC has the potential to aid startups in getting their solution concepts off the ground within a short time frame. The proposed design of the tool demonstrates how a possible implementation of the BC concept could work and highlights the possible benefits of such a realization.

At this point, the framework is designed specifically for startups in the software sector. The adoption of the agile philosophy for (software) product development, the identification of platform and infrastructure-as-a-service components, the success factors assessed, and the metric framework adopted were all considered from the viewpoint of the software sector. In the future, these can be adapted to better fulfill the needs of other sectors, such as education or manufacturing. Additionally, in the event that application usage data is collected via an “opt-in” mechanism, machine learning can be used to suggest components, such as a suitable platform-as-a-service, possible areas of IP protection, and possible competing entities, among other fields, which are most suitable for the startup using the tool. Besides these attributes, the framework itself can be extended to include end-to-end product development, which can potentially result in a more holistic framework for software startups to go from product idea/conception to operational realization.

As scope for future study, a functional specification, along with metrics, can be identified for the blitz canvas to aid in the implementation undertakings of the proposed tool design and to study the effectiveness of the framework. The proposed model could also be used to work through a case study by applying the framework as part of the startup development process with an inexperienced startup team. Such an implementation should provide a wealth of insight into the benefits of the model and scope for improvement. Based on such an implementation, further opportunities for refinement can be shortlisted and another iteration of the model can be proposed.

Another scope for future work can be to implement the framework in multiple scenarios in organizations of various sizes, rather than being used by only startups. The principles applied as part of the blitz canvas can be useful to an organization of any size to bring a product idea to the market in a reduced time frame. As noted, the proposed model is crafted to take advantage of the unique qualities of the software and information technology sector, in terms of the startups' efforts with business model creation. Similar frameworks can be created to benefit startups working in other sectors, such as healthcare or transportation, wherein the framework can be created to take advantage of the unique traits of those sectors.

Finally, similar frameworks can be created to help software startups with other parts of their journey, such as product development, so as to help with the end-to-end startup development process. Such a holistic approach to startup development has the potential to lower the barriers of entry for inexperienced startup teams who might have a good product idea but who are unsure how to develop their concept and create a business model around it.

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DOCS: A Data Ownership Confirmation Scheme for Distributed Data Trading

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Abstract: Data assets trading can encourage owners to distribute data and achieve large-scale data aggregation to promote the development of the supply chain system. Blockchain is a promising platform for constructing a decentralized data marketplace. The data may face risks in the marketplace, such as illegal theft, malicious tampering, or illegal distribution in the transactions process. The data ownership confirmation in a blockchain-empowered marketplace has attracted much attention in recent years. However, challenges still remain, including maintaining data integrity, traceability of illegal data, and accountability. In this paper, we propose a new data ownership confirmation scheme (DOCS) in the transaction scenario of blockchain-empowered distributed data assets trading. It integrates smart contracts, data-embedding technology, and data fingerprint to realize ownership confirmation and protection of data assets in transactions. DOCS ensures reliable mapping between on-chain data ownership information and off-chain data entities, which assists with the accurate prosecution of the illegal distribution of data assets. We demonstrate that DOCS can have desirable security properties in multiple attack models.

Keywords: supply chain; data ownership; data asset trading; block chain; smart contract

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1. Introduction

The effective application of data helps enterprise supply chains achieve business process transformation and product and service innovation, and it helps to improve supply chain operations. Enterprises wanting to maintain their competitive advantages must pay attention to the application of big data, which requires extensive access to data from internal and external sources, and data trading across organizations and between chains becomes very important, and data trading becomes an important means to strengthen data resource integration, open information silos, and activate data assets. However, data trading faces risks in practice, such as unclear ownership, complicated authorization, lack of transparency of transactions, and privacy leakage. Figure 1 shows a general data trading scenario. The data user sends a data purchase request, and the data owner responds to the request. When the data user pays, the data owner embeds the watermark into the data and sends it to the data user. However, the virtual, non-exclusive, and lossless characteristics make data easy to be tampered with, resold, leaked, and used beyond the scope in the process of circulation. The characteristics of the zero marginal production cost and the difficulty of complete physical delivery make it impossible for the ownership, use, and control of data to be delivered uniformly. Therefore, the static data watermarking model cannot be applied to dynamic data market transactions.

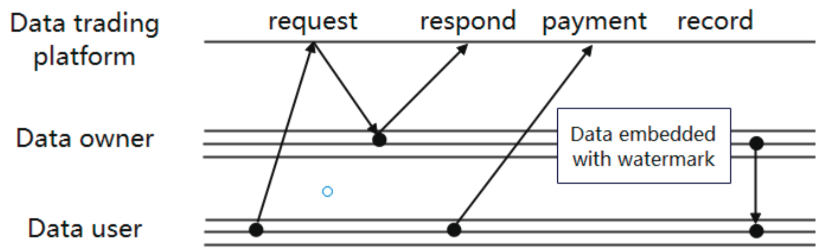


Figure 1. Data transaction scenario.

Blockchain, first proposed by Satoshi Nakamoto [1], is a public ledger, maintained by decentralized nodes for the distributed sharing and storage of data. Blockchain has the characteristics of decentralization, anonymity, privacy, traceability, and tamper resistance, which has attracted great attention from academia and industry (such as supply chain, Internet of things, and medical fields) [2]. New concepts, such as smart contracts [3] and smart attributes that originated from blockchain technology, were quickly accepted by the economic market. A smart contract is a computer transaction protocol that enforces the terms of contract, allows trusted transactions without third parties, and ensures that those transactions are traceable and irreversible. In recent years, blockchain technology has been successfully applied to IoT platforms [4,5], medical data sharing systems [6], data privacy protection [7], supply chains [8–10], biomedical research [11], and financial transactions [12]. The decentralization of the blockchain paves the way for data transactions in the supply chain data marketplace.

Related work. Zhao, Y. et al. [13] proposed a new protocol for distributed data transactions that uses ring signatures to enhance the privacy of data provider identities. In a ring signature, a user selects a group of users, called the ring, to generate a signature, where the verifier can be confident that the signature was generated by a member of the ring but cannot reveal which person actually generated the signature. The protocol also extends double-authentication prevention signatures (DAPS) to penalize signers who generate two signatures for messages with the same title and different payloads, and this guarantees the fairness of transactions between data providers and data consumers. Xiang, Y. et al. [14] proposed a smart-contract-based data trading scheme. The scheme uses smart contracts to ensure fairness of data sharing and data copyright in transactions and minimizes the risk of partial/combined resale or leakage of data by using a multi-type-based watermarking strategy. Jing, N. et al. [15] proposed a blockchain-based code copyright management system. The original verification model of code based on abstract syntax tree is applied to the verification process of blockchain to realize the copyright verification and protection of original code. However, there is a problem of originality verification cost and verifier's dilemma [16]. Xu, Y. et al. [17] proposed a game theory based Nash equilibrium model between watermarking robustness and data quality. The model uses a secure hashing algorithm to establish the mapping relationship between data groups and watermark bits and uses an improved particle swarm optimization algorithm to solve the optimal solution for each data group's data variation under the data availability constraint and then modifies the data accordingly to complete the embedding of the watermark bits and protect the copyright of the data. Kumar, R. et al. [18] proposed a distributed image- and video-sharing platform based on IPFS (Interstellar File System). The platform detects copyright infringement of multimedia by calculating the similarity between perceptual hashes (pHash) stored in the blockchain. Nasonov, Denis. et al. [19] proposed a distributed big data platform in which a blockchain-based distributed digital data market is used to ensure the integrity of data transactions. Zhou, J. et al. [20] addresses the trade-off dilemma between the effectiveness of data retrieval and the leakage risk of data indexing in distributed data transactions, and they propose a framework for distributed data transactions (DDV) by combining data embedding and similarity learning. The framework uses a privacy-preserving data-embedding procedure as an input to measure the similarity between data entries and achieves effective retrieval in data transactions while preserving data privacy. Elias Strehle and Martin Maurer [21] proposed the DibiChain protocol for the discovery and exchange of supply chain information, which is built on top of a distributed data store that maintains a high degree of anonymity and unlinkability while ensuring a high degree of privacy by minimizing data in the shared data store, avoiding persistent user identifiers and communicating anonymously with minimal intermediaries. Nawaz, A. et al. [22] proposed EdgeBoT, a platform for IoT based on smart contracts, considering the potential changes in interaction topology in data transaction scenarios. EdgeBoT enables more diverse interaction topologies between nodes in the network and external services, enabling direct data transactions at edge devices while guaranteeing data ownership and end-user privacy.

However, most of the current research on data ownership confirmation in data trading is focused on improving digital watermarking technology and similarity detection. This can only cover the detection of illegal data and cannot fundamentally cover the accurate tracing and timely accountability of illegal data. The current trading platform construction has no standard system for data ownership verification, traceability, and accountability.

Our contributions. This paper proposes a data ownership confirmation scheme (DOCS) for distributed data asset trading of the supply chain system, which has a credible and accountable architecture. We have studied in detail the structural methods of data storage, traceability, and accountability. (1) We adopt data signatures and similarity learning to enhance the reliable mapping between on-chain data ownership and off-chain data entities. It can effectively maintain the integrity of off-chain data. (2) We propose a smart contract-based data fingerprint generation protocol, which contains a two-part structure of mutual identity verification and data fingerprint generation. This ensures channel security under anonymous transaction networks and also achieves accurate traceability and market tracking of illegal data transactions. (3) We design a market supervision mechanism empowered by smart contracts to encourage market users to assist in prosecuting illegal data transaction in a timely manner.

The rest of this paper is structured as follows. Section 2 introduces the basic applications of DOCS, including data signatures, similarity learning, and smart contracts. Section 3 describes the structure of DOCS and the workflow and defines common data tenure attack models. Section 4 provides a security analysis of DOCS and demonstrates that DOCS can resist attacks on data tenure in data transactions. Section 5 evaluates the encoding performance and decoding performance of data-embedding techniques with supply chain data, and the experimental results show that data signatures can be used as reliable credentials for data ownership confirmation. Section 6 provides a conclusion.

2. Preliminary

2.1. Data Signature

Simple hash-based data signatures are unique and random. For the same data, as long as its content is slightly modified and finely distinguished from the original data, a new hash signature can be obtained even if the data does not satisfy the originality condition, and the characteristic relationship with the original data hash signature cannot be detected. In addition, the hash signature is irreversible and cannot be restored to the original data. When a data dispute arises, the hash signature cannot be used as the basis for the judge's decision.

Advances in deep learning have led to highly nonlinear embedding techniques, such as autoencoder [23], and recurrent neural networks for embedding in time series data [24]. The advantage of using data signatures based on a data-embedding technique instead of simple hash-based signatures is that it helps to achieve efficient data retrieval and similarity detection. The goal of data embedding is to project the data input into a generally lower-dimensional subspace so that the data input can be represented by a low-dimensional vector. As shown in Figure 2, the data-embedding framework consists of two major modules: the encoding process and the decoding process. The input sample X is mapped to the feature space Z through the encoder (f), which is the encoding process; then the abstract feature Z is mapped back to the original space through the decoder (g) to obtain the reconstructed sample $\widetilde{X}$, which is the decoding process.

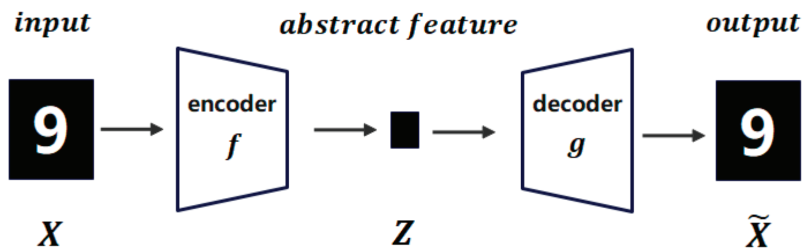


Figure 2. Data encoding and decoding process.

The optimization objective is to optimize the encoder and decoder at the same time by minimizing the reconstruction error, so as to learn the abstract feature representation Z for the sample input X.

$$f, g = argmin_{f.g} \ell(X_i,\ g_\gamma(f_\theta(X_i))) \tag{1}$$

where f is the embedding function, g is the inverse function, θ is the parameter of the f, and γ is the parameter of the g. The process of target optimization is the optimization process of θ and γ. Equation (1) is a process of objective optimization. Through it, we can obtain encoders and decoders with better performance.

$$f_\theta(X_i) = Z_i \tag{2}$$

When the data owner needs to update the data matrix or more data entities are available, data embedding can be done in a data-driven manner, so that we learn an embedding function such that the learned subspace can maximize the data recovery entity. Let $D = \{X_1, X_2 \cdots, X_n\}$ be a set of n data entities available for training; the data-driven embedding is given by the following objective function:

$$\min_{\theta,\gamma} \sum_{i=1}^{n} \ell(X_i, g_\gamma(f_\theta(X_i))) \tag{3}$$

where $\ell(\cdot,\cdot)$ is a loss function for evaluating the recovery error. Let θ^*, γ^* be the optimal solution in the pair (3); we can update the functional form of θ^* and f by calling the initialization contract.

$$V_j = f_{\theta^*}(X_j) \tag{4}$$

The embedding vector V_j is the data signature of the data matrix X_j.

In order to alleviate the problem of easy overfitting of the classic autoencoder, one way is to add random noise to the input layer of the traditional autoencoder to enhance the robustness of the model [23]. Another way is to combine the idea of regularization, by adding the autoencoder's Jacobian matrix paradigm to the autoencoder objective function to constrain the autoencoder to learn abstract features with anti-interference [25].

2.2. Similarity Learning

Distance metric learning has been extensively studied for decades and is widely used in computer vision, information retrieval systems, and bioinformatics [26]. It can greatly improve the performance of classification, clustering, and retrieval tasks [27]. Distance metric learning involves learning the distance relationship of specified data from pairs of similar but different points. In an information retrieval system, we can define similarity on specified data and learn a distance function d for efficient retrieval.

Let $(Z_1, Z_2) \in R_m$ represent two data abstract features, where m is the number of features. The Mahalanobis distance [28] between (Z_1, Z_2) can be expressed as:

$$d_M(Z_1, Z_2) = \sqrt{\| Z_1 - Z_2 \|_M^2} = \sqrt{(Z_1 - Z_2)^T M (Z_1 - Z_2)} \quad (5)$$

where M is the parameter matrix of the distance metric. We use distance metric learning to compute data similarity and make decisions. The metric learning algorithm is extended to multi-task settings when there are many tasks in [28]. In the multi-task setting, the distance for task t is defined as:

$$d_t(Z_1, Z_2) = \sqrt{(Z_1 - Z_2)^T (M_0 - M_T)(Z_1 - Z_2)} \quad (6)$$

The specific regularization term is defined as:

$$min_{M_0} = \gamma_0 \| M_0 - I \|_F^2 + \sum_{t=1}^{T} \gamma_t \| M_t \|_F^2 \quad (7)$$

The parameter γ_t controls the regularization of $M_t, t \in [0, \cdots, T]$. Multi-task metric learning can effectively improve the performance of distance metric for retrieval task learning.

2.3. Smart Contract

A smart contract is a self-executing program code first proposed by Nick Szabo [29]. Smart contracts are derived from the Bitcoin scripting language, a stack-based language that is not yet fully completed. Ethereum [30] is an alternative cryptocurrency for building the next generation of distributed applications that support smart contracts. Ethereum smart contract provides a more expressive and complete language, as well as the most widely reliable language; the transaction network in DOCS is built on Blockchain Ethereum, specifically; the basic functionality of DOCS is implemented through key smart contracts.

Some computationally intensive contracts (CICs) are very expensive to execute, which makes it impossible for us to execute complex algorithms with low gas cost. The implementation of CICs will also lead to the validator's dilemma problem [16], a miner must normally start mining a new block on one received only after verifying all its transactions. If the time taken to verify the transactions in the block is nontrivial then it delays the start of the mining process, thereby reducing the chances of the miner creating the next block. Skipping the verification step will save time but at the risk of quality. Although selecting a small group of miners to execute contract computations can reduce costs, it does not guarantee the trustworthiness of executing contracts.

YODA [31] proposes a method to implement CICs in the system while guaranteeing a threat model that allows Byzantine and selfish nodes in the system. YODA [31] selects one or more execution sets (ES) via Sortition to execute a particular CIC off-chain.

3. DOCS

3.1. DOCS Overview

In the DOCS, Blockchain Ethereum serves as the underlying blockchain infrastructure to build the transaction network in DOCS, where a combination of smart contract features can be enabled. There are also three participants: data owner, data user, and market users.

Blockchain Ethereum: Blockchain Ethereum is an open source public blockchain with smart contract functionality. The data owner and data user trade data on the Blockchain Ethereum.

Data owner: The data owner is usually the producer of the data. They have a list of topics to advertise the sales data, register the publication data with the Blockchain Ethereum, and generate a topic transaction.

Data user: The data user is usually a buyer of data. They query the data list through the Blockchain Ethereum and generate payment transactions to purchase the data.

Market users: Market users are data users who collect and trade data through black market. They are rewarded for assisting with the prosecuting of data users for illegal transactions.

The workflow of DOCS is shown in Figure 3. The data owner will then publish the list of topics on the Blockchain Ethereum. Data user search on the Blockchain Ethereum and request data on a specific topic to enter the publication stage. Data owner generate the data signature through the data-embedding function, and request to upload it to the transaction list. After the data user retrieves the availability of the data, the transaction enters the verification stage. The two parties conduct identity verification through the data fingerprint generation protocol based on smart contract, and after the verification passes, the transaction enters the payment stage; after the data user completes the payment, the subject data embedded in the data fingerprint is obtained, and the transaction enters the supervision stage; within the validity period of the supervision stage, market users obtain rewards by assisting with prosecuting data users for illegal transactions, and market users may also choose to resell data for profit.

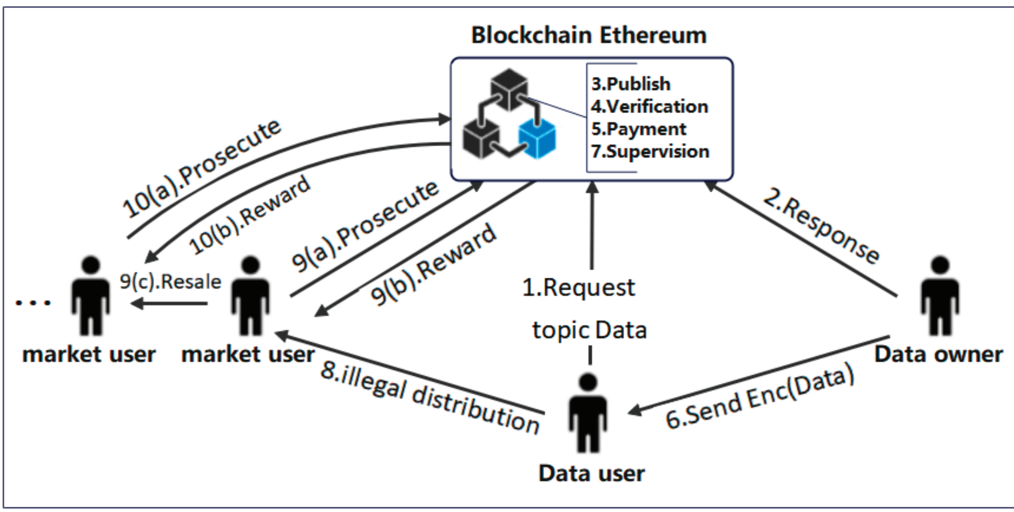


Figure 3. Architecture of DOCS. (a–c) indicates the sequence of market user' actions.

Adversary models. According to the real process of data trading, we identify six typical potential adversaries in distributed data transaction scenarios, which are the most common attacks on data ownership and the most threatening in terms of data transaction systems attacks. The specific definitions of these attacks are as follows:

Definition 1. *False identity attack. During the transaction process, the counterparty uses a false identity to evade the tracking of data fingerprint.*

Definition 2. *Repeat confirmation attack. After the adversary obtains the data copy of the data owner, it slightly modifies the data copy to obtain a new data ownership certificate, which is confirmed and traded on the chain.*

Definition 3. *Data corruption attack. Data are often stored and processed with the risk of data corruption, such as data loss and data distortion.*

Definition 4. *Illegal distribution. After the adversary obtains the data copy of the data owner, it circumvents the on-chain transaction network and conducts anonymous transactions off-chain.*

Definition 5. *Shared key attack. The adversary gets access to the data owner's encrypted data and causes data leakage by sharing the data decryption key.*

Definition 6. *Transaction fraud. In a transaction, the buyer and seller do not stay synchronized in the process of payment and delivery, specifically one peer is spoofed by another peer, resulting in the loss of data or tokens.*

The key symbols used in data trading are presented in Table 1.

Table 1. Key symbols and corresponding descriptions.

Notations	Description
L	Data Transaction List
$H(\cdot)$	Secure hash function
K_1	Secure session key of DU
K_2	Secure session key of DO
DO	Data owner
DU	Data user
DF	Data Fingerprint
TL	Transaction Protection Period
M_O	Deposit for DO
M_U	Deposit for DU
α	Random parameter of DO
β	Random parameter of DU
$G(\cdot)$	Security irreversible function
$Cert_{DO}$	Security certificate of DO
$Cert_{DU}$	Security certificate of DU
Sig_{Data}	Data signature
$Sig_{CA}(\cdot)$	CA signature

3.2. Workflow of DOCS

Publish. We argue that the process of publishing data to the Blockchain Ethereum is the confirmation process of data ownership, and Sig_{Data} can be used as a valid proof of data ownership. Algorithm 1 describes the publishing process implemented with smart contract.

Step 1: The data owner uploads a data signature Sig_{Data} based on data-embedding technology and the miner updates it to the blockchain transaction list $L(Sig_{Data})$ after verifying its legitimacy. The data user retrieves $L(Sig_{Data})$ and moves to the transaction verification phase after verifying the availability of the data through similarity learning.

Algorithm 1: Contract_publish

Input: Sig_{Data}, Issure, contract_state
Output: $L(Sig_{Data})$, contract_state
1. if Sig_{Data} = true
2. Sig_{Data} update to L
3. renew $L(Sig_{Data})$
4. contract_state=verification
5. else
6. return an error

Verification. Before data user can pay, we need an identifiable data fingerprint. For data transaction scenarios, data fingerprinting protocols that rely on third parties do not support anonymity, and the leakage of fingerprint information will also create risks for transaction participants. DOCS rely on data fingerprints to trace user and owner identities, so the security and trustworthiness of fingerprints is very important for member management and accountability tracking. In DOCS, a necessary but not sufficient condition for the credibility of a data fingerprint is to verify the identity of the other party. We propose a data fingerprint generation protocol based on smart contracts. The framework of the protocol is shown in Figure 4. The protocol requires mutual authentication of participant identity, confirmation of the identity of the sender, and channel security, and it then generates DF through $H(\cdot)$. The process is as follows:

(1) Authentication initialization

Step 2: The data owner and data user obtain their certificates through CA authentication. The certificate structure is as follows:

$$Cert_{DO} = \{PubK_O, L(Sig_{Data}), Issuer, Algorithm, Sig_{CA}(\cdot)\}$$

$$Cert_{DU} = \{PubK_U, Issuer, Algorithm, Sig_{CA}(\cdot)\}$$

The initialization smart contract generates random numbers α and β, the data owner computes Q_O, and the data user computes Q_U and uploads them to the smart contract along with the certificate.

$$Q_O = G(\alpha)$$

$$Q_U = G(\beta)$$

Step 3: The data user computes K_1 and uploads c_1 and c_2 to the smart contract; the data owner computes K_2 and uploads c_3 and c_4 to the smart contract.

$$\begin{gathered} K_1 = \beta Q_O = \beta G(\alpha) \\ c_1 = Enc_{PubK_O}(K_1) \\ c_2 = Enc_{K_1}(Cert_{DU}) \\ K_2 = \alpha Q_U = \alpha G(\beta) \\ c_3 = Enc_{PubK_U}(K_2) \\ c_4 = Enc_{K_2}(Cert_{DO}) \end{gathered}$$

(2) Session key authentication

Step 4: The data owner decrypts to get K_1 and $Cert^*_{DU}$. The data owner then sends $Enc_{PubK_U}(K_1)$ to the smart contract. The data user decrypts to get K_2 and $Cert^*_{DO}$. The data user then sends $Enc_{PubK_O}(K_2)$ to the smart contract.

(3) Identity verification

Step 5: The data owner gets K^*_2; the data user gets K^*_1.

$$K^*_2 = Dec_{PriK_O}(Enc_{PubK_O}(K_2))$$

$$K^*_1 = Dec_{PriK_U}(Enc_{PubK_U}(K_1))$$

(4) Generate data fingerprint

Step 6: Smart contract generates a DF by $H(\cdot)$.

$$DF = H(PubK_O \oplus Sig_{Date} \oplus PubK_U)$$

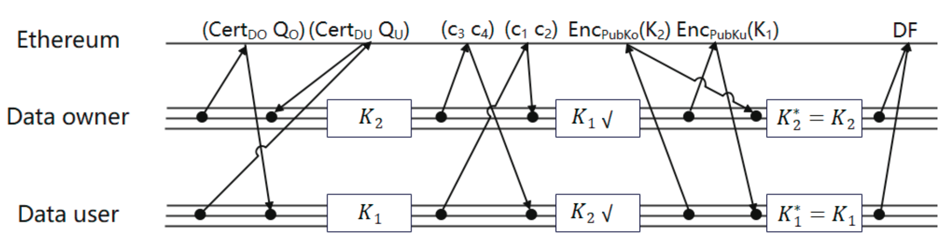


Figure 4. Schematic diagram of certificate-based data fingerprint generation.

Payment. Before the data user pays, both parties deposit a certain amount of deposit in the smart contract. If the payment is successful, the deposit will be returned after a time limit TL, and the transaction will enter the supervision stage. If payment fails, the data user will compensate the data owner for a certain loss, and the transaction will be terminated. Algorithm 2 describes the payment process implemented with smart contracts.

Step 7: The data user pays the data price, the data owner embeds DF to the corresponding subject data and uploads the encrypted data $Enc_{K_2}(Data)$ with DF to the cloud storage, and the data user downloads the decrypted data $Dec_{K_2}(Data)$.

Algorithm 2: Contract_payment

Input: M_O, M_U, TL, contract_state
Output: contract_state
1. if DU initiates a payment to DO
2. DO to embed DF in the data
3. DO sends $Enc_{K_1}(Data)$ to cloud storage
4. return M_O to DO after TL
5. return M_U to DU after TL
6. contract_state = supervision
7. else
8. termination transaction
9. destroy DF
10. return M_O to DO
11. DU compensates the loss from M_U to the DO

Supervision. There are two ways that market can obtain illegal copies of data. First, direct transactions between data user and market users. Second, transactions between market users. We greatly encourage all participants in the data market to assist with prosecuting a data user for unlawful conduct. When the market user purchases an illegal copy of the data, the smart contract will seek to upload the data fingerprint and send a verification request to the miner. If $DF^* = DF$ and the upload time t of DF^* is in an ownership protection period TL, return 1 to Contract_prosecution, then the market user sued successfully. If DF^* is invalid, or t exceeds one ownership protection period, then 0 is returned and the market user's prosecution fails. Algorithm 3 shows this process implemented with a smart contract. If return 1, smart contract Contract_payment will issue a reward b from M_U to the market user who successfully assist with prosecuting. Then, it will compensate v to the data owner, where v is the initial price of the data. Algorithm 4 describes the reward process implemented with smart contract.

Definition 7. *Reward mechanism. The price paid by market user u_i for a copy of the data is v_i. The reward for a successful prosecution is b. There is a scale factor λ_i for b and v for the price of the data, $b_i = \lambda_i v$ $(b_1 > b_2 > b_3 \cdots > b_n)$, and λ_i decreases in steps as the number of Contract_prosecution triggers increases.*

We assume that the data compensation is gradually reduced but not to zero, so that the deposit of data user always meets the requirements. The reason why this assumption can be made is that when the reward is low enough, the data owner has received enough compensation, and they are also satisfied that the data user will pay enough for the illegal distribution of data copies. Therefore, this game model is still valid.

Algorithm 3: Contract_prosecution
Input: DF^*, account(u_i)
Output: return 0 or 1
1. if $DF^* = DF$
2. $DF \rightarrow \langle PubK_O,\ PubK_U,\ \mathrm{L}(Sig_{Data})\rangle$
3. return 1 to contract_payment.rep(T)
4. else
5. return 0 to contract_payment.rep(T)
6. termination transaction

Algorithm 4: Expansion of Contract_payment
1. func rep( ):
2. var {account(u_i), T, b, t}
3. if (T = 1) $\wedge$ (t $\leq TL$)
4. successful prosecution
5. send b_i to account(u_i) from M_U
6. send v to DO
7. else if (T = 0) $\vee$ (t $> TL$)
8. prosecution failed

4. Security Analysis

In this section, we prove that DOCS can defend against various types of attacks on data ownership in data transaction scenarios.

Theorem 1. *DOCS can resist false identity attacks.*

Proof. There are two ways in which a data user can provide a false identity, which are analyzed as follows:

(1) The certificate itself is invalid. In DOCS, when the data owner receives $Cert_{DU}$, it will be verified by $PubK_U$ to $Sig_{CA}(\cdot)$. If the verification is successful, it means that $Cert_{DU}$ is valid. If the verification fails, it means that the data user holds an invalid certificate. Likewise, data user can be authenticated, $Cert_{DO}$, in the same way.

(2) Whether the data subject is the true owner of the certificate. Data user try to send other people's certificates to circumvent smart contract-based fingerprint generation protocols and avoid fingerprint tracking. The most effective way for DOCS to verify that the data subject is the true owner of the certificate is by verifying that the data subject actually owns the private key of $Cert_{DU}$. The data owner can obtain K_1, Q_U, and K_2^* of the data user during the transaction verification stage. From $K_1 = \beta G(\alpha)$, it can be reversibly deduced to β, and the data owner calculates $G^*(\beta)$. If $G^*(\beta) = Q_U = G(\beta)$ and $Cert_{DU}^* = Cert_{DU}$, it means that the data user's K_1 is correct. If $K_2^* = K_2$, the identity of the data user is correct. Likewise, data user can authenticate data owner in the same way. The data user can obtain K_2, Q_O, and K_1^* of the data owner during the transaction verification stage. From $K_2 = \alpha G(\beta)$, it can be reversibly deduced to α, and the data user can calculate G^*. If $G^*(\alpha) = Q_O = G(\alpha)$ and $Cert_{DO}^* = Cert_{DO}$, it means that the data owner's K_2 is correct. If $K_1^* = K_1$, the identity of the data owner is correct.

Therefore, no matter how the adversary provides false identity information, it will be detected, and DOCS can resist false identity attacks. □

Theorem 2. *DOCS can defend against repeat confirmation attacks.*

Proof. After the data user purchases and obtains the data entity X, corresponding to $L(Sig_{Data})$, they attempt to slightly modify and reacquire a new data signature to upload to the blockchain network for ownership confirmation and to initiate a transaction. Data signature based on data-embedding techniques are essentially abstract features of the data entity X, the data signature can be represented by a vector Z, equation (5) calculates the distance relationship between different data signatures, and the metric learning algorithm can be extended to a multi-task setup when there are many tasks (Equation (6)). In the following, we describe how this attack can be intercepted by a combination of data signature and similarity learning. □

We present YODA [31] in the defense process of DOCS to demonstrate that our defense is more robust. First, the anchor node broadcasts Sig_{Data}'s similarity learning request R to the entire network, and its retrieval scope includes the list of all serialized data signatures on the Blockchain Ethereum. Initialization smart contract pseudo-randomly selects miner M_i to join the execution set $ES = \{M_1, M_2, M_3, \cdots, M_i\}$ of R. M_i performs the similarity retrieval task of Sig_{Data} independently, returns the execution result $ER_i = \left(bool, R, Sig_{M_i}(\cdot), SR_i\right)$, and broadcasts it to other miners in ES, where bool represents the execution result of R is true or false; $Sig_{M_i}(\cdot)$ represents the signature of miner M_i, SR_i represents the result of RICE [31], and the miner who executes it through the PBFT consensus protocol reaches a consensus result ER. Then, the anchor node broadcasts ER to $\neg ES$, regenerates $ES' \in \neg ES$ and re-executes R.$\neg ES$ maintains the result set $\{true, false, dispute\}$, where $true$ means X is original data, $false$ means X is duplicate data, $dispute$ means X is in dispute, and you need to submit it manually for verification. Finally, $\neg ES$ decides the final execution result from the result set through likelihood estimation; $\neg ES$ serializes the result and sends feedback to ES to terminate the computation. Therefore, the repeat confirmation attack of the data user can always be blocked by DOCS.

Theorem 3. *DOCS can defend against data corruption attacks*.

Proof. Data storage and processing are often accompanied by risks, such as data loss and data distortion. Since Sig_{Data} is reversible, the data owner can decode Sig_{Data} by decoder g and get $X = g_\gamma(Sig_{Data})$. Sig_{Data} is stored in the Blockchain Ethereum as an ownership credential, and X is permanently trusted due to the tamper-proof nature of the blockchain. The data owner can use X as the credential to audit the data entity under the chain and effectively maintain the integrity of the data entity under the chain. Therefore, DOCS can resist data corruption attacks. □

Theorem 4. *DOCS can defend against illegal distribution*.

Proof. The illegal distribution of data cannot be realized in our data transaction network based on Blockchain Ethereum because it will be blocked in the transaction response stage. Data users often choose to avoid on-chain transactions and resell copies of data on the black market. DOCS rely on credible data fingerprints DF and timely incentives to encourage market users to sue data users for illegal distribution in an anonymous network. We denote the set of market users who purchase data copies in the black market as U and $U = \{u_1, u_2, u_3, \ldots\ldots, u_i\}$, market users want to maximize their own profits no matter how they obtain data copies. The policy space of U is $(r, p, none) = (resale, prosecute, none)$, and the action set of U can be expressed as $\{r \wedge p, \neg r \wedge p, r \wedge \neg p, none\}$. We analyze the market users benefit matrix under the four actions, as shown in Table 2. □

Table 2. The benefits of market users under different actions.

	$r \wedge p$	$\neg r \wedge p$	$r \wedge \neg p$	*none*
u_1	$v_2 - v_1 + b_1$	$-v_1 + b_1$	$v_2 - v_1$	$-v_1$
u_2	$v_3 - v_2 + b_2$	$-v_2 + b_2$	$v_3 - v_2$	$-v_2$
u_3	$v_4 - v_3 + b_3$	$-v_3 + b_3$	$v_4 - v_3$	$-v_3$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
u_i	$v_{i+1} - v_i + b_i$	$-v_i + b_i$	$v_{i+1} - v_i$	$-v_i$

Starting from the row of Table 2, the user gets the greatest benefit when executing $r \wedge p$; starting from the column of Table 2, the user who sues the earliest can always get the greatest benefit. Therefore, the illegal distribution of the data user can always be traced back in time. In Table 3, we analyze the payoff matrix of market users, data owner, and data user in the case of action $r \wedge p$.

Table 3. Action is the payoff matrix of $r \wedge p$.

U	*DO*	*DU*
b_1	v	$-b_1 - v$
b_2	$2v$	$-b_2 - 2v$
b_3	$3v$	$-b_3 - 3v$
$\vdots$	$\vdots$	$\vdots$
b_i	iv	$-b_i - iv$

From Table 3, we can see that if the ith market user u_i successfully sues, the return to the u_i is b_i, the compensation to the data owner is iv, and the loss to the data user is $-b_i - iv$. Therefore, the sued data user will face huge compensation beyond the value of the data itself. Under this kind of game, data users will not distribute copies of data illegally on the black market. If data users choose to distribute copies of data illegally, data owners will not suffer losses.

In the supervision model, the earlier a market user sues, the more rewards they can receive. A market user has to sue before other market users in order to get higher re-wards, so this creates a competitive relationship between market users. In most cases, market users do not know the source of illegal data copies. We can rely on this com-petitive relationship to encourage market users to initiate timely assistance with pros-ecutions and improve the timeliness of the monitoring model. Although we cannot eradicate the continuous distribution of illegal data copies and need to rely on compe-tition to encourage market users to file lawsuits in a timely manner, we have established a game relationship between market users and data user in this way. If data users choose to illegally distribute copies of data to the black market, they are likely to face high penalties in a short space of time. Moreover, the penalties are much higher than the benefits obtained by illegally distributing data copies. In this game, data users are forced to remain rational.

Theorem 5. *DOCS can defend against shared key attack.*

Proof. In the DOCS, the data owner encrypts the data with a randomly generated temporary session key K_2. During the generation of K_2 by the data owner, the data owner can set permissions and policies so that K_2 can only be used within the specified scope of permissions. For example, K_2 will be invalid after data are decrypted by the data user. Or K_2 expires after a certain time limit has been exceeded. Therefore, data user cannot leak data through the shared key. □

Theorem 6. *DOCS can defend against transaction fraud.*

Proof. The data user attempts to refuse delivery of the data after the data user has paid. In this case, the data user may set a return value and a time limit in the payment phase of the smart contract to return a value that triggers the smart contract to take effect after receiving the complete data. If the data user does not return the data in time after receiving it, the smart contract automatically becomes effective after a time limit is exceeded and the data owner is paid.

The data user attempts to refuse payment after the data owner delivers the data. In DOCS, the data user refuses to send encrypted data in case the data owner refuses to pay, all of which does not happen. □

5. Performance Evaluation

In this section, we evaluate the embedding performance and recovery performance of DOCS on real datasets. We use the supply chain geographic proximity data of nearly 30,000 listed enterprises as our simulation dataset, and the data information in the dataset contains user/supplier ID, spatial distance, and distance to user/supplier, etc. We can unify the data standards in the initializing smart contract and build a data standard repository chain network using Blockchain Ethereum, which is jointly constructed and maintained by all the nodes that join. After the new data standards are verified by the consensus algorithm of each node, they are linked to the standard library chain to ensure the stability and openness and transparency of the data standard library.

Our simulation platform is Intel(R) Core(TM) i5-5350U CPU @ 1.80GHz 8.00GB RAM and Windows 10 operating system. We evaluate the autoencoder-based stacked denoising autoencoder (SDAE) and convolutional autoencoder (CAE) performance in Figures 5 and 6, and the decoding efficiency in different dimensions in Table 4.

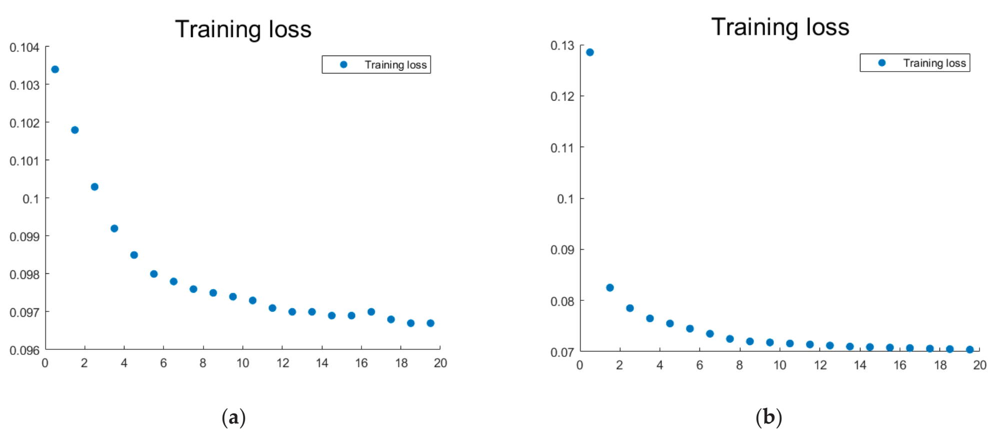
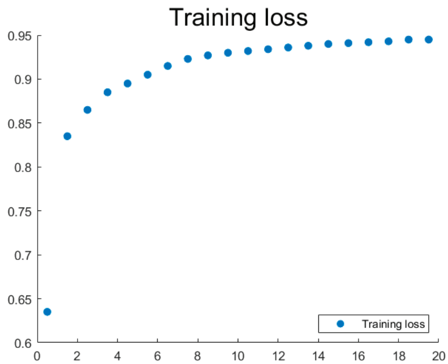
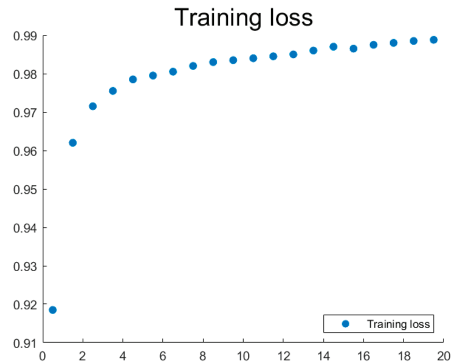


Figure 5. The loss change of the self-supervised pre-training process of SDAE is shown in (**a**), and the loss of the self-supervised pre-training process of CAE is changed, as shown in (**b**).



(**a**)



(**b**)

Figure 6. The variation in acc accuracy during SDAE unsupervised training is shown in (**a**), and the variation in acc accuracy during CAE supervised training is shown in (**b**).

Table 4. The decoding efficiency in different dimensions.

Dimension	Precision	Recall
500	0.771	0.650
1000	0.911	0.840
1500	0.919	0.878
2000	0.920	0.901
2500	0.922	0.916
3000	0.922	0.925
3500	0.923	0.932
4000	0.924	0.939
4500	0.925	0.941
5000	0.928	0.945
5500	0.927	0.943
6000	0.927	0.942

From Figure 5, it can be seen that the training loss of CAE self-supervision converges to about 0.07, which is smaller than 0.096 of SDAE. From Figure 6, the accuracy of CAE's supervised training process rises to 0.99, which is higher than SDAE's accuracy of 0.95. Therefore, CAE has certain advantages in reconstruction tasks and classification tasks in datasets.

Table 4 shows that the recovery performance of the decoder also tends to increase slowly as the data dimension increases, further illustrating that the recovery efficiency tends to saturate as the signature vector size increases. In Table 4, it can be seen that after 1000 dimensions, the improvement of recovery efficiency decreases significantly with the increase in embedding dimension. In order to achieve scalable feature representation and retrieval performance, we would like to use an embedding size that stays within a rational range, which compresses the raw data sufficiently without significantly sacrificing embedding accuracy. Therefore, we suggest using a 1000-dimensional embedding representation because it provides more than 30 times the compression of the original supply chain data while preserving most of the sparsity and temporal properties of the downstream tasks.

6. Conclusions

In this paper, we propose a distributed data ownership confirmation scheme (called DOCS) in a data transaction scenario. The advantage of a data transaction network built on Blockchain Ethereum is that it eliminates the single point of failure in the big data market. We describe the data signature and fingerprint generation protocols in the DOCS architecture, as well as the market supervision mechanism empowered by smart contracts, and build a standard system for data ownership verification, traceability, and accountability, maintaining data integrity and enabling accurate traceability and timely accountability for illegal data transactions. We demonstrated that DOCS can resist different types of attacks. We analyzed the encoding performance and decoding performance of different autoencoders through supply chain data.

Most smart contract applications, including DOCS, face privacy concerns because of the conflict between privacy needs and the transparency of blockchains and smart contracts. In the Blockchain Ethereum, anyone can view the current state of the smart contract, which also contains information about personal consumption and more. An effective smart contract access control mechanism plays an important role in resolving the above conflicts, and our future research will be carried out on this basis.

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FGAC: A Fine-Grained Access Control Framework for Supply Chain Data Sharing

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Abstract: With the rapid development of digital economics, a large number of data have been accumulated in the supply chain system, and data islands have appeared. Data sharing is an imperative way to unlock the data value of a supply chain system. A safe and effective access control mechanism for privacy-sensitive data is key in data sharing. At present, traditional access control mechanisms are static, single-factor control, and prone to a single point of failure. For dealing with these, a fine-grained access control (FGAC) framework for supply chain data sharing is proposed, based on the blockchain Hyperledger Fabric. It augments role-based access control (RBAC) by giving different attribute keywords to different types of users. This framework is implemented in smart contract Chaincodes and quantitatively verified by using the model-checking tool UPPAAL. The experiment results show that the FGAC framework enhances the efficiency and safety in the process of data sharing for the supply chain system, compared with the existing works.

Keywords: blockchain; supply chain system; data sharing; access control; system verification

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1. Introduction

With the rapid development of the digital supply chain, data are becoming important production factors and are beginning to affect every aspect of our daily life. A large volume of data, i.e., big data, also raises a series of challenges, some of which include data management inefficiencies, unauthorized access, malicious attacks, single points of failure through centralization, and many others [1]. Moreover, due to the uneven distribution of data resources, the data siphon effect of large enterprises is serious; meanwhile, some phenomena of "data islands" are emerging. Data sharing is an imperative way to unlock the data value of a supply chain system. At present, the centralized storage system, namely the cloud, is the main method for data sharing services. The cloud has the ability to process large volumes of data quickly, and it enables the accuracy, efficiency, and speed of data processing. According to the 2021 Cisco Global Cloud Index report, 94% of workloads will be processed on cloud servers by 2021, compared with 83% in 2016. In fact, using cloud services to share data may lead to the data owner not owning the data or even controlling the risk of data privacy leakage [2]. Especially for some health or financial supply chain systems, their sensitive data have very important value, so any violation of access is not allowed.

Compared with the traditional production factors, data resources own digital characteristics, such as easy-to-copy and difficult-to-maintain confidentiality. Traditional data sharing methods have some drawbacks. First, its dependence on third parties is costly and requires that all users have a high degree of trust in third parties. Secondly, if risks arise in the data sharing process, users will need to validate manually. This also requires exposing confidential data to third parties and incurs complex administrative overhead, such as the need for additional legal contracts, which is less efficient. Therefore, data sharing through traditional sharing methods may lead to the leakage of personal information or interest loss in multiple links in the supply chain system. As a decentralized architecture, blockchain is a promising technology for data sharing in supply chain systems. It may replace cloud services for data sharing and help to effectively protect data privacy and security.

Access control mechanism refers to the restriction of the permission or ability of the user to access the data. It is a key for data sharing based on blockchain. However, the existing access control mechanisms in blockchain, such as RBAC [3] or ABAC [4], generally verify access rights through centralized entities that are prone to a single point of failure. Moreover, they are static and single-factor control and have coarse granularity. Once the user's role or attribute is set, the user will always have access rights, even though they may not have the assumed role. Therefore, access control mechanisms have been an important research topic for data sharing, either in cloud-service-based data sharing or blockchain-based data sharing. However, traditional access control strategies cannot meet the requirements of security and fine granularity.

In this paper, we seek to solve the problem of fine-grained access control of data sharing in supply chain systems. Based on the blockchain Hyperledger Fabric, we propose a fine-grained access control framework (FGAC) by extending an access control mechanism, RBAC (role-based access control), and using smart contract Chaincodes in the blockchain to call and trigger FGAC. This will ensure the integrity, fairness, authenticity, and security of data sharing in supply chain systems. FGAC provides different attribute keywords for different types of users on the basis of RBAC and is related to data owners through smart contract Chaincodes when sharing data between users. The specific contributions of this paper are as follows:

1. We extend the RBAC (role-based access control) model with attribute keywords and propose a fine-grained access control (FGAC) framework.
2. We implement the FGAC framework with smart contract Chaincodes in blockchain Hyperledger Fabric and apply it to the data sharing of the supply chain system in Shanghai Port.
3. Using a model-checking tool as the system verification technique, we demonstrate and analyze the feasibility and safety of FGAC framework.

The rest of this article is organized as follows: Section 2 provides an overview of related research about data sharing based on blockchain and access control mechanisms. In Section 3, we propose a fine-grained access control framework (FGAC) and implement it in smart contract Chaincodes in blockchain Hyperledger Fabric. Section 4 presents the actual application scenario, i.e., the data sharing of a supply chain system in Shanghai Port. Section 5 models the FGAC framework by using the model-checking tool UPPAAL and presents system verification results and analysis. Finally, the conclusion and future work are given in Section 6.

2. Related Work

In this section, we highlight some studies that combine blockchain technology with data sharing and access control. In addition, the advantages and disadvantages of some access control strategies based on blockchains are discussed.

2.1. Blockchain and Blockchain-Empowered Data Sharing

Blockchain technology originated from the foundational paper "Bitcoin: A Peer-to-Peer Electronic Cash System" published in 2008 by "Satoshi Nakamoto" [5]. The blockchain does not involve any third-party authority or centralized server [6], and it is implemented in a decentralized network of computing nodes, in which each node keeps the same copy of transaction records [7]. This also enhances the system's ability to handle single points of failure and defend against attacks. In the blockchain, transactions are approved and recorded in the blocks created by miners, which are appended to the blockchain in chronological order. Due to the consensus mechanism implemented by miners' mining tasks on the network, users can trust the globally stored public ledger system instead of having to establish and maintain a trust relationship with a third party, which effectively solves the drawbacks of traditional data sharing.

As the key underlying technology behind modern cryptocurrency systems such as Bitcoin [5] and Ethereum [8], the blockchain was originally created as a distributed, immutable transaction ledger for cryptocurrency systems. Due to the invention and combination of smart contracts, the blockchain has now developed into an efficient platform for developing distributed and trusted applications and has attracted the attention of a large number of researchers [9]. The smart contract can effectively solve the problems in traditional data sharing and access control and become a link between blockchain technology and access control mechanisms. A smart contract is a coded contract written in a computer language and automatically verified and executed by a computer. Its essence is a collection of predefined instructions and data that have been recorded at a specific address on the blockchain. It automatically executes the contract through a coding program. As long as the contract terms are met, the transaction will be performed automatically without third-party supervision [10]. Like ordinary on-chain transactions, the node will first perform signature verification to ensure the validity of the contract, and the verified contract will be successfully executed after the consensus mechanism. All transactions generated in smart contracts and blockchain networks are saved in a Merkle tree structure in each block. Merkle trees are constructed bottom-up tree data structures, in which all transaction data are hashed and stored as leaf nodes, and the continuous child nodes from leaf to root are hashed until the root hash value is generated and stored in the block header [11].

Some works that combine blockchain systems with data sharing have shown initial results, and most of these works are currently being used in medical electronic records (EHR) and the Internet of Things. Azaria et al. proposed MedRec [3], a decentralized record electronic medical record management system using blockchain technology, which provides patients with a comprehensive, immutable log with easy access to their medical information, covering provider and treatment websites. Ref. [12] systematically discussed how to store, retrieve, and share files using a blockchain structure in a decentralized environment. They used the blockchain to realize the scheme of data integrity, and the main content of the discussion includes the definition of transaction information, block information, and other specific implementation measures. Ref. [13] proposed a medical data management framework named CrowdMed, which designed an access control scheme for medical data, allowing patients to fully control access to their medical data and how their data are accessed and used, and permissions can be revoked or modified according to the patient's wishes. Additionally, it also encourages patients to share more data for research purposes by designing reward tokens and innovative pricing mechanisms. Ref. [14] proposed a blockchain-based privacy and security-protected EHR sharing protocol for improving diagnosis and effective treatment in the TMIS (Telecare Medicine Information System). The study [15] proposed the concept of the data sharing agreement (DSA) as a basic path and template for the data management of AI applications between various actors. Ref. [16] proposed a blockchain-based medical data sharing model, which has the characteristics of decentralization, security, trustworthiness, collective maintenance, and non-tampering, and is suitable for solving the data sharing of various medical institutions. Ref. [17] designed a consortium medical blockchain system based on the Practical Byzantine Fault Tolerance (PBFT), which is maintained and shared by multiple nodes, and can prevent the medical data from being tampered and leaked. In addition, ref. [18] proposed a blockchain-based trusted data sharing scheme that uses the Paillier encryption system to achieve the confidentiality of shared data and realizes the transaction of shared data through the (p, t) threshold Paillier encryption system to protect transaction information. Ref. [19] proposed BMAC, which is a multi-authority access control scheme based on blockchain technology. It introduces the Shamir secret sharing scheme and blockchain authority and realizes the joint management of each attribute by multiple authorities. Additionally, it builds trust among multiple authorities by utilizing smart contracts to calculate tokens for the properties managed across multiple administrative domains. Ref. [20] designed a secure data sharing framework based on identity authentication and the blockchain Hyperledger Fabric and proposed a community detection algorithm that can divide clients into different data sharing communities based on the similarity of labeled data, select the scope of data sharing according to the community's detection results of sharing degree evaluation, and improve the efficiency of data sharing. Ref. [21] designed a compressed private data sharing framework that can provide efficient private data management for the product data stored on the blockchain. The scheme uses off-chain procedures to compress and encrypt product data before submitting them to the blockchain and designs two types of transactions to support off-chain/on-chain data access. Ref. [22] used smart contracts and inadvertent transfer protocols, combined with the proposed ether check system, to achieve transaction fairness, autonomy, and transaction time control. Ref. [23] introduced a new multi-keyword, searchable encryption technique that improved the accuracy of the retrieved results and proposed a secure, searchable encryption system based on attribute encryption (ABE), searchable encryption, and blockchain used in the data sharing framework for the letter. However, the above works only consider the security risks in data sharing frameworks and do not consider the security of access control mechanisms in data sharing.

2.2. Access Control Mechanisms

At present, traditional access control models mainly include the discretionary access control (DAC) model, the role-based access control (RBAC) model [3], the attribute-based access control (ABAC) model [4], and the capability-based access control (CapBAC) model [24]. In the studies of [25,26], RBAC models are used as access control mechanisms for blockchain data sharing. In an RBAC model, roles are associated with access rights (e.g., invoke, edit, and execute) and assigned to subjects, and a many-to-many relationship is established between access rights and subjects [27]. However, RBAC, which is widely used, has inherent problems that it cannot overcome. For example, RBAC can no longer restrict access to a role after it is set, unless the role is manually revoked, and RBAC cannot solve the problem of individual user authentication in an organization (people in a department have almost the same role attributes). In this way, once the data are obtained through role attributes, even if the user changes departments or even work units, he can still obtain the desired information (data) and even use it for editing and tampering, which obviously has the great hidden danger of security for the protection of private data. In addition, Wang et al. proposed a data access control and sharing model using a blockchain system [28] that uses attribute-based encryption to control and share enterprise data to achieve fine-grained access control and secure sharing. Ref. [29] proposed a medical data security sharing scheme with a time dimension based on an alliance chain. This scheme uses cloud storage to store medical data ciphertext, uses the alliance chain to store metadata, and encrypts smart contracts and ciphertext strategy attributes. Combined with ciphertext-strategy attribute-based encryption (CP-ABE) technology, a data security sharing protocol is designed to realize fine-grained access control with the time dimension. However, they only improved the access control policy in terms of encryption and did not solve the fundamental problem. Among the classic access control models, ABAC is the most promising model for fine-grained access control. This is because ABAC introduces the contextual information and attributes of subjects and objects in its access control policies. By adding more topic attributes, object attributes, and contextual information to the strategy, we can greatly improve the dynamics and granularity of ABAC. To implement an access control strategy using an ABAC-based scheme, ref. [30] combined various types of attributes in data sharing, such as user attributes, object (i.e., the entity that holds the resource) attributes, environmental attributes, etc. The strategy itself defined a set of rules that indicate the conditions under which the data owner can be granted access rights, but this work did not limit or describe the user role. Moreover, when setting access control policies, we also need to consider the required decision-making continuity and attribute variability; that is, the user still needs to be restricted in access after setting the role, or once the attributes of the role are changed, their permissions need to be changed; otherwise, it will still cause data leakage and damage the privacy of users.

2.3. Summary

In short, some works have tried to combine blockchain technology with access control for data sharing. However, in the existing works, the access rights of its validating principals are usually handled by a centralized entity, which can throw the entire system into a single point of failure if something goes wrong. In RBAC, if the role is set, it can no longer be restricted unless it is manually revoked, and there are many restrictions on the setting of the role. ABAC does not solve the problem of individual user authentication in an organization, which can lead to a department with almost the same attributes among its users. This makes it possible to obtain the desired information (data) even if the department or work unit is changed for the data obtained through the attributes of the user, which poses a huge security risk. Therefore, this paper proposes a blockchain-based, fine-grained access control mechanism for supply chain data sharing.

3. Fine-Grained Access Control Framework

The FGAC framework sets keywords for different roles, such as the environment, department, project name, etc., and when identifying access permissions, it not only lists the role attributes within the scope of permissions but also matches their attribute keywords to view and transfer data. In addition, it also considers decision-making continuity and the attributes' variability; that is, users still need to be restricted in access after setting their roles, and if role attributes change, their permissions need to also be changed. The FGAC framework is the extension of the RBAC model in essence and is implemented through smart contract Chaincodes. This section describes the model architecture and workflow of the proposed FGAC in detail.

3.1. Access Control Model and Workflow

The architecture and workflow of the FGAC model are shown in Figure 1. It involves four types of smart contract Chaincodes, IPFS [31], encryption algorithms, etc. The specific definition of the events and functions of the four smart contract Chaincodes are described in Sections 3.2 and 3.3.

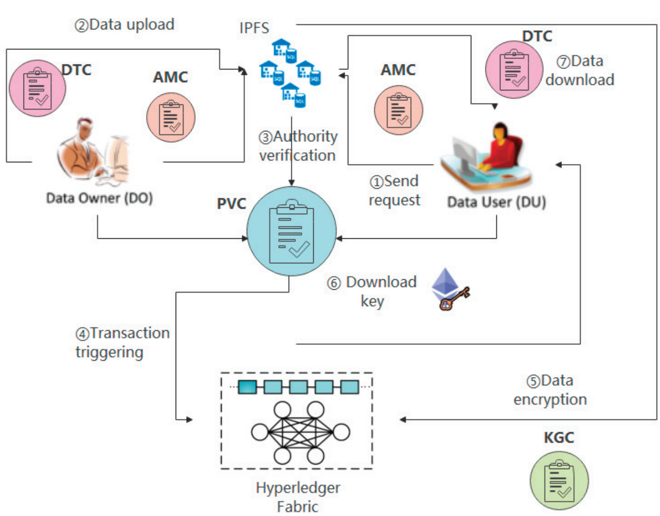

Figure 1. Fine-grained access control framework.

The overall process of the FGAC framework consists of six steps, each of which is explained in the following paragraphs:

1. Send Request: The DU sends a transaction to the data transmission contract to call the access request function in the contract. The transaction contains the target data and the name of the DU device. By calling the access request function in the contract, the DU role attribute is obtained from the database and triggered. The request access event in this function sends the transaction to the DO.
2. Data Upload: The DO sends a transaction request to the data transmission contract through the client to call the data upload function in the contract. The transaction includes the DO device name, the shared data information, and the role attribute keywords.
3. Authority Verification: When both the DO and DU are given their role information, and the attribute keywords are set, the transaction is sent to the attribute validation contract, and the validation function in the contract is called to validate the role attributes and data keywords of the DO and DU. Then, the function queries the attribute parameters in the contract according to the passed parameters, obtains the DO and DU parameters such as domain name, attribute, and blockchain account address, and triggers the matching request event in the function to verify whether both parties meet the permissions.
4. Trigger Transaction: When the data sharing parties satisfy the access control strategy, and the verification is successful, the transaction is packaged and executed. The request processing function in the property matching contract will call the DO and DU attribute information and send the result to the data transmission contract, triggering data sharing.
5. Data Encryption: The key generation contract is called to encrypt the identity information of the DO and DU and the requested shared data. When the verification result is successful, the contract distributes the key to the DU for decryption.
6. Data and Key Download: The DU obtains the key through the key generation contract after satisfying the access control strategy, triggers the transaction to view the shared data stored in IPFS, and matches the plaintext and ciphertext to decrypt the required shared data, to obtain plaintext data.

Users request to share supply chain data through smart contract Chaincodes that execute different functions. When a user requests the supply chain data in the hands of the DO, the DU starts to set user role information and attribute keywords and initiates data sharing with the DO. After receiving the request, the DO verifies the role with user rights and the attribute keywords assigned to the role. If the role information can be matched, the user can read the data but cannot download or use the data. When the attribute keywords are matched, the user who initiates the sharing request can obtain permission to use the data for data sharing.

3.2. Event Definition

This sub-section introduces the access control model and workflow and explains the framework of each step in detail. In FGAC, each user in the supply chain needs to set their own role information and attribute keywords and then can download and use sensitive data by verifying the attribute keywords. This effectively strengthens the security of data in the supply chain.

The four types of smart contracts in Chaincodes are the attribute management contract (AMC), the property verification contract (PVC), the key generation contract (KGC), and the data transmission contract (DTC). Users send request transactions to contracts, call contract-related functions, and complete specific operations to achieve fine-grained access control. In order to explain the detailed access control process in the data sharing between the data owner (DO) and the data user (DU), the definitions of some basic operations are given.

3.2.1. Transaction Sending and Processing

Transaction sending mainly refers to the signed packet of a message sent by an external account to another account on the blockchain. Transaction processing is a process that starts from the account initiating a transaction request and ends when the block containing the transaction is synchronized by the consensus node. When a transaction is sent through the contract, the contract will return the hash address of the transaction, which can be used to query the sender's address, receiver's address, and other related personal information during the data sharing process.

3.2.2. Event Notification and Execution

Events are the communication bridge between contracts and users. Events can be used to notify users (sender and receiver) so that they can easily query and access events through the client. In the actual supply chain data sharing process, users need to send transactions to call smart contract Chaincodes to execute the corresponding request. When the transaction is sent but not packaged and executed, the user will not be able to obtain the return value of the smart contract Chaincodes immediately. When certain operations are completed inside the contract function, the transaction is packaged and executed by triggering an event notification. Additionally, only after the contract writes the event to the blockchain can the front end respond accordingly.

3.2.3. Call of Functions

There are two types of function calls in smart contract Chaincodes, namely internal function calls and external function calls. An internal function call refers to a function calling another function in the same contract Chaincodes; an external function call refers to a function calling a function of another contract. In smart contract Chaincodes, users can perform their desired actions by calling functions.

3.2.4. Attribute Information

The administrator and related users publish their attributes and attribute relationship information to the blockchain, and the attribute management contract collects and integrates the corresponding attribute information and relationship. In addition to the role attribute of the user, for the user in the data sharing process, the attribute keywords can include address, trust degree, status, working time, department and level, etc. It is also possible to add environmental attributes such as the environmental conditions when the data sharing process occurs, the current time of the system, the security level of the system, the IP address it belongs to, etc.

3.2.5. Strategy Match

The administrator (user) publishes the access control strategy to other users in the blockchain, and the smart contract Chaincodes combine the attribute information to describe, collect, and integrate the access control strategy in the blockchain transaction to evaluate the access request. The property verification contract verifies whether the property information of the data requester meets the required requirements, thereby implementing fine-grained access control.

The relevant events are defined in this sub-section, in which the detailed access control process for data sharing between the data owner (DO) and the data user (DU) is described.

3.3. Access Control of Data Sharing Process Using Smart Contract Chaincodes

In this part, we introduce the smart contract part of the FGAC framework and explain the specific functions. According to the different purposes of the smart contracts involved in FGAC, we divide them into four types: the attribute management contract (AMC), the data transmission contract (DTC), the property verification contract (PVC), and the key generation contract (KGC).

3.3.1. Attribute Management Contract (AMC)

This contract is the most important contract in the process of realizing access control. In the process of supply chain data sharing, the access control strategy set by the data owner is collected and integrated by the contract, and the attribute information and its relationship with the data user are collected and integrated. The user's role attributes and the setting of their attribute keywords are received and distributed by the administrator or the user through the attribute management contract. In FGAC, when the data requester sends a transaction request to the system, the contract is executed. After the user registers and authorizes its role and its attribute keywords, the data user's request is forwarded to the data owner, and the properties are executed. The verification contract verifies whether the properties meet the requirements.

3.3.2. Data Transmission Contract (DTC)

This contract is used to upload and download the related data involved in packaging and sharing, as well as the role information and attribute keywords of different users. When the data requester makes an access request and obtains access permission, the data owner packages the data and uploads it to the blockchain through the contract, after which the data requester can obtain the required data and decrypt it.

3.3.3. Property Verification Contract (PVC)

The user's permission verification is performed by this contract. The nature verification contract identifies and evaluates the roles of the data owner and data user and compares whether their attribute keywords are consistent or similar. If the roles are the same, but the attributes are different, the user can only view the data, and data sharing is not available. If the verification is passed, the transaction process is triggered to allow data sharing, and the data user obtains the data through the data transmission contract.

3.3.4. Key Generation Contract (KGC)

When the nature of the data user is verified, the contract uses an encryption algorithm to encrypt the relevant data to be shared and upload the ciphertext to the blockchain. Once the verification of the nature verification contract is completed, the transaction can be triggered, and the data user can obtain the ciphertext and key required for the download through the data transmission contract, and after decryption, the required shared data can be obtained.

In FGAC, each user in the supply chain needs to set their own role information and their own related attribute keywords. At this time, the system obtains the sharing request sent by other users. Through the verification of the role attribute, the users in the supply chain can obtain viewing permission for the data, and then the key sensitive data can be downloaded and used by matching the verification attribute keywords. This effectively strengthens the security of the data in the supply chain.

4. Application Scenario

In this section, we use the supply chain in Shanghai Port as an actual scenario to illustrate the role and necessity of FGAC. The supply chain in Shanghai Port accumulates a large volume of data, such as maritime ships, maritime cargo, port data, and shipping routes. Through the sharing of supply chain big data, various departments in the supply chain can not only track ships and transport goods at sea but also provide supply chain participants with real-time, accurate, and visible individual dynamic information. The scattered dynamic data are precipitated, collected, sorted, and modeled to form a multi-dimensional basic big data model, which provides supply chain dynamics and industry intelligence for the relevant departments of the supply chain. Some cargo owners in the supply chain, especially direct cargo owners or large cargo owners, have higher requirements for information acquisition of transportation and hope that they can always grasp the information of cargo transportation. In the process of data sharing, this information not only needs to protect the privacy of users but also should not be easily viewed or tampered with by anyone. The FGAC framework can satisfy these requirements well. It is suitable for supply chain data sharing in Shanghai Port. The application diagram of the FGAC framework in the supply chain in Shanghai Port is shown in Figure 2.

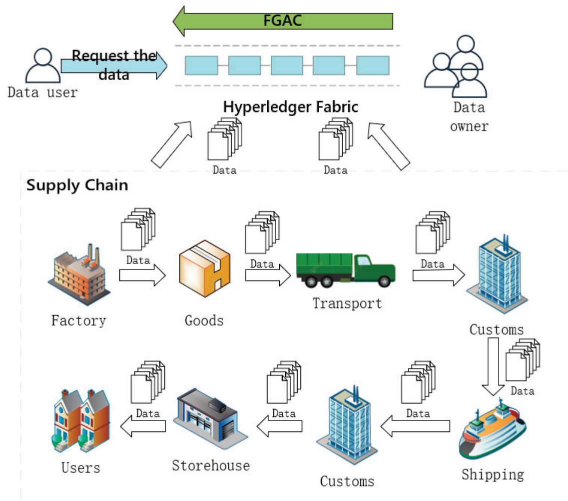

Figure 2. FGAC in supply chain of Shanghai Port.

We divided the data of the supply chain in Shanghai Port into four types: sensitive data, management data, transportation data, and personal data. In the proposed FGAC, the following points are taken into account when setting the access control rights:

- The data owner (DO) has access rights to all raw data;
- Authoritative organizations can obtain some data related to specific projects with high accuracy and timeliness (i.e., they cannot be changed without authorization);
- Data statistic agencies can access supply chain and management data but cannot change them;
- Other relevant departments and data technology companies can only access and obtain shipping-related data, but data accuracy and timeliness are not guaranteed (e.g., there may be a competitive relationship);
- Screening opponents and other companies in the same industry cannot obtain any type of data;
- Other company departments on the chain can share data according to priority, and sensitive data can also be shared depending on the situation and level;
- Neither private nor innovative data can be shared.

The data acquisition process after the FGAC authorization is shown in Figure 3. When the property matching step is passed, the DO downloads the data ciphertext and key together, decrypts and compares them, and downloads the required data from the distributed storage system.

The whole process of cargo transportation in the supply chain is illustrated in Figure 3. The data generated in this process are saved on the blockchain Hyperledger Fabric. When users send sharing requests for the data, the data owner can set the relevant attributes and trigger the FGAC mechanism to control the access of the requester, which makes the data in the entire supply chain effectively protected.

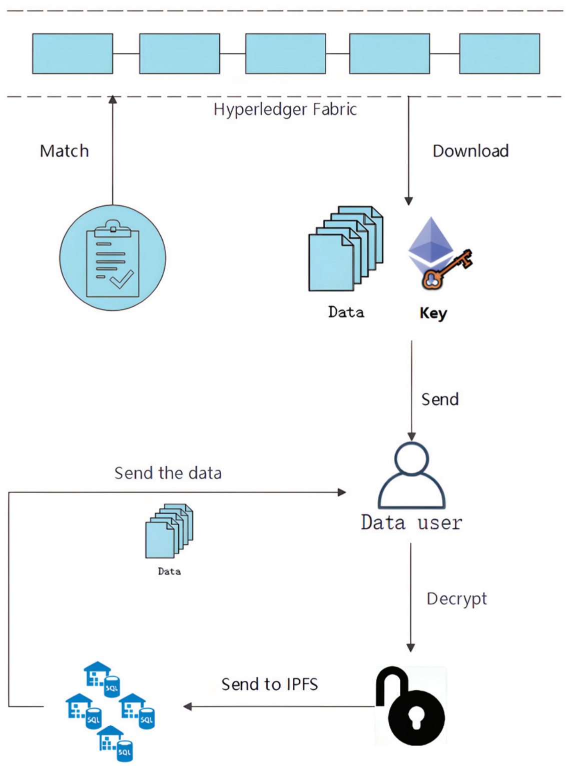

Figure 3. Validated supply chain data process.

5. Experimental Analysis and Verification

5.1. Comparative Analysis

At present, the combination of blockchain technology and access control has become one of the main applications of blockchain systems in data sharing. Table 1 outlines the research on the combination of blockchain and different access control models, which fully reflects the performance advantages of this work. In Table 2, a comparison of the advantages and disadvantages of integrating blockchain into the access control model is provided.

Table 1. Comparison of access control policies.

Scheme	Distributed	Flexibility	Dynamics	Fine-Grained
RBAC [6]	√ [1]	√	√	× [2]
ABAC [7]	√	√	√	×
CapBAC [8]	√	√	×	×
FGAC	√	√	√	√

[1] √ Means the performance is available in this framework. [2] × Means the performance is discrepant in this framework.

From the above two tables, we can see that the FGAC proposed in this paper has both flexibility and fine-grained access control. Compared with several traditional access control methods, it effectively improves the efficiency and security of the system.

Table 2. Integrating blockchain into an access control model.

Scheme	Characteristics
LBAC [32]	It proposes lightweight access control and uses smart contracts to ensure the correctness of outsourced decryption without additional verification on the user side but does not define role attributes.
BHEAC [33]	The blockchain-based token request mechanism allows users to request resources in batches and map the obtained tokens to multiple resources; it avoids repeated requests by users but has a broad division of permissions.
AI applications [15]	Only access control policies and data sharing protocols (DSAs) were designed to explain research strategies and research decisions, and no experiments and validation were performed.
FGAC of this work	It enhances role-based access control by providing different attribute keywords for different types of users. It is implemented in the form of smart contract Chaincodes and evaluated through quantitative verification.

5.2. Verification Results and Analysis

We used the model-checking tool UPPAAL [34] to verify and analyze the FGAC framework. The FGAC framework was modeled as the timed automata, which are shown in Figures 4 and 5, and the corresponding properties were specified as TCTL (timed computation tree logic), which are shown in Table 3. Our experiments were performed on a computer with an Intel (R) Core (TM) i5-9300HF CPU processor at 2.40 GHz, 2667 MHz, 4 cores, and 8 logical processors with 16 GB of RAM, running 64-bit Windows 10. The academic version 4.1.26 of the UPPAAL tool was used.

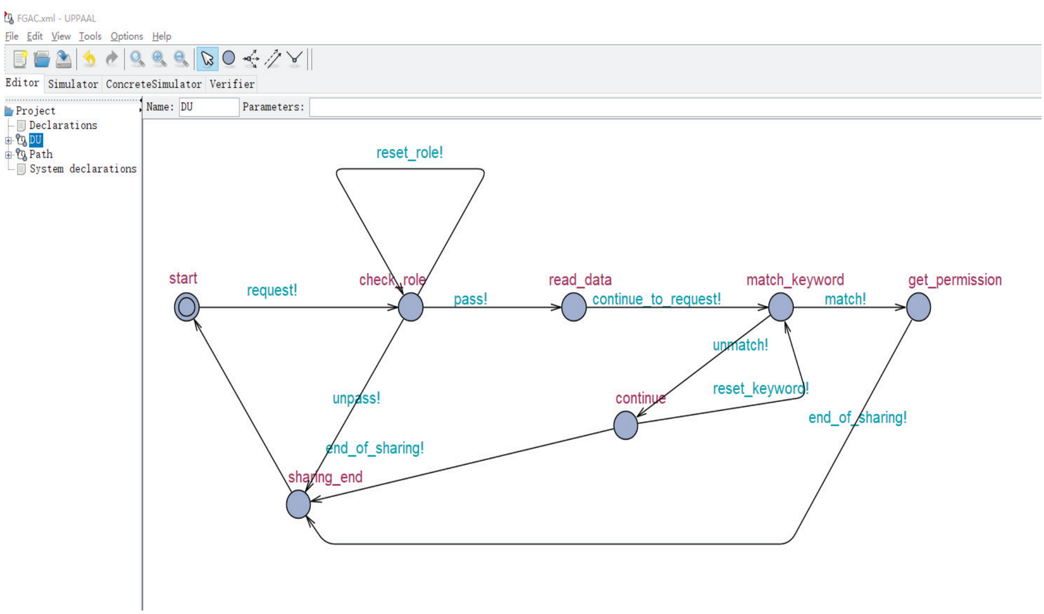

Figure 4. FGAC timed automata model.

Figures 5 and 6 above show the timed automata model and shared path of FGAC, respectively, which were built in UPPAAL. The FGAC model included the status of role checking, data reading, keyword matching, obtaining permission, etc. These statuses start from initiating a sharing request by the DU, after which the DU obtains the responding data through the assessment of the nodes in different statuses, and finally, the sharing process is completed.

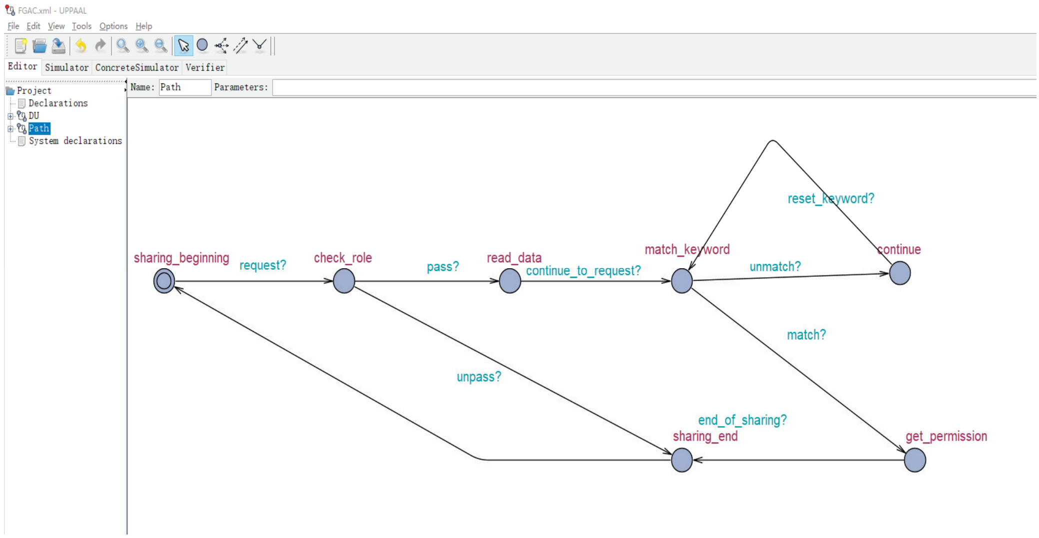

Figure 5. Shared pathway model.

Table 3. Property to be verified in UPPAAL.

Name	Property	Equivalent Property
Possibly	E<>η	
Invariant	A[]η	Not E<>notηη
Potentially always	E[]η	
Eventually	A<>η	Not E[]notηη
Leads to	η→Ψ	A[](ηimply A<>Ψ)

In order to verify the correctness of the model, after using UPPAAL to build the model, it was necessary to further extract the key attributes and verify the key attributes of the FGAC time automaton model. The main properties and corresponding expressions of validation were as follows:

1. The built model has no deadlock; Expression: A[] not deadlock
2. The data users in the above access control framework can normally access the status of read data; Expression: E<>DU1. read data
3. The data users in the above access control framework can normally access the status of obtaining permission; Expression: E<>DU1.get_permission

After triggering events for data sharing, UPPAAL displays the generated tracking trajectory, as shown in Figure 6.

After many experiments, the average value of the verification results we obtained is shown in Table 4.

Table 4 shows the verification results of the above properties in UPPAAL. From the verification results, it can be seen that the FGAC framework satisfies the aforementioned requirements and attributes, such as safety, no deadlock, etc. The FGAC framework could achieve data sharing normally, and access control was performed when user keywords did not match. In addition, it can also be determined whether the system model meets the requirements according to the verification time of the property formula and peak memory usage and can meet the usage time limit and resource constraints.

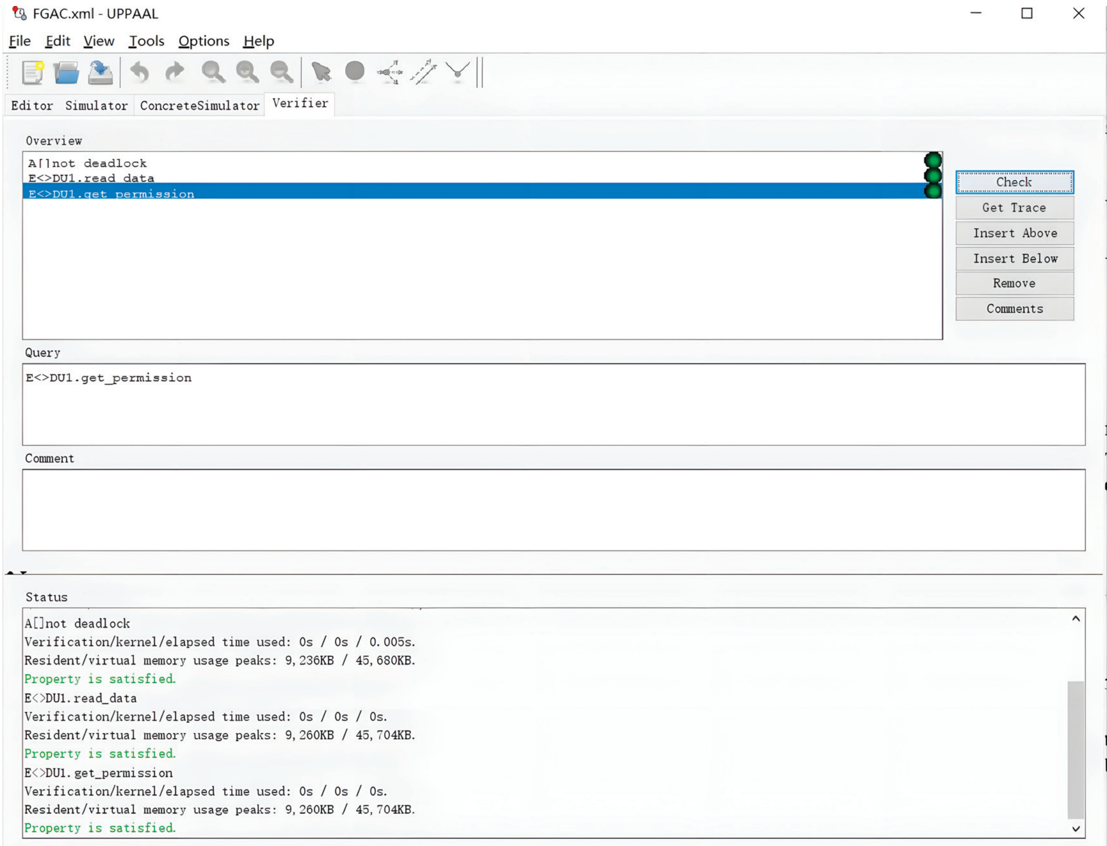

Figure 6. System verification results.

Table 4. System property validation results.

Property Formula	Validation Results	Verification Time	Peak Memory Usage
A[] not deadlock	Pass	0.001 s	9.306 KB
E<>DU1.read_data	Pass	0.001 s	9.236 KB
E<>DU1.get_permission	Pass	0.001 s	9.330 KB

The above comparative analysis and quantitative verification show that the proposed FGAC can effectively implement fine-grained access control in data sharing. It also has the characteristics of flexibility, high efficiency, and non-single-factor control, which effectively improves the security of data in the process of data sharing.

6. Conclusions and Future Work

Based on the blockchain Hyperledger Fabric, in this paper, we proposed a fine-grained access control (FGAC) framework for supply chain data sharing. It enhances role-based access control (RBAC) by providing different attribute keywords for different types of users. It was implemented in the form of smart contract Chaincodes of the blockchain Hyperledger Fabric and evaluated by the quantitative system verification tool UPPAAL. Moreover, it was applied to the supply chain of Shanghai Port to enhance data sharing security. In the future, we will apply the FGAC framework to more scenarios of supply chain data sharing and optimize its performance through system quantitative verification techniques.

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The Influence of Introducing the Concept of Sustainable System Design Thinking on Consumer Cognition: A Designer's Perspective

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Abstract: Environmental problems represent one of the most intensive focuses in the world. At present, the rate of environmental damage caused by peoples' consumption of products and services is still far faster than the rate of regeneration, processing, and recycling of natural ecosystems. In the face of increasingly severe environmental problems, consumers must change their consumption behavior toward a sustainable direction. Based on the ultimate goal of sustainable innovation and development, the introduction of sustainable system design thinking can enable the optimization of sustainable systems for production, manufacturing, consumption, or recycling. As with the concept of traditional system design thinking, sustainable system design thinking is not only a product form but also a creative systematic way to solve problems for the purpose of promoting innovation. It has been transformed from "giving form" to "design process", "design strategy", or "design system". Therefore, this study attempts to explore the potential structure of consumers' sustainable consumption cognition from the perspective of designers through the introduction of sustainable system design thinking. This study combined literature analysis and a questionnaire survey to propose a research model with seven constructs and eight hypotheses and then used a reliability test, validity test, and structural equation model to analyze and verify the data. The results show that the three constructs of design evaluation (aesthetics, innovation, and function) in system design thinking are feasible and effective in sustainable design. With the support of sustainability concept, the autonomy of consumers' consumption attitude and intention will be improved. This study can provide reference to governments, enterprises, and designers when formulating, implementing, and practicing sustainable innovative strategies. The results of this study can further influence the continuous promotion and deepening of sustainable design thinking in the cultivation of design talents in colleges and universities, and thus provide multi-field and recyclable theoretical guidance for sustainable design facing future life.

Keywords: sustainability; system design thinking; system innovation; designer

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1. Introduction

As one of the most important issues in the world at present, environmental problems are focused on by people all over the world. Due to the excessive exploitation of the earth's resources and the lack of corresponding management, resource depletion and environmental damage are caused, which concerns people about the earth's carrying capacity and the future of mankind [1]. Therefore, the United Nations and other international organizations and governments of various countries have put forward various ideas and suggestions to improve the current situation and reduce the damage to the environment and ecology. Among them, The Rio Declaration [2], the United Nations Guidelines for Consumer Protection [3], and other policies actively call on countries to reduce and eliminate unsustainable production and consumption patterns in economic, social, and environmental aspects. This is to meet the needs of present and future generations for goods and services in a sustainable manner, and to include "sustainable consumption and production patterns" [4] as one of the 17 Sustainable Development Goals (SDGs), which aim to help the world completely solve social, economic, and environmental problems by 2030 and achieve sustainable social transformation worldwide. China listed "green" as one of the five development concepts for the first time in the 13th Five-Year Plan and reaffirmed the importance and necessity of "continuously improving environmental quality" and "accelerating the green transformation of development mode" in the 14th Five-year Plan. China has also actively carried out the practice of constructing sustainable developing-related concepts in "developing circular economy" [5], "accelerating the construction of ecological civilization", "promoting green lifestyle" [6], "promoting sustainable consumption" [7], and other aspects.

In fact, the rate of environmental damage caused by human consumption of products and services is still much faster than the rate of regeneration, processing, and recycling of natural ecosystems [8]. Considering increasingly severe environmental problems, consumers must change their consumption behavior toward a sustainable direction [9]. Surveys show that most consumers are willing to protect the environment by purchasing more sustainable products [10]. However, there is a contradiction between consumers' statements on sustainable behavior and the oral expressions and actual intentions (or behaviors) [11]. Although more and more international companies are engaged in sustainable production and consumers are paying more attention to sustainable products, this phenomenon does not translate directly into the actual purchasing behavior of sustainable products [12]. This phenomenon is also called the Green Gap. It is mainly used to explain the attitude–intention–behavior gap in sustainable consumption [10]. At present, consumers have not formed the concept that environmental protection issues take precedence over personal interests, and the imperfect environmental protection laws and regulations also lead to most consumers' superficial approach to environmental protection [13]. In addition, consumers generally believe that the attributes and quality of sustainable products are lower than that of general products, which also leads to the expansion of Green Gap [14]. However, it has been reported that smart cities have not been successful in promoting smart recycling and that the use of a large number of smart recycling systems has been inefficient. A change in the public's intention to participate in recycling affects its effectiveness and the utilization rate of the recycling facilities [15]. The use of recycling facilities is closely related to environmental awareness, but the intention of residents to participate in recycling is at odds with efforts to support the environmental initiative [16]. Therefore, encouraging active public participation in smart recycling is a real challenge [17,18]. On the other hand, the weak environmental consciousness of producers, government departments, and other stakeholders, and the unsystematic and imperfect concept of sustainable development are also important factors affecting sustainable consumption. Relevant surveys show that most enterprises are not aware of sustainable consumption and production. Even if they are aware of sustainable development, they will face downward competition from social consumption due to a lack of consumer recognition or low product profits, and the market cannot form internal motivation for sustainable consumption [19].

In response to this situation, the most common approaches at present are to extend the life cycle of products [20], produce recyclable products, and use recycled materials, innovate systems [21], or establish new business models. Regardless of which approach is adopted, design is considered to be the core of the driving force of system innovation and change [22] and complementary of technological innovation and social innovation [23]. Based on the ultimate goal of sustainable innovation and development, the introduction of sustainable system design thinking can complete the optimization of sustainable systems for production, manufacturing, consumption, or recycling and waste. As with the concept of traditional system design thinking, sustainable system design thinking is not only a product form but a creative systematic way to solve problems for the purpose of promoting innovation [24], which has been transformed from "giving form" to "design process", "design strategy", or "design system" [25]. This also means that designers need to be aware of their new responsibilities and make concrete contributions to the green transition to a sustainable society [26]. If designers follow the concept of sustainability at the beginning of the design and development stage, it will definitely lead the design results in a more environmentally friendly and low-carbon direction. Designers' past consumption experience will also play a key role in the whole design system [27]. Under the influence of the trend of sustainable development, designers can introduce the design method into the sustainable system design thinking to design and develop various sustainable products and indirectly promote consumers' recognition of sustainable value through these sustainable products. Therefore, in the context of sustainable development, the power of design innovation not only drives more consumers to have more recognition of sustainability but also reduces the impact of environmental damage to a certain extent [28]. Therefore, designers play an even more important role in promoting sustainable development, in order to lead consumers to create a highly sustainable society through the professional ability of innovative design.

Designers are consumers themselves. Compared with ordinary consumers, designers have certain experience and levels of product innovation ability as well as aesthetic cultivation and evaluation. At the same time, designers have a deeper familiarity and understanding of sustainable design. Therefore, in a broad sense, designers themselves have dual identities, that is, designers are also consumers, or consumers with a designer identity. When designers are brought into the role of consumers, it is easier to think about how to attract consumers to identify and buy sustainable products through professional ability [29].

Therefore, this study attempts to explore the potential structure of consumers' sustainable consumption cognition from the perspective of designers through introducing sustainable system design thinking. This study mainly focuses on the following points. Firstly, what are the specific implementation methods of sustainable system design thinking? Secondly, from the perspective of causality prediction, a structural equation model is used to analyze the factors affecting consumers' cognition of sustainable consumption. Thirdly, through conceptualization and hypothesis verification, a consumer sustainable consumption cognition model is established for future research by introducing sustainable system design thinking.

2. Literature Review

2.1. Environmental Concerns

Environmental concerns refer to someone's views and concern about environmental issues, or attitude and willingness to protect the environment [30]. International public opinion surveys show that as the global environmental deterioration increases year by year [1], the public's concern about environmental issues remains high, and the vast majority of people regard environmental protection as one of their important personal goals [31]. Environmental concerns will influence the consumption value and consumption choice [32], and consumers' subjective environmental concerns and concern about the environment will influence their purchasing behavior of green products [33]. Consumers' behavioral decisions often depend on their attitude towards the environment [34]. When individuals have higher environmental concerns, they may be more environmentally friendly than others.

In recent years, many designers have realized that what they do is to promote the sales of commodities and products, which leads to consumers' unsustainable consumption behaviors [35]. Therefore, sustainable design thinking is attracting more and more attention from designers and researchers. Most designers feel that the sustainable design education they have received is not perfect because of the troubles brought by environmental problems in their daily life [36]. However, their work experience makes them recognize the importance of environmental protection and sustainability to design and development. To consumers, the production and manufacturing field is too specialized, but designers can serve as a communicator between consumers and the production and manufacturing field and establish a close relationship with them so that consumers can also understand the importance of a sustainable society and their own responsibilities [37]. Moreover, designers are also consumers in life, so the double identity of designers is worth our attention. Therefore, the focus of this paper is to establish a new thinking of user-centered sustainable design by putting designers in the role of consumers.

2.2. Sustainable System Design Thinking

Sustainable system design thinking adds sustainability considerations on the basis of traditional design thinking. Generally, design thinking is considered to be a systematic, critical, and creative design method that explores solutions based on human values, needs, emotions, and desires [38]. In different scenarios or situations, design thinking is called logic, principles, practices, tools, discourse, philosophy, mental model, etc. [39]. Therefore, design thinking is multidimensional and needs to be defined in specific problems and objects. In this study, the role of design thinking in sustainability is emphasized. From the perspective of system design thinking, sustainable design refers to a rationalized and structured process of creating new things to solve problems related to sustainability [40]. It promotes people's understanding of sustainability by changing products, consumer behaviors, business services, and even the social and economic system [23,41]. The role of designers is not only to connect the whole development process but also to integrate the innovative ability and design methods of designers [42] so as to find the best sustainable solution for design and development. From the perspective of products, sustainable design usually needs to incorporate environmental factors and pollution prevention measures into product design at the design stage and take environmental performance as the design goal and starting point of products, so as to minimize the impact of products on the environment [43]—for example, using a product service system to reduce waste and resource consumption caused by product purchasing, using green design and ecological design to solve the impact of existing products on the environment, and connecting enterprises and community through social innovation design. Therefore, as a system attribute rather than an attribute of various elements in the system, sustainability needs to be gradually realized through system design thinking [23].

Christensen and Ball believe that the evaluation of design is reflected in three dimensions, including aesthetic value, innovation value, and functional value, and these three dimensions can help predict designers' thoughts or behaviors [44]. Innovation value is a very important attribute in design. Meanwhile, aesthetic value and functional value are "two high-level and important values in design" [44,45]. Buhl et al. believe that sustainability-oriented innovation should have a system scope to explain multidimensional objectives [46], while system design thinking is to implement design concepts into the design process and manufacturing process in a user-centered approach [47]. Therefore, we integrate the three dimensions of aesthetic value, innovation value, and functional value with system design thinking to form the concept of sustainable system design thinking and then introduce it into the consumer cognitive mode, and we carry out subsequent research and discussion on this basis and establish research models and hypotheses.

2.2.1. Sustainable Aesthetic Value

The essence of design is to make things in the world more beautiful, useful, elegant, and gorgeous [48]. Emphasis on beauty in product design is not only conducive to product usefulness but also to the success of products in the market [49]. However, when it comes to sustainable design, due to the principle of the reduction and recycling of materials, compared with general products, the aesthetic feeling and design sense are decreased. However, some scholars have found that if the method of design aesthetics is injected into sustainable design, this phenomenon can be improved. Claxton and Kent believe that consumers can carry out multi-season mixing and matching through reasonable color matching and prolong material life, thus extending the lifecycle of clothing products [50]. In a relatively simple way, the design aesthetic feeling of products can be maintained and the product strength can be greatly improved [51]. Meanwhile, it also caters to the concept of sustainable design. For example, modern aesthetic techniques such as contrast, deconstruction, and realistic or minimalist style are used to express environmental thinking to consumers or emphasize the scientific and technological aesthetic feeling of innovative and sustainable technology.

On the other hand, the accumulation and training of aesthetic quality of designers come from the learning of professional design education, so they have a stronger perception of aesthetics than ordinary consumers and easily become pioneers in leading the trend. Designers' pursuit of both the beauty and function of products is the necessary attitude and responsibility of consumers. Therefore, designers must pay more attention to the transmission of sustainable concepts in the design-implementation process and ensure that sustainability is achieved through the use of the known design methods, such as sustainable design standards, product semantics, and emotional design approaches. Designers can deliver the basic requirement of the aesthetic feeling of product forms to consumers. Consumers can also effectively prolong the lifecycle of the product and understand the importance of sustainability concepts. As a result, designers can obtain balance in executing the concept of sustainable products and aesthetic pursuits. However, the perception of design aesthetics mainly depends on the quality of a specific individual (individual, group, or society), and the perceived aesthetic differences of different individuals may lead to the differentiation of product reputation. Therefore, from the perspective of perception, aesthetics is the most influential part of the three dimensions on consumers' judgment, so the aesthetic cultivation of designers is very important and even affects consumers' judgment on the aesthetic feeling of product types.

2.2.2. Sustainable Innovation Value

Under the 17 Sustainable Development Goals proposed by the United Nations, the prospect of sustainable development has more possibilities [52]. Therefore, the active international investment in sustainable development increasingly highlights the higher value attached to a sustainable future. The effective progress of sustainability is conducive to the continuous commitment of various economic and innovation activities at all industrial levels to sustainable development, transforming the traditional market into an emerging development prospect with sustainable innovation value [46,53]. The input of these industries to sustainable development also indirectly affects the effective utilization of resources and the innovation of production efficiency. Therefore, in addition to the sustainable social responsibility of the enterprise, the accumulated green image and sustainable business strategy also promote consumers to have more trust in the enterprise [54]. In addition to the industrial end of sustainable innovation, the active fields of sustainable innovation include the promotion of green activities of various circular economy so as to expand the breadth of enterprise product lifecycle from the perspective of effective development of circular economy [55]. Additionally, with the continuous increase in the concept and investment of the product service system, ordinary consumers have the opportunity and focus to transform into green consumers. It also lays a strong development condition and foundation for sustainable innovation and related industries, which not only expands future prospects but also establishes a complete green service system [56]. Therefore, as the population base of emerging sustainable consumers continues to grow, enterprises are willing to invest in more innovative research and development of sustainable products and become more enthusiastic about the production and supply of sustainable innovation [57].

In addition, sustainable innovation also means that designers add the concept of sustainable goals into their creative development process under existing constraints. In particular, designers strive to develop materials, assembly parts, and related hint symbols in accordance with the needs so as to enhance the value of sustainability [58]. In this way, the sustainable innovation value is immeasurable behind the creative products designed by designers. Correspondingly, enterprises are willing to invest more resources in the cultivation of sustainable talents so as to achieve a virtuous cycle mechanism of sustainable talents and a mutually beneficial multiplication of consumers, designers, and enterprises [59]. As the most creative people in the whole enterprise, designers can provide added value to sustainable brands from a creative perspective, such as logo, mascot, brand packaging, etc. In this way, consumers can perceive the uniqueness of sustainable products [60], have more trust and goodwill towards products, and further perform more purchase behaviors.

2.2.3. Sustainable Function Value

In the design evaluation stage, the consideration of usefulness or functional value is an important part [61], and also one of the methods to improve consumer satisfaction [62]. The functional value of generally designed products is reflected in various social factors, such as culture, fashion, health, etc. [63]. From the perspective of sustainability, the functional value of a product is reflected in whether the product can effectively participate in sustainability in the stages of design, development, use, and recycling. Therefore, sustainable functional design and functional value require designers to consider more specific methods, tools, or steps of sustainable design development.

As tools for sustainable product design and development, the product life cycle and product simplification can better assist designers in their design work [64]. The reason is that if designers want to improve the environmental protection properties of the product and perceptions of consumers, they should aim to simplify the product to achieve the optimal manufacturing process and modular replacement (production or consumer use phase) or use lifecycle assessment analysis, which refers to the comprehensive consideration of the product from raw-material extraction to the final disposition of the environmental impact, to extend the product life [65]. Ortiz and Castells argued that product life-cycle assessment (LCA) can be used to evaluate individual product materials and components, thereby assessing the product life cycle after composition [66]. Similarly, designers often need to analyze the environmental lifecycle performance of their designed products through product LCA results [67]. Therefore, this study considers that product lifecycle assessment is an inevitable consideration for designers in sustainable design and development. In system design, in order to achieve the sustainable goal, it is necessary to reduce the generation of waste in the whole production system and establish the collaborative connection between the production process, natural process, and local resources [23]. Therefore, designers are also required to play a positive role in the whole system. Among the 6R concepts [68], the most relevant ones to designers are 'Reduce', 'Reuse', and 'Recycle', which are also in line with product lifecycle considerations. Designers must consider the complete 6R of the product design, development, production, and use phases, in other words, simplifying the product design. Common methods are design for disassembly, design for remanufacturing, design for recycling, and modular design. However, product simplification is performed not to reduce the function and beauty of the product but to reduce the waste of space, material, process, or use in the product through the design experience and ability of the designer, so as to achieve the effect of product sustainability [43].

2.3. Value–Attitude–Behavior (VAB) Model

Homer and Kahle put forward the value–attitude–behavior model in 1988 to explain the flow of individual cognition: "influence should flow from abstract values to midrange attitudes to specific behaviors" [69]. The model is considered to be a valid theoretical basis for predicting individual behavior or intentions. In their model, value is interpreted as an individual's persistent belief that a particular behavior or pattern of behavior is personally and morally preferable [70]. In the research of consumer behavior, value perception will affect the value of consumer domain and the product attribute belief. Consumers' value perception will affect the product attribute belief, while the product attribute belief will affect consumers' attitude towards products [71]. In this study, as with the dual identity of the designer, value also has a multi-meaning. In other words, aesthetic value, innovation value, and functional value under sustainability are the value embodiment of designers' design and development elements and sustainable products guided by sustainable system design thinking with environmental consciousness as a starting point. In addition, these three values also need to be perceived by consumers and guide or change consumers' consumption attitudes and intentions through value guidance.

The value–attitude–behavior model is generally used to explain the direct and indirect relationship between value, attitude, and behavior. In addition to the basic model application, the value–attitude–behavior model has also been used variously by different scholars. Cheung and To established an extended value–attitude–behavior model and explained the green purchasing behavior of Chinese consumers [72]. Tajeddini et al. explored the decision-making process of guests in Airbnb and hotel accommodation by using value–attitude–behavior model and planned behavior theory [73]. Lee et al. explored the moderating effect of 3D-printed food attributes and food phobias, which explained behavioral stages with intention and tested the relationship between value and attitude [74]. This is consistent with the model constructed in this study and provides strong evidence for the research theory of this study.

The attitude and intention of individuals have been discussed in many models, including the Theory of Reasoned Action [75], Theory of Planned Behavior [76], and Technology Acceptance Model [77]. In these models, attitude is interpreted as an individual's internal experience that affects an individual's intention, while intention is an individual's tendency to take action [78]. Generally speaking, consumers' sustainable consumption attitude refers to individuals' positive or negative evaluation of sustainable products, while sustainable consumption intention refers to individuals' self-commitment to purchase sustainable products [79]. Thus, there is a correlation between sustainable consumption attitudes and intentions, especially when evaluating specific environmentally friendly products or behaviors, such as sustainable products, green hotels, or organic food. Verma et al. believe that attitude plays a more positive role in environmental protection behavior, and consumers' specific attitude towards energy-saving products will positively affect their purchase intention [80]. Malik and Singhal found that consumers with a stronger sustainable consumption attitude would prefer to buy environmentally friendly products [81]. If consumers' attitudes towards the environment are changed, their intentions and behaviors towards the environment can be further changed [82]. More and more consumers are willing to change their purchasing habits by buying more sustainable products [10].

2.4. Sustainable Policy

In recent years, due to high energy consumption, how to curb excessive carbon emissions has attracted high international attention. Governments of various countries and regions have formulated relevant laws and regulations on energy conservation and emission reduction to prohibit relevant enterprises from carrying out high-pollution manufacturing [83], and stimulate enterprise transformation with incentive policies [84]. In order to gain benefits from government incentive measures, enterprises must adopt green technologies or improve existing technologies to reduce carbon emissions [85]. Some automobile enterprises are also forced to produce three-cylinder vehicles or electric vehicles to meet the carbon emission targets set by the state. China is also actively formulating environmental policies, from national strategies to individual policies and regulations. The garbage classification system has been promoted in recent years, although the recovery rate is still very low at the present stage [86]; consumers also lack the corresponding cognition of garbage classification recovery. From the perspective of consumption, policies can help. For example, due to policy regulations, publicity, and reward and punishment systems, consumers have begun to understand dry waste and wet waste, and gradually learned about garbage classification; subsidy policies for new energy vehicles will affect consumers' attitudes towards new energy vehicles and stimulate their purchase intentions and behaviors [87], etc. Therefore, designers need to maintain high sensitivity, respond to current policies and regulations on green environmental protection, inject sustainable system design thinking into product design and development, assist enterprises in green production and manufacturing, and try to guide and change consumers' cognition and behavior. This also means that the higher consumers' perception of policies and regulations, the more obvious the attitude and intention of sustainable consumption. As consumers, designers can perceive the rapid establishment and implementation of sustainable policies and also realize the important role of sustainability in design, so it will also affect the product design and development stage.

3. Research Structure and Methodology

3.1. Research Process

The purpose of this study is to investigate whether the concept introduction of sustainable system design thinking has guiding significance for consumers with designer identity in future design and development. In order to explore the relationship between different dimensions, structural equation modeling was used to analyze the data. Hair [88] pointed out that the steps to establish the research framework and process include the following (Figure 1): (1) the first step is to review and discuss the literature, revise the research results of previous scholars, construct the theoretical framework of this study, and establish statistical hypotheses for each dimension. (2) The second step is to establish a theoretical framework and design questionnaire and conduct survey, as well as questionnaire reliability analysis according to the topic discussed. (3) The third step is to establish a research model based on the theoretical framework of this study. Confirmatory factor analysis, convergence validity, and discriminant validity are used to verify the fitness of the model. (4) The fourth step is to use a structural equation model to analyze and verify the validity of the statistical hypothesis between each dimension.

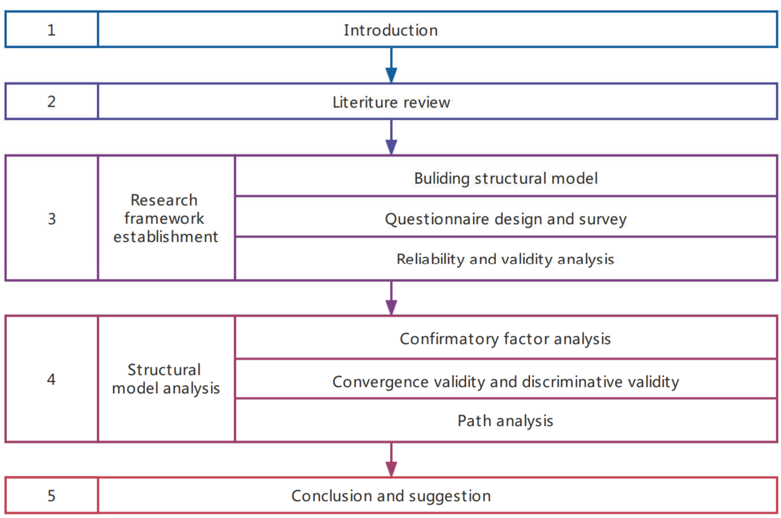

Figure 1. Research process.

3.2. Research Object

This research requires designers to substitute themselves into two identities (designer and consumer) and understand the consumer cognitive model introduced by the sustainable system design thinking concept constructed in this research through their own design skills and experience and consumption experience as consumers. This study believes that designers and consumers are mutually complementary and mutually reinforcing. Designers design products that meet consumer needs, and consumer satisfaction, in turn, fuels designers' inspiration and enthusiasm. Therefore, when designers have dual identities, they can better appreciate similarities and differences and deduce relevant results. Considering that sustainable products are not limited to industrial products, clothing, advertising, architecture, etc. can all be included in the scope of sustainable products; therefore, the research object is designers from all fields. It is worth mentioning that the double identity that we emphasize is the consumer with the identity of designer. We asked the target respondents to reflect on the deficiencies in the design or environmental attributes of the items or products they used, and to explore the possibilities for improvement through the concept of sustainable design thinking in this study.

This study attempts to propose a consumer cognitive model of sustainable system design thinking based on the dual role of designers. It is hoped that the model will be introduced in the next stage for verification research. In the past, there have been a lot of introductory studies on participatory design methods that allow consumers to actively participate in the product design and development process. The introduction of participatory design is to narrow the distance between the mental model of design developers and consumers so that the final product will not fall into the vortex of "over-design" and reduce the failure rate of products. Especially in a consumer era of iteration and development, product design, development, and positioning are more likely to be dominated by consumers. Therefore, the rise of consumer awareness also promotes public participation in the progress of society more effectively than in the past. The dual identity given to the respondents of this study, that is, consumers with designer identity, can obviously play a more helpful and efficient role in the process of product design and development, reduce the product failure rate, and prolong the life cycle of products.

3.3. Research Structure and Model

Based on the literature review and the sustainable theme of this study, a theoretical model is constructed from the designer's environmental concerns and based on the value–attitude–behavior model. The three dimensions of aesthetic value, innovative value, and functional value of design evaluation are regarded as the necessary factors in the design and development stage to construct the design dimension. The consumption dimension is composed of sustainable policy, sustainable consumption attitude, and sustainable consumption intention. Finally, a consumer cognitive model combined with the concept of sustainable system design thinking in this study is formed (Figure 2), and eight related research hypotheses are established.

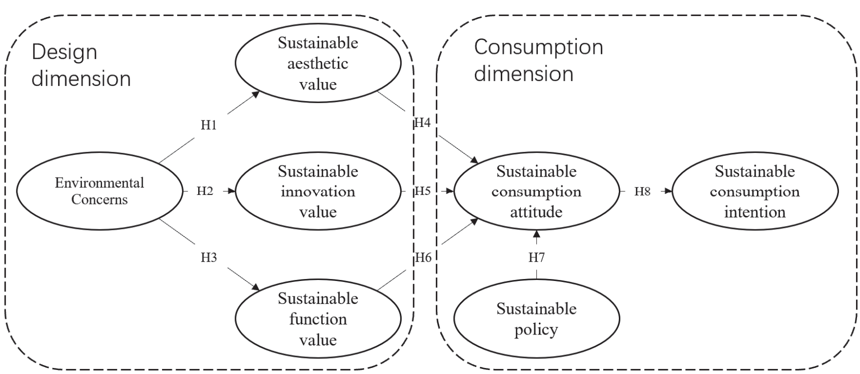

Figure 2. Theoretical model.

Hypothesis 1 (H1). *Environmental concerns significantly influence sustainable aesthetic value.*

Hypothesis 2 (H2). *Environmental concerns significantly influence sustainable innovation value.*

Hypothesis 3 (H3). *Environmental concerns significantly influence sustainable functional value.*

Hypothesis 4 (H4). *Sustainable aesthetic value significantly influences sustainable consumption attitude.*

Hypothesis 5 (H5). *Sustainable innovation value significantly influences sustainable consumption attitude.*

Hypothesis 6 (H6). *Sustainable functional value significantly influences sustainable consumption attitude.*

Hypothesis 7 (H7). *Sustainable policy significantly influences sustainable consumption attitude.*

Hypothesis 8 (H8). *Sustainable consumption attitude significantly influences sustainable consumption intention.*

3.4. Definitions of Research Variables

Structural equation modeling is generally used to verify the causal relationship between different permutations and combinations of inherent variables. In this study, four new factors are constructed according to the concept of sustainable system design thinking. Therefore, the items of the new factors will be reconstructed by referring to the existing literature and discussed internally by the authors. This study designed the questionnaire items according to the research theme and relevant literature. Reference sources for variable definitions, items and scales are shown in Table 1.

Table 1. Reference sources for variables and items.

Variable	Operational Definition	Reference
Sustainable policy	The extent to which policies and regulations affect consumers' attitudes towards sustainable consumption.	[89]
Sustainable aesthetic value	Designers' perception of aesthetic value and the impact of aesthetic value on sustainable consumption attitude.	[44,90]
Sustainable innovation value	Designers' perception of innovation value and the impact of innovation value on sustainable consumption attitude.	[44,90]
Sustainable functional value	Designers' perception of functional value and the impact of functional value on sustainable consumption attitude.	[44,90]
Environmental concerns	The designer's self-perception of environmental concerns.	[39,91]
Sustainable consumption attitude	The actual attitude and evaluation of sustainable products from the consumer perspective.	[92,93]
Sustainable consumption intention	The extent to which a consumer's perspective actually influences decisions about sustainable products.	[92,94]

3.5. Research Samples and Questionnaires

The survey was conducted online from January to March 2022. Ethical approval for this study was obtained from the National Cheng Kung University Human Research Ethics Committee. In addition to demographic variables, a 7-point Likert scale was used, ranging from 1 (strongly disagree) to 7 (strongly agree). Considering that the subject of this study was a specific profession (designer), a snowball sampling method was adopted by inviting designer friends to fill in the form and then asking them to send forms out to other designers [95]. The specific way of questionnaire distribution is to push QRcode and webpage links through Wechat private chat, Wechat moments, Weibo, and other forms. All respondents browsed the questionnaire's website to view the research description. They volunteered to answer questionnaires and could withdraw from the survey at any time. Therefore, all respondents agreed to complete the questionnaire under the principle of being fully informed and voluntarily participating.

At the beginning of the questionnaire, in addition to the basic research statement, designer respondents are required to understand the aesthetic value, innovation value, and functional value defined in this study, and perceive the role of the three values in the design dimension as designers, and then perceive the role of the three values in the consumption dimension as consumers. For example, in functional value, this study will inform designers of the definition, practice, and significance of functional value in the study: the presentation form of functional value can improve and design environmental protection packaging of existing products and new products (such as using less paper and plastic materials; using the minimum amount of materials to develop and design products; considering whether the product is easy to recycle, reuse, decompose; etc.). It is used to facilitate the designer to understand and answer the questionnaire. At the same time, we asked designers to recall whether they found any deficiencies or defects in design or environmental-protection attributes of some products in their daily life, and to evaluate whether the sustainable system design thinking of this study would have any guiding role or significance in product design or improvement if they were developing or modifying products.

Finally, 433 samples were collected in this study. After removing invalid samples (due to logical errors or too many of the same options), 386 samples were left, and the validity rate was 89.15%. In this study, there were 28 questionnaire items, and 386 questionnaires met Jackson's standard that the ratio of estimated parameters to sample number should be higher than 1:10 [96], so the sample size was suitable for subsequent data analysis. According to the data of subjects in valid questionnaires, the distribution of demographic variables in this study is shown in Table 2.

Table 2. Sample description.

Category	Items	Frequency (n = 386)	Ratio (%)
Gender	Male	117	30.31
	Female	269	69.69
Age	Younger than 30	161	41.71
	31–40	189	48.96
	41–50	27	7.00
	Older than 51	9	2.33
Marriage status	Unmarried	197	51.04
	Married	189	48.96
Monthly income	Less than 4000	30	7.77
	4001–8000	129	33.32
	8001–12,000	165	42.75
	12,001–16,000	45	11.66
	More than 16,001	17	4.40
Educational status	Junior high school or below	0	0.00
	High school or junior college	0	0.00
	University	198	51.29
	Graduate school or above	188	48.71
Major	Industrial Design/Product Design	172	44.56
	Visual Communication Design	57	14.78
	Environmental Art Design	22	5.7
	Architectural Design	26	6.7
	Digital Media Design	35	9.07
	Clothing Design	74	19.17

4. Results and Discussion

4.1. Reliability Analysis

In order to make the results more reliable, this study first conducted reliability analysis and item analysis on the questionnaire data to delete the unstable items and test the reliability and identification degree of the questionnaire data. As shown in Table 3, Cronbach's α values of each dimension were all greater than 0.7, and Cronbach's α values of any dimension after deleting any of the included items were all lower than the current results, indicating that none of the items should not be deleted in this test. It shows that the reliability quality of the data is good and the data can be used for further analysis.

Table 3. Reliability and item analysis of dimension items.

Dimension	Item	CITC	Cronbach's α after Item Deletion	Cronbach's α
EC	EC1	0.650	0.727	0.798
	EC2	0.582	0.762	
	EC3	0.629	0.739	
	EC4	0.580	0.762	
AV	AV1	0.571	0.680	0.751
	AV2	0.595	0.666	
	AV3	0.566	0.682	
	AV4	0.458	0.739	
IV	IV1	0.527	0.734	0.768
	IV2	0.604	0.693	
	IV3	0.575	0.709	
	IV4	0.569	0.713	
FV	FV1	0.649	0.753	0.811
	FV2	0.637	0.759	
	FV3	0.640	0.757	
	FV4	0.588	0.782	
SP	SP1	0.601	0.737	0.790
	SP2	0.576	0.751	
	SP3	0.628	0.723	
	SP4	0.591	0.742	
SA	SA1	0.654	0.722	0.797
	SA2	0.562	0.769	
	SA3	0.591	0.754	
	SA4	0.625	0.738	
SI	SI1	0.628	0.738	0.798
	SI2	0.540	0.782	
	SI3	0.674	0.716	
	SI4	0.602	0.751	

4.2. Exploratory Factor Analysis

In this study, exploratory factor analysis was used to test the unidimensionality of the seven dimensions of the hypothesis model. Firstly, principal component analysis was used to extract new factors with eigenvalues greater than 1 in each dimension. The results showed that the KMO (Kaiser–Meyer–Olkin) value of each dimension was greater than 0.7, and the significance of Bartlett sphericity test was less than 0.05, indicating that the questionnaire samples in this study were suitable for exploratory factor analysis [97,98]. A total of seven dimensions with eigenvalues greater than 1 were extracted, and the cumulative interpretation of variation was 62.7%, while the interpretation of single dimension was less than 40%. There was no single dimension that explained most of the interpretation of variation, which was in line with Thompson's criteria. Therefore, it can be proved that the questionnaire in this study did not show common method variation [99]. In addition, it can be seen from Table 4 that in the default model, the items of each dimension are well aggregated in the corresponding dimension, which indicates that the default model of this study is reliable. In addition, the factor loading of AV4 item in the aesthetic value dimension was lower than 0.4, so AV4 was deleted at this stage for subsequent structural equation model analysis.

Table 4. Rotated factor analysis component matrix of dimension items.

Dimension	Item	Component						
		1	2	3	4	5	6	7
EC	EC1	0.124	0.730	0.142	0.101	0.162	0.174	0.198
	EC2	0.196	0.667	0.175	0.188	−0.019	0.190	0.120
	EC3	0.179	0.719	0.095	0.163	0.235	0.140	0.070
	EC4	0.049	0.692	0.201	0.146	0.162	0.131	0.111
AV	AV1	0.069	0.201	0.281	0.102	0.197	0.268	0.601
	AV2	0.143	0.040	0.146	0.134	0.143	0.240	0.746
	AV3	0.173	0.236	0.027	0.160	0.122	0.061	0.755
	AV4	0.305	0.133	0.233	0.232	0.223	0.149	0.364
IV	IV1	0.220	0.198	0.080	0.165	0.308	0.552	0.075
	IV2	0.137	0.174	0.139	0.101	0.113	0.740	0.183
	IV3	0.047	0.163	0.295	0.175	0.168	0.628	0.200
	IV4	0.266	0.176	0.115	0.155	0.086	0.672	0.143
FV	FV1	0.068	0.166	0.149	0.725	0.299	0.163	0.071
	FV2	0.186	0.164	0.126	0.736	0.197	0.147	0.050
	FV3	0.175	0.111	0.254	0.682	0.142	0.117	0.203
	FV4	0.226	0.239	0.150	0.621	0.029	0.146	0.265
SP	SP1	0.322	0.129	−0.008	0.075	0.688	0.212	0.136
	SP2	0.208	0.118	0.259	0.166	0.627	0.016	0.217
	SP3	0.098	0.231	0.156	0.200	0.720	0.135	0.092
	SP4	0.128	0.090	0.205	0.234	0.649	0.236	0.135
SA	SA1	0.708	0.205	0.094	0.148	0.207	0.172	0.186
	SA2	0.614	0.099	0.179	0.211	0.206	0.192	0.032
	SA3	0.702	0.087	0.262	0.076	0.118	0.126	0.134
	SA4	0.693	0.159	0.207	0.167	0.142	0.109	0.133
SI	SI1	0.279	0.125	0.691	0.199	0.124	0.111	0.089
	SI2	0.091	0.114	0.633	0.157	0.151	0.269	0.134
	SI3	0.217	0.216	0.738	0.169	0.144	0.109	0.084
	SI4	0.270	0.271	0.588	0.140	0.147	0.123	0.211
Eigenvalue		2.729	2.666	2.561	2.552	2.532	2.364	2.151
Variance interpretation		9.746	9.521	9.145	9.115	9.042	8.444	7.684
Cumulative variance interpretation					62.7%			
Kaiser–Meyer–Olkin						0.947		
Bartlett's sphericity test		Approximate chi-square				4559.037		
		df				378		
		Sig.				0.000		

4.3. Measurement Model

AMOS V22.0 was used in this study to conduct confirmatory factor analysis on the measurement model. AMOS was used for analysis in a large number of studies, which proved to be reliable structural equation modeling software. According to a study by Anderson and Gerbing, data analysis can be divided into two stages [100]. The first stage is the measurement model, which adopts the maximum likelihood estimation method, and the estimated parameters include factor loading, reliability, convergent validity, and discriminant validity [100]. According to the studies of convergent validity by Hair et al. [89], Nunnally [101], Fornell and Larcker [102], and the standardized factor loading by Chin [103] and Hooper et al. [104], the standardized factor loading in this study is higher than 0.7. In this study, the standardized factor loading is higher than 0.7, and the reliability of the composition of the research dimension is higher than 0.7, while the mean variance extraction is between 0.456 and 0.519 (close to or higher than 0.5) [88], indicating that the dimension has good convergent validity (Table 5).

Table 5. Convergent validity results of measurement model.

Dimension	Item	Unstd. Factor Loading	S.D.	Unstd. Factor Loading/S.D.	*p* Value	Std. Factor Loading	Composite Reliability	AVE
EC	EC1	1.000	-	-	-	0.751	0.800	0.501
	EC2	0.886	0.072	12.224	0.000	0.675		
	EC3	0.922	0.070	13.142	0.000	0.729		
	EC4	0.831	0.068	12.133	0.000	0.670		
AV	AV1	1.000	-	-	-	0.732	0.737	0.484
	AV2	1.040	0.090	11.523	0.000	0.689		
	AV3	0.926	0.083	11.219	0.000	0.667		
IV	IV1	1.000	-	-	-	0.645	0.769	0.456
	IV2	1.157	0.105	10.981	0.000	0.690		
	IV3	1.115	0.101	11.003	0.000	0.692		
	IV4	1.024	0.095	10.733	0.000	0.669		
FV	FV1	1.000	-	-	-	0.739	0.812	0.519
	FV2	0.990	0.076	13.037	0.000	0.719		
	FV3	0.999	0.075	13.316	0.000	0.736		
	FV4	0.902	0.072	12.455	0.000	0.686		
SP	SP1	1.000	-	-	-	0.693	0.791	0.486
	SP2	1.040	0.090	11.550	0.000	0.677		
	SP3	1.076	0.089	12.116	0.000	0.717		
	SP4	0.996	0.084	11.916	0.000	0.702		
SA	SA1	1.000	-	-	-	0.760	0.799	0.499
	SA2	0.860	0.070	12.220	0.000	0.662		
	SA3	0.864	0.069	12.610	0.000	0.683		
	SA4	0.900	0.068	13.189	0.000	0.714		
SI	SI1	1.000	-	-	-	0.714	0.800	0.501
	SI2	0.872	0.078	11.129	0.000	0.624		
	SI3	1.004	0.075	13.381	0.000	0.764		
	SI4	0.963	0.075	12.884	0.000	0.731		

Fornell and Larcker's [102] study was adopted for discriminant validity analysis. If the square root of AVE of each dimension is greater than the correlation coefficient between any pair of dimensions, the model has discriminant validity. The results show that all the values on diagonal in this study are greater than those outside the diagonals, indicating that each dimension of this study has good discriminant validity (Table 6). Therefore, the data in this study have good convergent validity and discriminant validity, so they can be used for further analysis.

Table 6. Discriminant validity results of measurement model.

	AVE	SD	AV	IV	FV	SP	SA	SI
SD	0.501	0.708						
AV	0.435	0.482	0.696					
IV	0.456	0.552	0.551	0.675				
FV	0.519	0.527	0.493	0.537	0.721			
SP	0.484	0.498	0.502	0.558	0.567	0.697		
SA	0.499	0.490	0.479	0.543	0.535	0.568	0.706	
SI	0.501	0.541	0.502	0.558	0.569	0.535	0.598	0.708

NOTE: The items in bold on the diagonal are the square root of AVE. Other elements are correlation value.

4.4. Model Estimantion

Based on the studies of Jackson et al. [105], Kline [106], Schumacker and Lomax [107], and Hu and Bentler [108], several indexes (MLχ^2, DF, χ^2/DF, RMSEA, SRMR, NNFI, CFI, GFI, AGFI, PGFI, PNFI, IFI) were selected to evaluate the fitness of the structural model. Environmental concerns, sustainable aesthetic value, sustainable innovation value, sustainable functional value, sustainable policy, sustainable consumption attitude, and sustainable consumption intention were measured according to the research hypotheses and model. It can be seen from Table 7 that, except for NFI, all standard model fitness evaluation indices meet both the independent level and combination rules of the recommended fitness, which proves that the structural model has good fitness. The theoretical framework of the research hypothesis is consistent with the actual survey results.

Table 7. Results of measurement model fitness.

Fitness Indices	Ideal Range	Results	Judgement
$ML\chi^2$	Larger is better	517.113	
DF	Larger is better	315.000	
χ^2/DF	$1 < \chi^2/DF < 5$	1.642	support
RMSEA	<0.08	0.041	support
SRMR	<0.08	0.049	support
TLI (NNFI)	>0.9	0.946	support
CFI	>0.9	0.951	support
NFI	>0.9	0.885	nonsupport
GFI	>0.8	0.907	support
PGFI	>0.5	0.756	support
PNFI	>0.5	0.795	support
IFI	>0.9	0.952	support

Note: $ML\chi^2$ = maximum likelihood chi-square test, DF = degree of freedom, χ^2/DF = ratio of χ^2 to degree of freedom, RMSEA = root mean square error of approximation, SRMR = standardized root mean squared residual, CFI = comparative fitness index, NNFI = non-normed fit index, GFI = goodness-of-fit index, AGFI = adjusted goodness-of-fit index, PGFI = parsimony goodness-of-fit index, PNFI = parsimony normed fit index, IFI = incremental fitness index.

4.5. Path Analysis

According to the path analysis results, environmental concerns (EC) significantly affected the sustainable aesthetic value (AV) (b = 0.747, p = 0.000), sustainable innovation value (IV) (b = 0.726, p = 0.000), and sustainable functional value (FV) (b= 0.795, p = 0.000). Sustainable aesthetic value (AV) (b = 0.156, p = 0.043), sustainable innovation value (IV) (b = 0.312, p = 0.001), sustainable functional value (FV) (b =0.253, p = 0.000), and sustainable policy (SP) (b = 0.332, p = 0.000) significantly affected the sustainable consumption attitude (SA). The sustainable consumption attitude (SA) (b = 0.829, p = 0.000) significantly affected the sustainable consumption intention (SI).

The explanatory power of environmental concerns (EC) to sustainable aesthetic value (AV), sustainable innovation value (IV), and sustainable functional value (FV) was 59.1%, 69.1%, and 59.9%, respectively. Sustainable aesthetic value (AV), sustainable innovation value (IV), sustainable functional value (FV), and sustainable policy (SP) had 70.0% explanatory power to the sustainable consumption attitude (SA). The explanatory power of the sustainable consumption attitude (SA) to sustainable consumption intention (SI) was 67.5%.

4.6. Hypothesis Verification

The purpose of this study is to use the structural equation model (SEM) to find out the consumer's sustainable consumption cognition model integrated with sustainable system design thinking, and form the research strategy based on this, so as to provide reference for relevant scholars and practitioners. Table 8 shows the regression coefficients of the structural equation model in this study. The larger the coefficient is, the more important the independent variable is in the dependent variable. The results show that all the hypotheses of this research model are valid, and Figure 3 shows the relationship between factors.

Table 8. Regression coefficient.

Fitness Indices	Dependent Variable	Independent Variable	Unstd. Estimate	S.D.	Unstd. Estimate /S.D.	*p* Value	Std. Estimate	R^2	Results
H1	AV	EC	0.747	0.073	10.201	0.000	0.769	0.591	Valid
H2	IV	EC	0.726	0.073	10.008	0.000	0.831	0.691	Valid
H3	FV	EC	0.795	0.075	10.628	0.000	0.774	0.599	Valid
H4	SA	AV	0.156	0.077	2.024	0.043	0.150	0.700	Valid
H5	SA	IV	0.312	0.096	3.262	0.001	0.269		Valid
H6	SA	FV	0.253	0.070	3.597	0.000	0.257		Valid
H7	SA	SP	0.332	0.080	4.144	0.000	0.309		Valid
H8	SI	SA	0.829	0.074	11.269	0.000	0.822	0.675	Valid

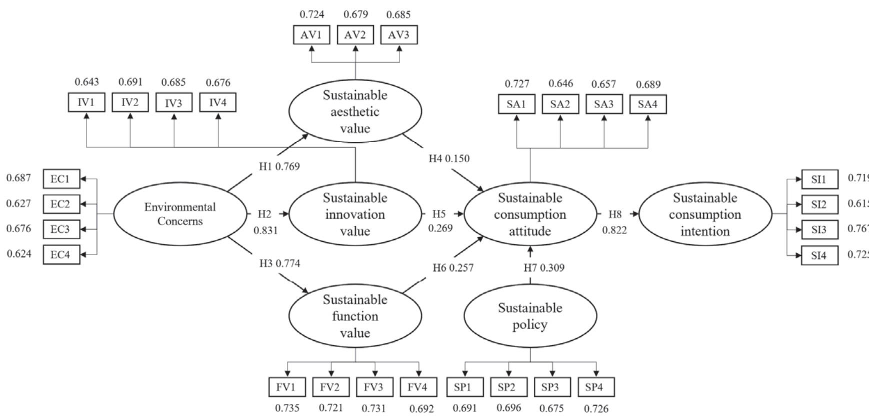

Figure 3. Validation of research results.

4.7. Discussion

The results of the empirical analysis provide some key findings, which are discussed below.

H1 is valid, indicating that environmental concerns significantly affect the sustainable aesthetic value. H2 is valid, indicating that environmental concerns significantly affect the sustainable innovation value. H3 is valid, indicating that environmental concerns significantly affect the sustainable functional value. These three hypotheses indicate that environmental concern is an important motivation for designers to design sustainable systems. In sustainability, individual environmental concerns are always very important and are considered as an important prerequisite for environmental intentions or behaviors [109]. Such environmental protection intention or behavior is not only the consumer's consumption intention or behavior but also makes designers change their mind and behavior from the perspective of design. That is, environmental concerns are added to exploration, demonstration, development, and other stages of design so as to achieve sustainable system design. The high path coefficients of EC on AV, IV, and FV also indicate that designers' thinking on environmental issues is highly relevant to sustainable system design. It also indicates that sustainable design is designers' independent behavior and responsibility for the environment.

H4 is valid, indicating that sustainable aesthetic value significantly affects sustainable consumption attitude. It means that the aesthetic value of sustainable products is one of the factors that determines consumer attitudes. As one of the cores of design, design aesthetics is the theoretical basis to make products have a better sense of design. Designers themselves, as designers and consumers, believe that products with aesthetics will attract consumers' attention so as to achieve better sales volume and create profits for enterprises [110]. It also means that aesthetic value still needs to be emphasized in sustainable design. Integrating environmental aesthetics or ecological aesthetics into products can help consumers perceive the environmental value of green products and improve their purchase intention [111].

The validity of H5 represents the significant impact of sustainable innovation value on the sustainable consumption attitude. Innovation has always been considered as the core of sustainable development. For consumers, the concept of sustainability enables them to switch from ordinary consumers to green consumers, so sustainable innovation is extremely important to consumers. It includes industry investment and research on sustainable development goals, business strategies with sustainable ideas, and even the promotion and popularization of sustainable product and service systems. In addition, sustainable innovation also includes designers' innovative thinking on products, the mastery of sustainable design rules, and breakthroughs in product assembly methods and material applications so that consumers can be more independent in their consumption attitudes towards purchasing products. Therefore, in addition to the aesthetic value of the products, consumers will also more closely examine the attitude and enthusiasm of the manufacturers of the products available on the market, which will be reflected in their sustainable consumption attitude.

The validity of H6 indicates that sustainable functional value significantly affects the sustainable consumption attitude. This study has always emphasized that the significance of three design values is perceived by consumers. Therefore, from the perspective of sustainable functional value, products should have special functional attributes that are different from other products. In sustainable design, the functional differences between sustainable products and ordinary products are reflected in the design concept, structure, material and use mode, etc. Some sustainable products with modular functions also have functional attributes that are convenient for assembly, disassembly, and recycling. For consumers' sustainable consumption attitude, these functions with environmental attributes can meet their demand for environmental protection and also serve as the purchase incentive. Regarding the design concept, structure, and material, designers should also simplify steps to improve the efficiency of product design and development and improve sustainability. In sustainable design, there are material selection, green structure design, modular design, and easy disassembly design criteria corresponding to this [112]. The simplified design helps to avoid the inconvenience caused by the use, waste, maintenance, or recycling of products; reduce the impact on the environment; and improve the eco-efficiency of enterprises.

The validity of H7 indicates that sustainable policy significantly affects sustainable consumption attitude. This indicates that the more consumers pay attention to or understand the policies and regulations, the more they will change their attitudes towards sustainable consumption, thus affecting their intentions. In other words, the friendlier the policies are towards sustainable consumption, the more positive the attitudes and intentions of consumers will be. However, in general, policies are made primarily for business and are of great importance to business. For example, energy-saving policies would increase the economic costs of a business, and businesses must find new ways to maintain profits. When policies and regulations are strict enough, they will restrict the production, manufacture, and sale of conventional products, thus triggering market demand for green products [113]. For designers, keeping high sensitivity to policies and regulations can ensure targeted design innovation and adjust design strategies so as to maximize the interpretation and utilization of policies and regulations, and also ensures that products are not subject to resistance in production and sales.

The validity of H8 indicates that the sustainable consumption attitude significantly affects sustainable consumption intention. This means that when consumers have a more positive attitude towards sustainability, their intention of sustainable consumption also increases. Attitude has become one of the most critical factors in determining intention and behavior, reflecting the gradual improvement of individual environmental concerns in recent years [114]. Most consumers also hold a positive attitude towards green products, believing that they have a good prospect [115], and are willing to replace general products with sustainable products, although the cost may be relatively high. This study also proves that the three elements of sustainable design are also important factors to improve consumers' sustainable consumption attitude and intention, which means that the more designers focus on these three elements, the more consumers may have higher purchasing attitude and intention. More and more consumption cases are also showing that consumers' attitudes and behaviors will also affect designers' attitudes and intentions and behaviors of subsequent design and development. If consumers have higher demands for sustainable products, designers will also provide more sustainable design products to cater to the market demand.

5. Conclusions and Suggestions

The main contribution of this study is the establishment of consumers' cognitive model, which is integrated with the concept of sustainable system design thinking (Figure 4). In the conclusion, this study also answers the research questions raised in the first chapter. Through the consumer cognitive model established in this study, we confirm and verify the feasibility and effectiveness of the three dimensions of design evaluation in system design thinking (namely aesthetics, innovation, and function) under sustainable design. Through the dual identity of designers, this study also explores the flow process of the sustainable concept from the design dimension to the consumption dimension. Through the verification results, it is confirmed that sustainable system design thinking has an important impact on consumers' attitudes and intentions. However, the results also show that we cannot ignore the impact of policy. With the support of the sustainability concept, the autonomy of consumers' consumption attitude and intention cannot be ignored.

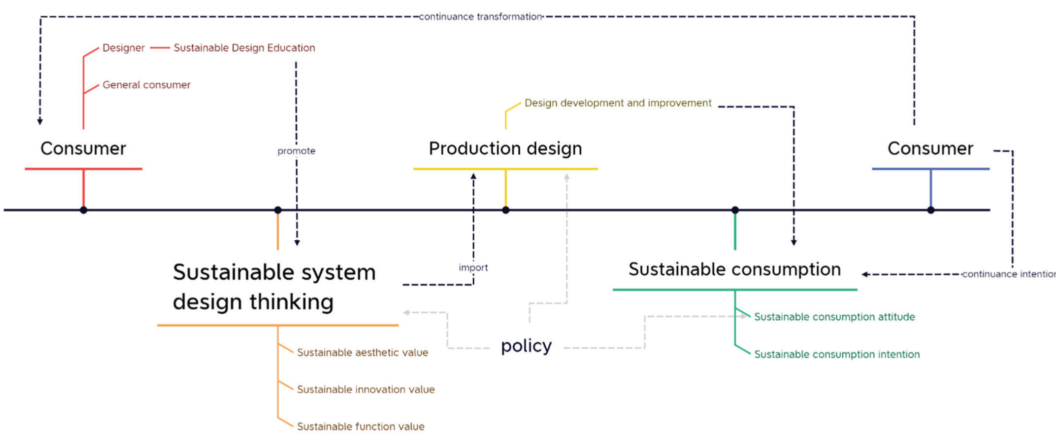

Figure 4. Consumption cognition model under sustainable systems thinking.

The results obtained in this study can not only serve as a reference for designers to implement sustainable design but also serve as an auxiliary reference for governments and enterprises to formulate sustainable innovation strategies and invest in implementation. Moreover, it can also be imported and planned as a reference for the training of design talents in colleges and universities, so that the knowledge and thinking quality of sustainable design majors can effectively root and promote more talent with sustainable practical design ability, to effectively and continuously promote the concept and goal of sustainability.

Some limitations of this study also imply the development and construction of future research directions, including that the object of this study is mainly discussed from the perspective of designers' dual identity. Therefore, future research can focus on the perspective of ordinary consumers and explore from different perspectives, such as sustainable perceived value and risk, to echo or verify the conclusion of this study. In addition, the three dimensions of design evaluation discussed in this study, namely aesthetic value, innovation value, and functional value, also deserve further exploration, including the use of new dimensions, such as the use of second-order dimensions and mediating variables, so as to enhance the explanatory power of the constructed model and improve the model perfection. Finally, qualitative research and exploration and investigation and interview can be added to supplement the depth of thinking and expression of meaning that quantitative statistical data cannot show, so that the follow-up research and exploration and the content and results can be more perfect.

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systems

Article

Verifying the Smart Contracts of the Port Supply Chain System Based on Probabilistic Model Checking

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Abstract: Port supply chains play a very important role in the process of economic globalization. Lack of trust of the mechanism is the main factor in restricting the development of port supply chains. Blockchains have great potential to solve the trust problem among all participants using port supply chains, which can reduce costs and improve efficiency. As the bridge between blockchains and port supply chains, smart contracts reconstruct the business process of blockchain-empowered port supply chains. In this article, we present an architecture of a consortium blockchain-empowered port supply chain system, and propose a system verification framework for the smart contracts of port supply chains with probabilistic behaviors. The smart contracts are modeled as DTMCs (Discrete-Time Markov Chains), which are automatically transformed through the BPMN (Business Process Model and Notation) description of the smart contracts. The requirements are specified by PCTL (Probabilistic Computation Tree Logic). Moreover, we implement the customs clearance process of the Shanghai Yangshan Port based on blockchain Hyperledger Fabric, and reconstruct the clearance process with smart contracts. We use it to demonstrate the effectiveness of this framework, and identify the smart contracts that do not meet the expected needs of users.

Keywords: port supply chain; blockchain; smart contract; probabilistic model checking

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1. Introduction

With the development of economic globalization, the world economy has increasingly become a closely integrated whole system. Port supply chains play a very important role in this process, as they undertake about 80% of the total international trade [1]. A port supply chain refers to when a city center uses its own port to develop the comprehensive service systems that cover all of the of functions of supply chains, which exploit advanced ICT (Information and Communication Technologies) to optimize the port's resources and strengthen its radiation ability [2,3]. It takes a port as the nexus that supports interaction between global supply chains and regional production and consumption markets. Port supply chains have become a new engine of national economic development, an important part of national economy, and one of the important symbols to measure the level of modernization and comprehensive national strength of a country [2]. At present, emerging technologies such as the Internet of Things, Cloud Computing and Big Data are promoting the continuous expansion of port supply chains, and are driving a new round of port supply chain industry innovation [3]. However, the participants in port supply chains do not cooperate efficiently and effectively, which is the key to reducing costs and improving efficiency. The direct cause of this situation is a failure to share data and other resources effectively among all participants, and the root cause is the lack of trust of the mechanism among all participants in port supply chains. Various parties in port supply chains cannot achieve trust consistency, and some core suppliers or distributors cannot provide reliable trust endorsements for upstream and downstream.

Blockchain is a peer-to-peer, distributed ledger that is cryptographically-secure, append-only, immutable (extremely hard to change), and updateable only via consensus or agreement among peers [4]. As it is decentralized, tamper-proof, auditable (provenance), transparent and so on, blockchain has great potential to solve the problem of trust among all participants in port supply chains. In practice, blockchain has just begun to be used in the port supply chain, thus, it is still in the internal experimental stage. The customs of Mexico, Peru, and Costa Rica, with the support of the Inter-American Development Bank, initiated the construction of an operator sharing platform based on blockchain technology in March 2018. Therefore, the Tianjin Port blockchain verification pilot project was launched with the aim of protecting data privacy and maximizing the operation efficiency of the port supply chain. The U.S. Congressional Research Institute discussed the application of blockchain technology in the field of customs supervision in June 2019.

We argue that smart contracts are the bridge for application of blockchain technology to port supply chains. A smart contract is a coded contract written by computer language and automatically verified and executed by a computer. It is a digital form of a paper contract. With the help of smart contracts, any party in the entire transaction process can access the exact same data, which is essential to improve process efficiency. Smart contracts can automatically trigger and ensure the smooth flow of files among participants, so specific access rules can be effectively implemented, and new information can be instantly and securely shared with all related parties. Leena and Sultan [5] summarized the latest research and showed how smart contracts can change the method of fund flow tracking, improve liquidity in the real estate field, reduce risks, and have a positive impact on the safe operation of the national economy. Stefania [6] closely follows the current hot sharing economy, integrates smart contracts to systematically improve smart cities and public sectors, manages services such as house leasing, greatly reduces third-party commissions, reduces the risk of fraud, and prevents potential high-end processes. This has a very similar application in the order process of the port supply chain. Whether the smart contracts are correct determines the success of blockchain empowered port supply chains. The current research on the smart contracts of port supply chains has hardly taken into account the probabilistic aspects of port supply chains. The probabilistic aspects are essential for, among others: (1) port supply chains themselves contain the randomized behaviors, e.g., non-determinism, consensus mechanism; (2) unreliable and unpredictable behaviors incurred by execution environment, e.g., message loss, processor failure; (3) performance evaluation by random variables assigned artificially, e.g., reliability, availability [3].

In this article, we propose a verification framework for the smart contracts of port supply chains with probabilistic behaviors. The smart contracts are modeled as DTMCs (Discrete-Time Markov Chains), which are automatically transformed through the BPMN (Business Process Model and Notation) description of smart contracts. The BPMN is the most widely used and simplest tool to describe the business process of port supply chains. It can clearly display the business relationship between each link and department, and visualize the information flow. It can serve as a communication medium between users of port supply chains and developers of smart contracts. DTMC is the formal model for analyzing the user requirement properties that the smart contracts should satisfy; it can be automatically generated from the BPMN. The requirements, such as safety, reliability and reachability, are specified by PCTL (Probabilistic Computation Tree Logic). We use this framework to model the smart contract for the cargo clearance process of the Shanghai Yangshan Port, to abstract the probabilities involved in each contract during the process based on questionnaires from port practitioners, and we use PCTL to specify user requirement properties.

The remainder of this article is structured as follows. Section 2 describes related works about blockchain-powered port supply chain optimization and smart contract verification, and points out their weaknesses. Section 3 presents the scenario of blockchain smart contract reconstructing of the port supply chain, and proposes the verification framework for the probabilistic model checking of smart contracts for port supply chains. Section 4 takes the port customs clearance process as a case study to demonstrate the effectiveness of this framework. Section 5 provides a conclusion.

2. Related Works

Smart contracts using blockchain technology have been mentioned by a large number of risk analysis agencies in the field of port supply chains. The credit rating agency MOODY'S summarized the three major steps to automate the international trade process using smart contracts: Firstly, design smart contracts based on paper letters of credit; Secondly, store the form; Finally, use the blockchain to record the ownership of each link [4]. In order to overcome difficulties such as overcapacity, increasingly strict environmental regulations, and security threats faced by the shipping industry, the Danish block shipping company is committed to building a global shared container platform (GSCP) based on blockchain technology to improve shipping efficiency and business. The digital transformation of processes and infrastructure ensures the long-term profitability of the industry. The project's white paper stated that the platform will save the shipping industry at least 5.7 billion USD in the future and will reduce carbon dioxide emissions by 4.6 million tons per year [7]. In the current supply chain mechanism, people use the traction system to track data, however, this method cannot avoid business friction, let alone update data in real time without manual query. Shuchih Ernest Chang et al. [8] proposed a blockchain-based BPR (Business Process Re-engineering) framework, which can help companies re-engineer cross-border business processes and track some key links in the supply chain process. Blockchain smart contract technology has been proven to have a very positive effect on supplier inventory management, the dynamic realization of the digital supply chain, and efficient transportation [9–12]. With the continuous and widespread application of blockchain smart contracts, coupled with the immutability of blockchain technologies, stability and security have increasingly become the focus of attention among researchers. Antonio proposed ESAF (Ethereum Security Analysis Framework), which can be used as a security monitoring tool for the persistence of a set of target contracts [13]. Haya Hasan et al. [12] used IoT-SC to jointly collect data on the chain, taking the vaccine supply chain as an example to test the relationship between smart contracts and entities, interactions between participants, information flow and so on. They proved that this technology can ensure real-time freight tracking performance which can be applied to multi-level and multi-party settings. It has practical applications in the transportation and information traceability of pharmaceutical products and agricultural products [14–20]. Pietro De Giovanni et al. [21] proved through a game theory model that blockchain technology can reduce business risks and transaction costs, which is more suitable for transactions with large-scale fund transfers such as cross-border bulk trade. Arnab Banerjee et al. [22] comprehensively analyzed the advantages of a blockchain-driven supply chain from the perspectives of ERP (Enterprise Resource Planning) transactions, master data management, order-purchasing, demand and supply management, manufacturing, and logistics management. The traditional concept suggests that smart contracts are designed to achieve traceable and irreversible transactions through the use of distributed databases. However, Gunnar Prause and his team [23] believed that their greater potential is reflected in the promotion of entrepreneurial collaborations across organizational business processes held up by smart supply chains.

Due to the immutability of the blockchain, the smart contract must be strictly verified before being put on the chain. Li et al. [24] proposed a formal method of BPMN (Business Process Modeling Notation) based on the extended Petri net model. They used model-driven development technology to design BPMN model elements to the extended Petri net model elements. Transformation rules and performing the mapping through the ATL model transformation language achieves formalized automatic execution. Tala Najam and Alexander Perucci [25] converted the BPMN2 choreography diagram into a color choreography network mapping for the lack of formal semantics of the BPMN2 specification, but they did not solve the problem that the Petri net model cannot reflect the content of time and does not support the construction of large-scale models. Due to the immutability of the blockchain, any error will become a permanent error once it occurs. In this regard, researchers have designed a large number of methods and tools to verify the correctness of smart contracts, the most representative of which is formal verification. Researchers have designed many formal verification frameworks and analyzed mainstream platforms [26–30]. Mouhamad Almakhour and his team [31] classified the existing smart contract verification tools and introduced a series of analysis tools such as Oyente and MAIAN, and deeply analyzed the cutting-edge technology of smart contract verification from the perspectives of static verification and runtime verification. Devrim Unal et al. [32] put forward the FPM-RBAC model from the perspective of policy regulation. He analyzed smart contracts from the three perspectives of identity management, access control, and compliance checking, and fully considered transaction risks and security requirements in 5G networks. Zhang and Mackey [33,34] proposed several methods for the verification of smart contracts for the online social network and antifraud framework. Nguyen and Li [35,36] used a certificate authentication system and puncturable signatures to detected smart contracts and improve overall fault tolerance. Lennart Ante [37] proposed six mainstream smart contract analysis streams, including smart contract standardization, verification and security, and blockchain and smart contracts for the disruption of existing processes and industries. Prashar et al. [38] used OMNeT++ to verify contract stability. Amritraj Singh et al. [28] proposed DSL (Domain specific languages) to formalize smart contracts on the basis of formal testing and automated verification. Flora has done significant research in the field of BPMN modeling smart contracts. Flora Amato et al. [39] believe that smart contracts must be based on laws to restrict the behavior of participants, thus, they proposed a formal model for verifying the compliance of smart contracts in the IoT environment. Compared with the BPMN, this model pays more attention to the interaction between participants. At the same time, they use the TCTL (timed computational tree logics) formula to describe the attributes. At the same time, Wei Wan [40] considered the relationship between PCTL and DTMC and made a relatively complete theoretical summary and expansion. Flavio Corradini [41] introduced the relationship between the blockchain and the BPMN and designed a simple model-driven automatic blockchain code generator.

In short, there have been attempts to apply smart contracts to the port supply chain. Their successful application will achieve a decentralized, traceable, efficient, and trusted global supply chain system. However, correctness research on the smart contracts of port supply chains has not been involved. Some work has been accumulated on the verification of smart contracts themselves, but this has not considered the random factor in the business process execution of smart contracts. Based on this, we propose a verification framework for the smart contracts of port supply chains with probabilistic behaviors.

3. Verification Framework

3.1. Blockchain Enpowered Port Supply Chain

The emergence of blockchain technology has brought new possibilities for solving the complicated trust problems of the port supply chain. As shown in Table 1, there are three types of blockchains: public blockchains, private blockchains and consortium blockchains [42]. The public blockchain is completely decentralized and suitable for multi-user scenarios, the private blockchain is completely centralized and suitable for independent organizations, and the consortium blockchain is partially decentralized and suitable for the common scenarios of multiple organizations. The three types of blockchain have different features in supply chain management. The public blockchain mainly reflects network security, while the private blockchain and the consortium blockchain have the advantage of real-time information transmission. The existing port supply chain involves a large number of departments. There is no unified information verification standard throughout the entire process, and a large number of manual audits are required, while the blockchain smart contract technology has an independent and general consensus mechanism. Users who agree to a certain encryption algorithm will use the smart contract by default. At the same time, the encrypted information verification is extremely fast, which can save a lot of time in the intermediate process.

Table 1. Feature comparison among blockchains.

Features	Public Blockchain	Private Blockchain	Consortium Blockchain
Accessibility	Anyone	Central Incharge	Multi-central Incharge
Ledger Keeper	Anyone	Central Incharge	Permissioned identities
Consensus Mechanism	PoW/PoS	Solo/PBFT	Distributed consensus algorithm
Incentive Mechanism	Need	Optional	No
Transaction Speed	Slow	Lighter & Faster	Lighter & Faster
Centralization Degree	Decentralization	Weak Centralization	Strong Centralization
Representative	Bitcoin/Ethereum	Ark Blockchain	R3/Hyperledger Fabric
Programming Language	C++/Solidity	C++/Java	Java/Go
Main features in supply chain management [43]	Transparency/Traceability/ Cyber-security	Traceability/Real-time information sharing/Visibility	Traceability/Real-time information sharing/Flexibility

The port supply chain has the following three main characteristics and requirements: (1) medium transaction speed and medium number of transactions, (2) multiple participants, and (3) high transaction information privacy and time-sensitiveness of transportation information. The public chain cannot solve the problem of transaction speed and cannot guarantee the confidentiality of transaction information, while the strong centralization mechanism of the private chain makes it impossible to have multiple participants, which is contrary to the demands of port supply chains. At present, almost all supply chain blockchain platforms use private chains to ensure that information is not leaked; these are currently in the internal test stage. In this article, we chose the consortium blockchain Hyperledger Fabric to recontruct the port supply chain, as shown in Figure 1. This will be beneficial for large-scale port supply chains. The participants of the port supply chains are authorized to join and participate in data maintenance together. At the same time, the processing speed of 10,000 transactions per second is sufficient to meet the transaction volume requirements of port supply chains.

It can be seen intuitively, from the above figure, that smart contracts are used to implement the business process of port supply chains. Based on the consensus mechanism, once the supply chain information is uploaded to the blockchain, it cannot be changed. Any authorized user can check the chain information at any time. Port administrators can easily check the authenticity of the information by hash verification. We designed the on-chain and off-chain information transfer process of port supply chains as showin in Figure 2. The supplier uploads the purchasing information and transportation information to the supplier chain (SC), and the Hyperledger Fabric automatically integrates it with the port chain (PC) and manufacturer chain (MC), which can also automatically generate a distributor chain (DC) at any time for purchasers to track the progress of the transportation. Due to the characteristics of the Hyperledger Fabric, all authorized participants can read and upload the information on the chain, so multiple sub-chains can be deployed at the same time.

3.2. Verification Framework for the Smart Contracts of Port Supply Chains

The overall verification framework of this paper is shown in Figure 3. In the formalizing branch, the requirements of PSC (port supply chain) smart contracts are specified by the PCTL (Probabilistic Computation Tree Logic) formula. In the modeling branch, the PSC smart contracts described in BPMN (Business Process Model and Notation) are modeled as DTMC (Discrete-Time Markov Chains) through a conversion algorithm. The verification process is implemented by the probabilistic model checker PRISM.

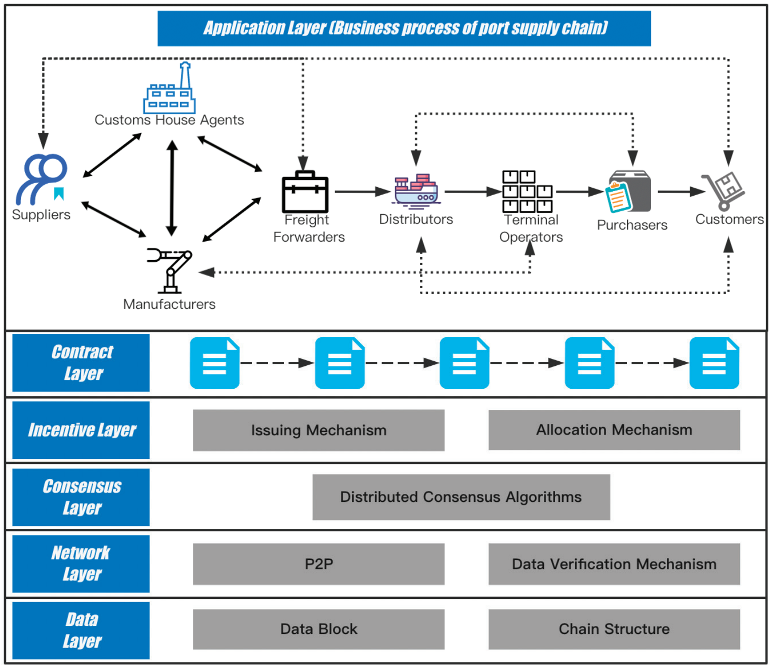


Figure 1. The hierarchical structure of a blockchain empowered port supply chain system.

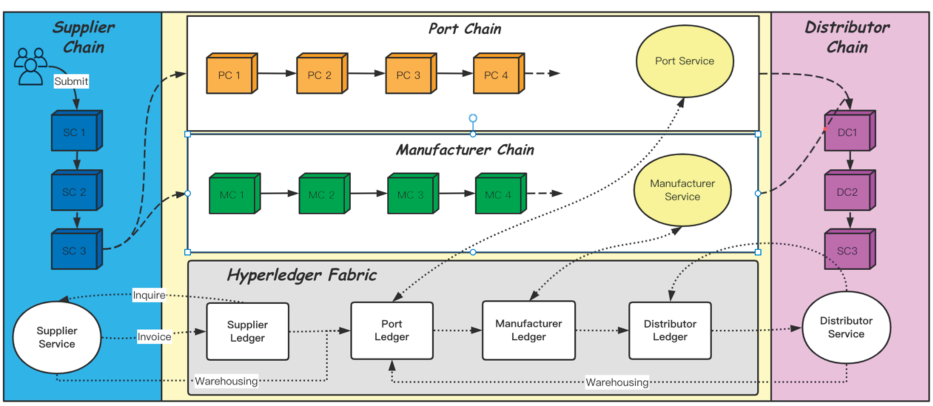


Figure 2. On-chain and off-chain information transfer process.

3.3. Modeling PSC Smart Contracts

Smart contracts are the programming codes run on blockchain platforms, which are very difficult to understand for the non-professional participants of port supply chains. As a quasi-natural language, BPMN can act as the intermediate language for all users in port supply chains, including business analysts, software developers, and business managers and supervisors. It provides a graphical model for creating a business process that can be used to construct a visual business process diagram of the port supply chain. There are dedicated tools for translating the BPMN into smart contract programming code, such as Caterpillar [44]. We model PSC smart contracts from the BPMN description of smart contracts. Moreover, we model the probabilistic aspects of smart contracts, which are an inherent characteristic of port supply chains. The reasons for this are as follows: (1) port supply chains themselves demonstrate randomized behaviors, e.g., non-determinism, consensus mechanism, (2) unreliable and unpredictable behaviors incurred by execution environment, e.g., message loss, processor failure, and (3) performance evaluation by random variables assigned artificially, e.g., reliability, availability [3]. We use the DMTC modes to model PSC smart contracts.

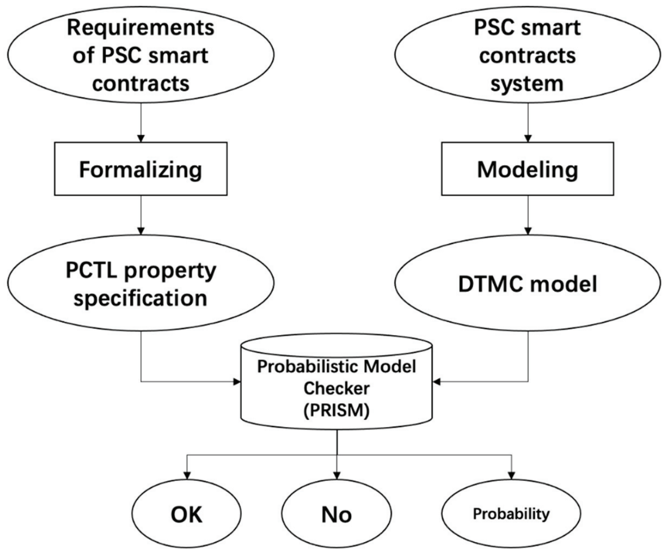
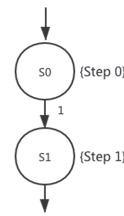
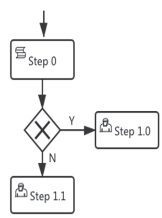
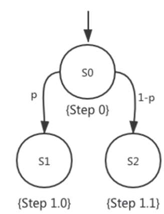
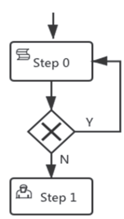
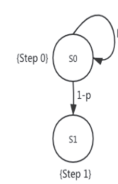


Figure 3. Verification framework diagram.

The DTMC model of a PSC smart contract is defined as a six-tuple, $SC = (S_{normal}, S_{abnormal}, s_{init}, P, AP, L)$. S_{normal}: A set of limited non-empty states, which means that the PSC smart contract is in a normal state space. This set contains the normal status, for example, the supplier sub-contract is normal or the transfer sub-contract is normal. In addition, it includes the initial status and the end status of the port supply chain; $S_{abnormal}$: A set of limited non-empty states, which indicates that the PSC smart contract is in an abnormal state space. This set contains all abnormal states, such as the quality inspection contract failed or the goods were lost; $s_{init} \in S_{normal}$ represents the initial state; L:$S \rightarrow 2^{AP}$ is a label function used to describe the set of propositions on the state, and identify the sub-smart contracts being executed or abnormal situations corresponding to each state. AP is the set of atomic propositions. $S = S_{normal} \vee S_{abnormal}$ is a collection of all state spaces; P: $S \times S \rightarrow [0,1]$ is the state transition matrix, indicating whether it will transition from one state to another and the probability of transition.

Each state of the DTMC model corresponds to an event in the BPMN diagram. The transitions between states correspond to the migration of events. The sequence flows and message flows in the BPMN description represent the completion of the port supply chain sub-process of the previous department and the procedures of the next department. The corresponding mapping rules are shown in Table 2. The left side of the table is the sub-process of the BPMN components, and the right side is the corresponding sub-process of the DTMC model. We automate this process by Algorithm 1.

Table 2. Mapping PSC smart contracts in BPMN to DTMC.

Sequential event conversion	
	
Conditional branch event conversion	
	
Cyclic event conversion	
	

Algorithm 1 presents a conversion algorithm which can convert the PSC smart contracts in BPMN description into a DTMC model. The premise of the conversion algorithm is to accurately divide the complete BPMN description into sub-models and then map them. It is more of a flowchart level mapping than a semantic mapping.

The algorithm takes the events, activities and gateways of the BPMN as an input, and performs the following operations: first, the counter s that records the number of nesting times is set to zero, the initial event E_0 is pushed into the stack STATES, and then the following loop is started. The purpose is to add each node of the BPMN to Array[]. Pop the event m from the stack to Array, and make the following judgment: if m belongs to {S (Original Event), A^M (Manual Activity), A^S (Script Activity), A^B (Business Activity)}, push all the subsequent nodes $n \in$ LATER(m) that meet the conditions into Array[], and emit them into the DTMC state variable. If the node n does not belong to events, activities, and two restricted gateways (decision gateway and Parallel gateway), the node will pop out. However, for Decision Gateway G^D and Parallel Gateway G^P, it needs to be converted in the order of G^P first and G^D later, which is placed in SUBPROCESS here.

Algorithm 1: DTMC Model Mapping

```
Input: BPMN = (E, A^M, A^S, A^B, G^D, G^P)
Output: DTMC[s]
s←0
STATES.PUSH(E_0)
while STATES ≠ ∅ do
  m←STATES.POP()
  Array[]←m
  if (m ∈ S ∪ A^M ∪ A^S ∪ A^B) then
    for all the n ∈ LATER(m) do
      Array[]← Array[] ∪ (m,n)
      Emit Array[]
    DTMC[s]←Array[]
    Prob[]←p
    s← s + 1
    if (n ∉ BPMN[]) then
      Array[].PUSH(n)
 SUBPROCESS ← ∅
 if (x ∈ G^D) then
    STATES.PUSH(G^D)
    Search for G^P
    STATES.PUSH(G^P)
    x←STATES.POP()
    y←STATES.POP()
    Array[]←(x,y)
    Emit Array[]
    DTMC[s]←Array[]
    x← x + 1
    y← y + 1
    s← s + 1
 END SUBPROCESS
```

Theorem 1. *For a BPMN process, if it can be transformed into a DTMC, the process must be physically reachable*.

Proof. Let the highest layer of the DTMC be k, the next higher layers are $k-1$, $k-2$, ..., and the lowest layer is *0*. There is only a sequential structure at the k layer. For a BPMN with only a sequential structure, all states are physically reachable, so the subnet is physically reachable. At the $k-1$ layer, all k layer subnets are represented by nodes such as events and gateways, and the $k-1$ layer has only a sequential structure. Therefore, the $k-1$ layer including the k layer is also physically reachable. By analogy, all states of layer *0* are physically reachable, so that the DTMC model is physically reachable. □

Algorithm 1 has an upper complexity bound of $O\left(n^2\right)$, where n is the number of nodes in the BPMN process. The upper limit corresponds to the cumbersome degree of the supply chain process. In the most common case, only the decision gateway appears in the BPMN process, and there are no different types of gateway nesting.

3.4. Properties Specification

We use PCTL to specify a set of user requirements. PCTL is defined by the following syntax:

$$\Phi ::= \text{ true}|a|\Phi \wedge \Phi|\neg\Phi|P_{\bowtie p}(\Psi) \quad (1)$$

$$\Psi ::= X\Phi\Big|\Phi U^{\leq t}\Phi \quad (2)$$

where $p \in [0,1], \bowtie \in [<, \leq, >, \geq], t \in R_{\geq 0}$, a is the atomic proposition. The tense operators X and U are called Next and Until, which is the same as the temporal logic. The formulas produced by Φ are called state formulas, and their true value can be judged by the true value of each state included. The formulas generated by Ψ are called path formulas, and their true value needs to be evaluated by calculating each execution path.

In most cases, Φ only describes the atomic proposition corresponding to the absorption state. When it describes the failure state, the probability constraint is expressed as $\leq x$, where x is the upper bound of the failure probability; when it describes the success state, the probability constraint is expressed as $\geq x$, where x is the lower bound of the probability of success.

As shown in Table 3, we set up the following DTMC states to model the status of PSC smart contracts, respectively, to make the property specification more universal. $Current_{Sup}$ represents the extent of the supplier link among them. Since there is more than one supplier, goods circulation and fund exchange are between suppliers, and they also bring out the document information, thus, it is necessary to split this link in order to present the smart contract of each exchange process. There is a multimodal transportation situation in the transportation part. $Current_{Trans}$ is used to present the sub-contracts generated by different transportation means or different transportation stages of the same transportation means, and it is used to track the steps of the transportation link. There will be multiple buyers or distributors in the procurement process, and $Current_{Pur}$ is used to track the progress of the goods flowing among the buyers. End_{Sup}, End_{Trans}, End_{Pur} are Boolean variables used to monitor whether the supplier link, transportation link, and purchase link are actually completed or not. The completion is 1, and the error is 0. Finally, we use $Current_{PSC}$ and End_{PSC} to monitor the progress of the entire port supply chain $(m, n, u \leq v)$.

Table 3. PSC smart contracts states and ranges.

State	Ranges
$Current_{Sup}$	{0,1,2, ... ,m}
End_{Sup}	{0,1}
$Current_{Trans}$	{0,1,2, ... ,n}
End_{Trans}	{0,1}
$Current_{Pur}$	{0,1,2, ... ,u}
End_{Pur}	{0,1}
$Current_{PSC}$	{0,1,2, ... ,v}
End_{PSC}	{0,1}

On the basis of the above states' definition, we specify requirement and regulation properties for the PSC smart contracts.

***Property* 1**: What is the probability that a certain batch of goods will complete the entire port supply chain smart contract?

$$P =?[\ F(Current_{PSC} = v)\&(End_{PSC} = 1)] \tag{3}$$

Since it is impossible to guarantee the smooth completion of each branch chain in the actual process, the probability is usually less than 1. Under the premise that all links are not required to be perfectly realized, we can make the probability interval in [0.95,1] fuzzy to 1, so that people can compare the actual value with the expected value.

For the three links, there can be more detailed specifications as follows:

***Property* 2**: What is the probability that the supplier link smart contracts are completed but the entire process of the port supply chain is not completed?

$$P =?\left[F\left(End_{Sup} = 1\right)\&(End_{PSC} = 0)\right] \tag{4}$$

***Property* 3**: What is the probability that the transportation link smart contracts are completed but the entire process is not completed?

$$P =?[F(End_{Trans} = 1)\&(End_{PSC} = 0)] \tag{5}$$

***Property* 4**: What is the probability that the procurement process of the smart contracts are completed but the entire process is not completed?

$$P = ?[F(End_{Pur} = 1)\&(End_{PSC} = 0)] \quad (6)$$

The above three properties allow the port supply chain supervision agency to track the completion of a certain batch of goods in a timely manner, but it is impossible to know where the problem lies when the probability drops. Therefore, we propose the following three more detailed specifications:

***Property* 5**: What is the probability that the supplier link progresses to the step $x(x < m)$ but the total status of the supplier link smart contracts are completed and the whole process status is also completed?

$$P = ?\left[F\left(Current_{Sup} = x\right)\&\left(End_{Sup} = 1\right)\&(End_{PSC} = 0)\right] \quad (7)$$

***Property* 6**: What is the probability that the transportation link progresses to the step $y(y < n)$ but the total status of the transportation link smart contracts are completed and the whole process status is also completed?

$$P = ?\left[F\left(End_{Sup} = 1\right)\&(Current_{Trans} = y)\&(End_{Trans} = 1)\&(End_{PSC} = 0)\right] \quad (8)$$

***Property* 7**: What is the probability that the procurement process progresses to the step $z(z < u)$ but the overall status of the procurement process smart contracts are completed and the whole process status is also completed?

$$P = ?[F(End_{Trans} = 1)\&(Current_{Pur} = z)\&(End_{Pur} = 1)\&(End_{PSC} = 0)] \quad (9)$$

3.4.1. Accuracy

The accuracy of the migration rate must be ensured before model checking. Due to the different levels of manual participation in each link of the port supply chain, we define the manual participation time between all levels of the suppliers as λ_1~λ_M, and the manual participation time between all levels of the purchasers as μ_1~μ_N, where necessary participation time is defined as λ_m and μ_n, respectively, and the accuracy is analyzed through the rewards structure in PRISM.

Randomly generate $\frac{1}{\lambda}$ and $\frac{1}{\mu}$ under different node numbers, and the accuracy of the entire model is shown in Table 4. Obviously, when the number of sub-contracts is too large, it will greatly affect the completion of the entire process and reduce the operating efficiency of the main contract.

Table 4. Accuracy under different N.

N	Property		
	Nodes	**Time Per Iter: (s)**	**Probability (False)**
2	14	<0.00001	0.072
4	30	<0.00001	0.081
8	57	0.00001	0.113
16	105	0.00001	0.141
32	197	0.00002	0.179
64	377	0.00001	0.239
128	729	0.00002	0.285
256	1437	0.00012	0.373
512	2849	0.00004	0.490

3.4.2. Reachability

The essence of reachability analysis is to check whether each smart contract is effectively invoked. Each sub-contract of the port supply chain running on the blockchain platform must be accurately invoked and effectively executed to ensure the smooth progress of the entire process. However, in reality, it is difficult to ensure that the hash values of each sub-contract are consistent. We created a module for each contract model. If the contract verification fails, it will be marked as affected, otherwise it will be marked as correct. We designed an algorithm to verify reachability which is shown in Algorithm 2. We can initially obtain whether the status of each sub-process is reachable and whether the status result is true. If the total process is true, then further calculations can be made.

Algorithm 2: Reachability algorithm

Input: the property formula to be verified ***F***
Output: True, False
1. Preprocess ***F***, if the formula is false, return **False**
2. Select the next state variable that has no value
3. Deduction
4. The derived formula = = true, return **True**
5. Conflict, then
6. Analyze the conflict and go back
7. Cannot go back, return **False**
8. No conflict is deduced, return to Step **2**

Taking three supply terminal processes as an example, the PRISM module code is as follows in Algorithm 3:

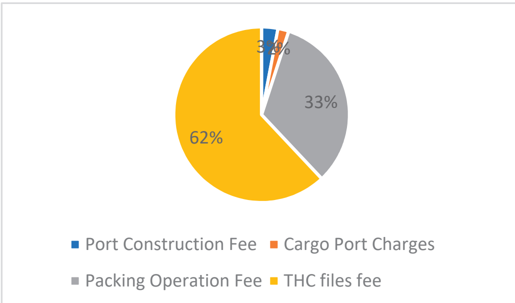
Algorithm 3: PRISM module code of three supply terminal processes

module *Sup_1*
Sup1_affected: **bool init false**;
[Sup1_affected] = **false** & M> = m → (Sup1_affected′ = **true**);
[Sup2_correct] Sup2_correct_SupplierSC = **true** & Sup1_affected = **true** → 1:**true**;
[Sup3_correct] Sup3_correct_SupplierSC = **true** & Sup1_affected = **true** → 1:**true**;
endmodule

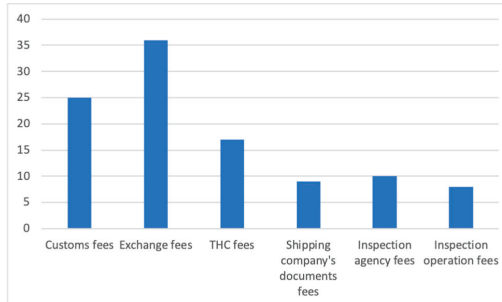
4. Case Study

We have selected the port customs clearance process of port supply chains as a case study. Import and export customs procedures refer to the activities of going through customs procedures for inbound and outbound goods that are subject to different customs systems in accordance with the law.

The way that customs clearance has changed from the traditional 'territorial declaration-port inspection and release' to the current 'integrated customs clearance' is that various obstacles between departments and regions have basically been cleared. However, there are still many cumbersome processes that have not been eliminated. Figure 4a shows that according to the 2020 Shanghai Water Transport Port Container Freight Cross-border Trade Expenses and Compliance Cost Assessment Report, the shipping company's document fee reached JPY 1071, which is an amazing proportion. Figure 4b shows that in the questionnaires for import and export companies (55 import responses and 52 export responses), the replies with subjective experience higher than the average mainly focused on customs declaration fees, order replacement fees, and terminal THC (Terminal Handling Charge) fees. It can be seen that there is still a lot of room for optimization in the port supply chain customs clearance process. For the convenience of research, we model the macroscopic customs clearance process smart contracts. The macro-level customs clearance process includes multiple suppliers, purchasers and transportation links. In order to promote the linkage between ports and shipping enterprises, speed up the application and information sharing of digital platforms, and promote the electronic release of imported containers based on blockchain, we have tentatively conducted pilot projects in the Shanghai Yangshan port of China. We cooperated with the Shanghai Yangshan Port to upload and model its customs clearance process, reducing the average processing time of major imported e-commerce cargo documents from 2 days to less than 4 h.



(**a**)



(**b**)

Figure 4. Disadvantages in the customs clearance process (**a**) The proportion of various expenses in customs clearance expenses; (**b**) Customs clearance fees and exchange fees account for a high proportion.

Appendix A is a simplified version of the on-site customs declaration manual for a certain customs' rapid customs clearance. We can see that for import and export companies, they have to fill in a large number of forms and provide a large number of letters each time they import customs clearance and export customs clearance, which is the root cause affecting the efficiency of customs clearance.

4.1. Modeling Smart Contracts of the Port Customs Clearance Process

Suppliers need to fill in a large amount of contract information during the export stage of goods, such as manifest contracts, inspection and quarantine contracts, and tax payment contracts mentioned in Appendix A. The customs clearance process is an important section of the port supply chain, in which all the import and export goods must go through various procedures of entry inspection when they arrive in another country. It plays a critical role in order to ensure the safety of the goods and enable the owner to pick them up smoothly. However, each port department has different requirements for verification of contract internal information. For example, the customs department needs to check the goods required to pay customs duties and tax deductions according to law, while reviewing the value and exchange rate of the goods, the customs declaration department needs to proofread the delivery, loading and transportation information in the manifest, and the quarantine department needs to check whether the quarantine information of the cargo is effective. All departments must upload the results to the smart contract after completing the information verification. The validation of each document is time-consuming. The whole process takes 2–3 days, however, it only takes a few hours to validate with a smart contract, instead of manual validation.

There are many reasons for difficulties and these can be divided into two categories: external and internal. External reasons may include delays caused by weather conditions, lower-than-expected quality of raw materials, delays caused by the dispatch of containers in and out of the port, and supplier or purchaser's breach of contract. Internal reasons may be caused by improper filling of contract information. In the smart contracts of various links in the port supply chain, there is information, such as Port Loading, Port Discharging, Cargo Description, Consignee's name and address, which is greatly affected by the filling specifications, and there is a considerable probability that the hash verification will not pass. This article only discusses external reasons.

Since a certain container or a certain ship of goods corresponds to a large number of suppliers, the failure of any supplier's sub-contract will have an impact on the entire supplier contract, so the relationship between each supplier's sub-contract is 'And'. There is a calling relationship between contracts. When different types of suppliers upload information and call contracts, there is a certain probability that they will default. For each supplier, when completing the various processes in Appendix A, such as filling in the manifest smart contract, completing the export customs declaration smart contract, or applying for the customs clearance inspection and quarantine smart contract, there will be a certain probability that they will not pass. At the same time, purchasers also face the same problems when applying for an import customs clearance smart contract and completing tariff contracts. In this article, we consider such a situation: for a supplier's cross-border transportation smart contract, three different departments are required to review at the export terminal which are independent of each other. During the cargo transportation stage, only the mode of transportation within the port is considered. When goods arrive at the port for the import process, three different departments are also required. Every department needs an auditor to proofread the information. The BPMN description of smart contracts from the customs clearance process is shown in Figure 5.

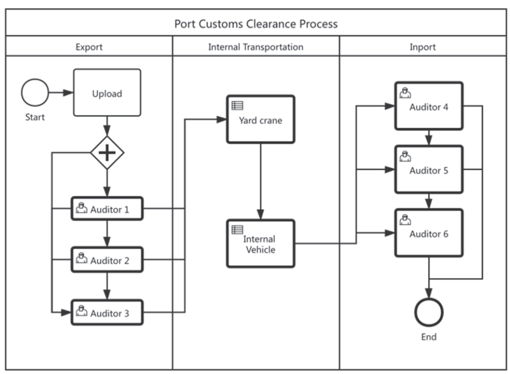


Figure 5. The BPMN description of smart contracts from the port customs clearance process.

Smart contracts in BPMN description can be converted into a DTMC model through Algorithm 1 and shown in Figure 6. Three auditors correspond to the customs declaration department, the taxation department, and the inspection and quarantine department, respectively. Some goods, such as bulk goods, do not need to be inspected by the quarantine department, while duty-free goods do not need to be reviewed by the tax department. The symbol p represents the transition probability between two departments.

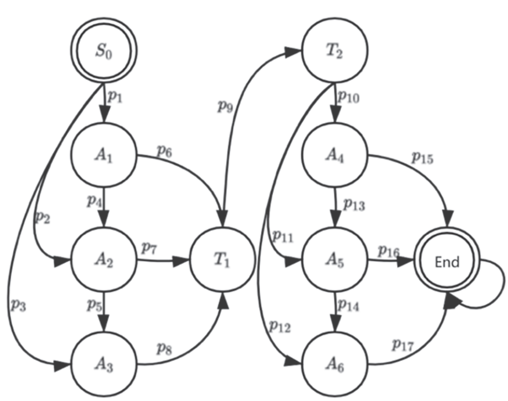


Figure 6. DTMC model of smart contracts form the customs clearance process.

4.2. Verification Results and Analysis

Let $m = n = u = 3$, $v = 8$, we can redefine the property specification in Section 3.4 as follows:

***Property* 1**: What is the probability that all contracts are failed?

$$P = ?[\ F(Current_{PSC} = 8)\&\ (End_{PSC} = 0)] \tag{10}$$

***Property* 2–*Property* 4**: use a similar description.

***Property* 5**: What is the probability that the export contract 2 is successfully passed and the entire customs clearance process contract is failed?

$$P = ?[F(Current_{ex} = 2)\&(End_{ex} = 1)\&(End_{PSC} = 0)] \tag{11}$$

***Property* 6**: What is the probability that the transition contract 2 is successfully passed and the entire customs clearance process contract is failed?

$$P = ?[F(End_{ex} = 1)\&(Current_{Trans} = 2)\&(End_{Trans} = 1)\&(End_{PSC} = 0)] \tag{12}$$

***Property* 7**: What is the probability that the import contract 2 is successfully passed and the entire customs clearance process contract is failed?

$$P = ?[F(End_{Trans} = 1)\&(Current_{ex} = 2)\&(End_{ex} = 1)\&(End_{PSC} = 0)] \tag{13}$$

In order to make the code more universal, we present part of the PRISM code in a modularized style in Figure 7. The user can freely define the number of states and the probability of state transitions according to the actual situation. We count them by N and Max. The characteristic x12 represents the migration from state one to state two, p1 represents the migration probability, and meanwhile the success or failure is represented by a Boolean variable.

```
dtmc
const double p1;
const double p2;
const double p3;
const Max;
//further probabilities if needed
module N
N:[0..Max];
 [x12]N=0->(N'=N+1);
 [x13]N=0->(N'=N+1);
 [x14]N=0->(N'=N+1);
 [x23]N=0->(N'=N+1);
 [x24]N=0->(N'=N+1);
//further transitions if needed
endmodule
module M12
x12:bool;
 [x12]true->p1:(x12'=true)+(1-p1):(x12'=false);
endmodule
module M13
x13:bool;
 [x13]true->p2:(x13'=true)+(1-p2):(x13'=false);
endmodule
//further module if needed
```

Figure 7. PRISM Code of the DTMC model of the customs clearance process.

According to the questionnaire survey of port practitioners in the Shanghai Yangshan Port, we selected the actual passing probability of three main links and preset the success probability of the smart contract for the export part and the import part as 80%, 90% and 95%. By default, there are no accidents in the smart contract for internal port transportation. We took property one in the first set of preset values as an example for verification, and set the probability index in reverse to get the calculation result shown in Figure 8. The rest of the verification results of the three sets of preset values are shown in Table 5.

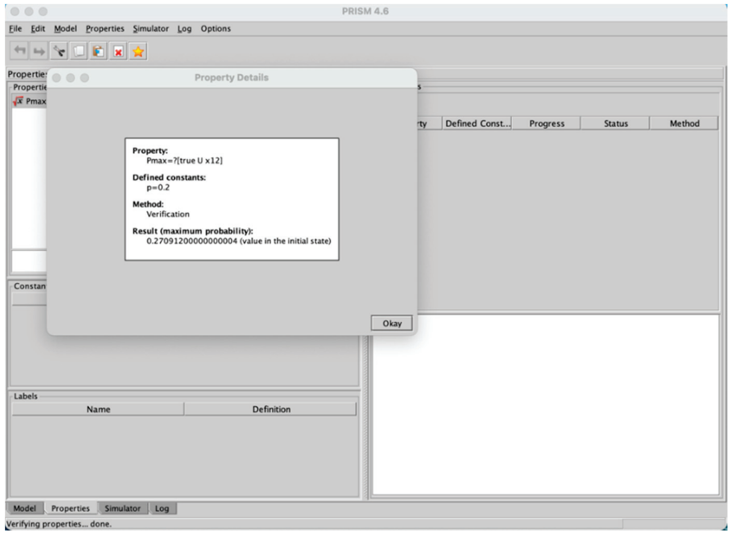


Figure 8. PRISM calculation result of Property 1 in Set 1.

Table 5. PRISM calculation results of each property.

	Set 1	***Set 2***	***Set 3***
***Property* 1**	27.1%	13.9%	8.3%
***Property* 2**	14.3%	12.5%	7.1%
***Property* 3**	14.3%	12.5%	7.1%
***Property* 4**	100%	100%	100%
***Property* 5**	26%	14.8%	10.6%
***Property* 6**	19.6%	9.3%	7.8%
***Property* 7**	19.6%	9.3%	7.8%

The status of smart contracts in the entire port supply chain can be analyzed with different probabilities, and fault contracts can be located under different preset values to achieve the purpose of supervision. Through the longitudinal analysis of different preset value groups, the influence of different parts in the port supply chain on the success rate can be judged separately in Figure 9. International logistics and port practitioners informed that the pass rate of each link must reach 90–95% to ensure the continuous and efficient operation of the entire port customs clearance business. Thus, we set the expected probability to 90%.

Since we assume that the transportation contract is not damaged, the results of ***Property* 2** and ***Property* 3** are the same. There is no obvious difference between the impact of export contracts and import contracts on the overall success rate, which shows that what really affects the port supply chain smart contract is the failure probability of the local contract. If the value of ***Property 5~7*** is greater than the complement set of ***Property 2~4***, the damage contract can be located as export-department contract 3 and import-department contract 3. If the probability of damage to the internal transport contract is considered, we can use the same method to compare ***Property* 3** and ***Property* 6**. In this case, for the export section, only the probability of the third set of preset values is higher than the expected probability. At the import section, the pass rate of contract 5 in the three sets of preset values is lower than 90%, and only contracts 6 and 7 in the second and third set of preset values are higher than expected. Therefore, this method can quickly locate unqualified smart contracts.

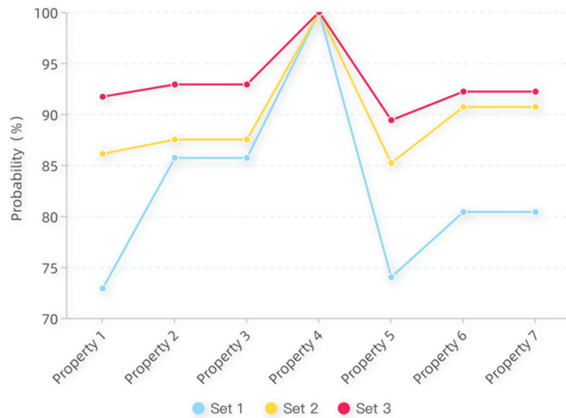


Figure 9. Failure analysis under expectation probability.

Through comparing the values of the same property under different preset probabilities horizontally, it can be seen that the smaller the number of state transitions, which means the smaller the number of sub-contracts, the higher the success rate of the entire port supply chain contract. At the same time, the export contracts have a more important impact on the overall success rate than the import contracts, which requires contract programmers and suppliers to pay more attention to accuracy in the process of information uploading and contract construction.

5. Conclusions

In this article, we present an architecture of consortium blockchain empowered port supply chains, and propose a framework for the smart contracts of port supply chains with probabilistic behaviors. The consortium blockchain is a compromise between decentralization and efficiency. The public blockchain takes too long time to validate transactions, while the private blockchain has a high degree of centralization which is contrary to the original intention of a blockchain. The consortium blockchain combines the advantages of both. The smart contracts are modeled as DTMCs, which are automatically transformed through the BPMN description of smart contracts. The requirements, are specified by PCTL. A casestudy of the port customs clearance process of port supply chains is used to demonstrate the effectiveness of this framework. The limitation of this work is that this framework only considers the probability aspect of the port supply chain, and the time variable, reward mechanism, etc.,s are not included, which also affects the integrity of the smart contract for port supply chains. In the future, we will exploit MDP (Markov decision process) to the model smart contracts of port supply chains, which can include non-deterministic and probabilistic behaviors simultaneously. Alternatively, we will use CTMDP(continuous-time Markov decision process) to model smart contracts which involve continuous-time behaviors, and we will consider the more complex user requirement properties, such as security, privacy and liveness, which can be specified by PCTL* (super set of PCTL).

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Port Customs Clearance Declaration Procedures

<table>
<tr><th colspan="2">Import</th><th colspan="2">Export</th></tr>
<tr><td rowspan="4">Manifest transmission and customs declaration entry declaration</td><td>Transmission of manifest electronic data to customs through the platform</td><td rowspan="4">Customs declaration entry and declaration link</td><td rowspan="2">Entry and declaration</td></tr>
<tr><td>Entry of customs declaration</td></tr>
<tr><td>Customs declaration</td><td rowspan="2">Customs declaration chargeback</td></tr>
<tr><td>Customs declaration chargeback</td></tr>
<tr><td rowspan="3">Customs review and on-site presentation</td><td>H2000 manual review</td><td rowspan="3">Customs review</td><td>H2000 manual review</td></tr>
<tr><td>EDI, POP query</td><td>EDI, POP query</td></tr>
<tr><td>On-site delivery, release delivery, post-delivery (paperless customs clearance)</td><td>On-site delivery, release delivery, post-delivery (paperless customs clearance)</td></tr>
<tr><th colspan="2">Pay taxes</th><th colspan="2">Pay taxes</th></tr>
<tr><td rowspan="3">Inspection and release</td><td>The logistics monitoring department handles the second confirmation of the manifest</td><td rowspan="3">Inspection and release</td><td>The terminal supervision department handles inspection and release procedures</td></tr>
<tr><td>Application for clearance procedures at the clearance post of the Customs Clearance Section</td><td>The enterprise ships the ship with the "Export Goods Shipment List"</td></tr>
<tr><td>The terminal supervision department handles inspection and release procedures</td><td>Logistics Monitoring Section handles ship export customs clearance procedures</td></tr>
<tr><th colspan="2">Customs clearance and issuance certificate</th><th colspan="2">Customs clearance and issuance certificate</th></tr>
</table>

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Supporting Luxury Hotel Recovered in Times of COVID-19 by Applying TRIZ Method: A Case Study in Taiwan

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Abstract: The current COVID-19 pandemic, which is alarming for another global economic recession, puts the sustainable development of the tourism system under high consideration. The tourism industry is a key generator of foreign exchange across the region. However, tourism is one of the sectors most affected by the global pandemic. Through a case study in Taiwan, the objective of this study is to show how an Evergreen hotel fixed itself on existing and recovering in the hospitality business during the COVID-19 pandemic in 2020 using the combination of the problem hierarchy analysis (PHA) and the Teoriya Resheniya Izobreatatelskih Zadatch (TRIZ) or the so-called theory of inventive problem-solving technique. Following PHA technique and extensive investigation, the management team determined that the most recent problems at the Evergreen hotel are in marketing and human resources. The 39 parameters and 40 principles of TRIZ were used to determine the improvement solution and create a solution strategy that simultaneously simplified critical control-point (CCP) processes and improved the correctness of tasks, increasing CCP efficiency and supporting and satisfying customer demands in the COVID-19 pandemic in the world in general and in Taiwan in particular. The results revealed that customer bookings grew over the four quarters of 2020 due to adjusting the cancellation policy, discounting, and segmenting the market from international to domestic, increasing the CCP efficiency percentage and customer rating score from 19% to 40% and 8.3 to 8.5 score, respectively. Aside from that, changing the hotel structure with a partnership with the Taixie company assisted Evergreen in reducing various cost pressures to manage the business and recover after a difficult period. This paper can be a useful reference for managers, investors, governments, and policymakers to improve the sustainability performance in the tourism industry.

Keywords: luxury hotel; COVID-19; marketing; human resource; efficiency; TRIZ; decision making

1. Introduction

The world is currently fighting a global infectious pandemic known as COVID-19, which started in December 2019 [1]. Not only has the global healthcare system been put in a state of emergency, but the global economy is also predicted to suffer. To stop the spreading of the coronavirus, limitation on human interactions is reported to be a feasible measure that is commonly applied across countries and regions [2]. The main activities comprising this limitation can be listed as social distancing, lockdown, border closure, home quarantine, and school closures, with different levels of compliance. Despite the effectiveness, the impact of these measures together with the current burden of the healthcare system has increased vividly in both micro and macroeconomics. Fernandes et al. [3] conducted a review and forecasted the effect of this pandemic. Due to the uncertainty of lockdown duration and the recovery, the study predicts that the GDP growth can be decreased from

2.8% in mild scenarios and up to 15% in a critical situation. The study also discussed the industries at risk, such as tourism and supply chain. As a result, Fernandes estimated each additional month of crisis costs 2.5–3% of global GDP.

Hospitality has grown steadily in recent decades, becoming one of the fastest expanding economic sectors, including Taiwan. According to the UNWTO's March projection, the sector has seen a 59% increase in international tourist arrivals over the last decade, from 880 million in 2009 to 1.5 billion in 2019. With tourist-specific improvements in increasing national and international destinations, tourism is also a vital driver of socioeconomic progress. In 2019, the tourist business provided USD 8.9 trillion to global GDP, a contribution of 10.3%. However, because of the global COVID-19 epidemic, significant historical growth ended in 2020. Since the beginning of the virus's spread, travel and tourism has been one of the most affected sectors, with planes grounded for extended periods, hotels closed, and travel restrictions imposed [4].

As a result of the COVID-19 outbreak, numerous businesses in the hospitality industry in Taiwan were stymied and disrupted, particularly for overseas businesses. The pandemic imposed a travel ban on overseas tourists in February 2020, with only Taiwanese being allowed to return to their homeland. Following the COVID-19 pandemic outbreak in the first two quarters of 2020, the UNWTO report estimated that at least 93% of global citizens were in countries with coronavirus-related travel restrictions, with approximately three billion people living in countries that enforced complete border closure to foreigners. However, in Taiwan in 2020, with perfect supervision, an Evergreen hotel (Chiayi), part of the Evergreen group's Taiwanese chain, decided to reform the system to safeguard the company and help it recover from the difficult period. There have already been successful critical control-point (CCP) experiences with private sector participation [5]. At the moment, the Taiwanese business is mostly focused on domestic clients.

It is important for hotel sales and marketing to understand customer behavior to create effective marketing [6] because the rule of kind of business will depend on the number of selling bookings and the price of booking to earn the net income. Evergreen is a large corporation with a large chain of 5-star hotels that spans the globe to lead high-level customers, such as international businessmen and high-class customers in other countries. COVID-19, in 2020 when it first emerged, posed a significant challenge to Taiwan's 5-star hotels, especially Evergreen hotels. Due to closing the border, nearly all 5-star hotels were forced to close their doors because of increased cancellations and a lack of new bookings until an unforeseeable time. However, due to the government's strong control over diseases and analysis of hotel-recovery tactics in Taiwan [7], Evergreen hotels decided to continue operating to get through the difficult COVID-19 period by breaking the old, firm structure to follow the new segment customers (domestic customers) in Taiwan and innovating the old standard operating procedure (SOP) to address the new needs from the government. Despite being a large corporation in a challenging circumstance, Evergreen has managed to endure and develop steadily throughout time.

The Teoriya Resheniya Izobreatatelskih Zadatch (TRIZ) or so-called theory of inventive problem-solving technique, in particular, was created to solve problems relating to manufacturing systems. However, in recent times, a new TRIZ-based technique for improving service quality has been suggested to the service industry. For example, Su et al. [8] used TRIZ and fuzzy quality function deployment (QFD) to generate creative solutions for service quality improvement with a case study in an e-commerce company. In this paper, fuzzy QFD is applied to identify the critical determinants relating to customer satisfaction. Then, in the TRIZ contradiction matrix, the related TRIZ engineering parameters may be successfully employed to identify the creative concepts. Furthermore, Lin and Su [9] applied TRIZ to identify the corresponding inventive principles with a sample case of a company that provides online application software services in Taiwan. In order to reason about the issues among relevant stakeholders in the tourism industry, Chang and Wu [10] used TRIZ and decision-making trial and evaluation laboratory (DEMATEL) to clarify the complicated relationship results generated by conflicting challenges across sectors to resolve contradictions and innovative principles and to establish the extent of influence between innovation principles and which principles have had the most significant impact. Furthermore, conversion policies and tourism regulations were considered for the performance of the tourism industry in the current pandemic.

Because of COVID-19, researchers have focused on studying the hospitality scenario, but no example has focused on the CCP of a luxury hotel, such as Evergreen. During the most difficult period of COVID-19, the Evergreen hotel focused on developing a new technique to increase bookings from high-end domestic consumers starting in Q3 of 2020 at the lowest possible cost. The purpose of this study is to employ Teoriya Resheniya Izobreatatelskih Zadatch (TRIZ) contradiction matrix to identify the key issues with domestic customers' booking habits and old SOP produced by the marketing and manager departments during the COVID-19 period. Following that, 39 parameters and 40 principles were used to find the best solutions or approaches for improving CCP processes, the correctness of new SOP tasks, and company structure, effectively supporting all Taiwan hotel-repair missions and meeting fleet maintenance and servicing demands in order to recover from the economic effects COVID-19 and other diseases.

The rest of the paper is organized as follows: Section 2 presents the literature review, while Section 3 elaborates the methodologies, including problem hierarchy analysis and TRIZ innovation approaches. Section 4 presents the empirical analysis with a case study of the Evergreen hotel chain in Taiwan. Lastly, Section 5 gives the discussions, concluding remarks, and limitations and suggests future work directions.

2. Literature Review

As the coronavirus (COVID-19) has shown, natural disasters and tourism have a history together [11]. Because of on-pharmaceutical interventions, lack of a vaccine, and minimal medical capacity to cure the disease, COVID-19 knocked out all of the world's tourists from 2019 until late 2020 [12,13]. COVID-19 causes public panic, which leads to reduced demand and lower customer demand prices, and the price of the tourist industry continued to fall in lockstep with the decline in demand [14–16]. On many levels, the government played a vital role in the fight against the COVID-19 before things get out of hand by sponsoring loans with no interest to help businesses get through this difficult period [17]. In COVID-19's impact on tourism, control of tourism activities, disputes, and solutions, government assistance is among the key themes identified during this difficult period of time globally [18]. Besides, the image of a place influences visit intention and mediates the relationship between the determinants and visit intention [19]. After that, many people utilize the Internet for travel planning, such as travel information search and booking [20].

Many sorts of research were conducted to identify effective marketing techniques and unique products that might be used to reach and enter a new market or increase value quickly. As a result, benefit segmentation is influenced by the design and modification of attractions, such as part of the product holiday packaging or activity programming [21]. Then, customers' price expectations are how to acquire products that fit their quality expectations, and they may even receive an offer that exceeds their initial expectations. Market segmentation is not focused on increasing or improving profit; rather, it is viewed as a strong strategic notion for achieving long-term financial goals and limiting the risk of a long-term plan [22].

Some studies have found that while there are many distinct forms of crises and disasters, and each incident is likely to be unique, it is critical to document as much information as possible to better anticipate future possibilities [23]. The high number of essays about this special issue reflects the desire for people to express themselves as a way of releasing their fears and integrating their hopes in the wake of the COVID-19 pandemic [24]. Sobaih et al. [25] investigated the direct impact of small hospitality company resilience on sustainable tourism growth as well as the indirect influence via performance. Besides, Rahman et al. [26] studied the influence of the COVID-19 outbreak on visitors' views of travel risk and management. The data show that the COVID-19 epidemic has had a significant impact on travel risk and management attitudes. The COVID-19 epidemic has had an impact on the tourist sector owing to travel restrictions and a drop in demand among travelers. To negotiate the uncharted territory created by the epidemic, hotels must re-evaluate current business processes and establish new and inventive tactics that protect the health and safety of guests as well as staff and, as a consequence, restore customer trust [27].

One of the effective methods widely used for process improvement in industries or services is the TRIZ approach (so-called Teoriya Resheniya Izobreatatelskih Zadatch or the theory of inventive problem-solving technique). TRIZ has the potential not only to anticipate but also to invent new approaches. Because of its structure and algorithmic approach, TRIZ also delivers repeatability, predictability, and reliability. Some applications of TRIZ, such as that of Wang et al. [28], commended TRIZ in steel manufacturing to improve the design of the tester, which may cause severe oxidation of zinc to solve the oxidation problem. Feniser et al. [29] proposed TRIZ to discuss the concepts of sustainability, innovation, and risk management in small- and medium-sized enterprises (SMEs) to develop a flow chart for evaluating the state of innovation in such companies. Through the use of the TRIZ method in the field of SMEs, fast and efficient processes, products, and sustainable services have been obtained. Renjith et al. [30] merged axiomatic design with TRIZ to redesign the housing cover of design for additive manufacturing in additive manufacturing. The results showed that the redesigned part had improvements in structural properties, and the proposed design framework can be effectively used to transform an original product design for traditional manufacturing into a new method suitable for additive manufacturing by incorporating the additive manufacturing capabilities into the product design. Wang et al. [31] used TRIZ to improve chip sidewall crack issue in the nanometer packing process of semiconductors caused by a poor laser waveform during the laser cutting process, resulting in debris along the chip sidewall. Lin and Chen [32] executed TRIZ with supply chain management in new product development for SMEs of Taiwan. The study explored practical alternatives for SMEs to develop various value-added products that meet customers' changing requirements and succeed in competitive markets to achieve a sustainable business operation. Ramírez-Rios et al. [33] conducted TRIZ in the plantar orthosis field that designed a support device for the foot. Yang and Tsai [34] mingled TRIZ, failure modes and effects analysis (FMEA), and Internet of Things (IoT) to explore research and application of energy management in industry 4.0 with a case study is the semiconductor manufacturing of Taiwan.

During the COVID-19 period, hotels provide the most services, such as offering a price comparable to competitors as well as low-cost rooms and discounts [35]. As a result, the COVID-19 management framework was presented with digital and intelligent transformation and market upheaval to cover the anti-pandemic phases. Marketers seek out guests who will spend money rather than merely time on their tourism offerings to increase their market share [36,37]. Tourist hotels in Taiwan are focusing on enhancing customer service quality. Human resource management (HRM) techniques can help a company develop an environment that supports positive employee behavior and improves service quality. Their study aimed to investigate the relationship between human resource management methods, service behavior, and service quality in tourist hotels experimentally. HRM practices were discovered to directly impact consumer perceptions of service quality. The ramifications of their findings for HRM and future research were highlighted [38]. Chand [39] looked into the impact of HRM practices on service quality, customer satisfaction, and hotel performance.

This paper analyzes a concrete situation generated by the pandemic and look for the future forecast of Evergreen Hotel to attract new customers, keep order bookings, and fulfill requirements. Problem Hierarchy Analysis (PHA) has two directions of research: the first is to analyze the larger demand, and the second is to narrow down the specific difficulty. The contradiction matrix Teoriya Resheniya Izo breatatelskih Zadatch (TRIZ) is used as a method to identify issues related to the habits of domestic customers regarding reservations and the old standard operating procedure (SOP) used by the marketing and management departments during the pandemic period. By analyzing and forecasting the future of the Evergreen hotel based on the financial situation and marketing department results in Q1 and Q2 of 2020 and the new regulars of Taiwan Government for safety during 2020 with relevant customers' requirements, the purpose of this paper is to analyze and forecast the future of the Evergreen hotel to attract new customers, keep ordered bookings, and fulfill requirements. Based on the results of this study, the Evergreen hotel decided to attract investors by revising the old running systems to adapt to the recent crisis time; expanding the market from international customers to domestic customers through discounts; and repairing, adding, and changing hotel equipment, such as infrared thermometers, room partitions, and plastic masks, to satisfy customers. As the result's proposal, the management team is responsible for making choices based on the marketing and financial department's reports and projecting future trends and plans to ensure that the hotel's operation runs smoothly. Evergreen created a new design of the application due to modifying the structure of marketing and HR strategy. The proposed system's efficiency and benefits are demonstrated through this study.

3. Methodology Approaches

3.1. Problem Hierarchy Analysis (PHA)

Problem Hierarchy Analysis (PHA) is a powerful tool for identifying hazards early in the design process for problem solving. PHA is a requirement of the MIL-STD-882D concerning Standard Practice for System Safety, according to the CCPS Hazard Evaluation Guidelines by Kavianian, Rao, and Brown (1992) [40]. The structure of the PHA is shown in Figure 1. There are two parts to the research: the first is to analyze the larger demand, and the second is to narrow down the specific difficulty. The PHA can solve a company's shortage of points to fix business difficulties, train new visions, and identify better points to establish a new environment. PHA assists us in determining the most important things to address. That we might identify and label the source of the problem with a hasty decision is not the primary error or omission to consider and address. We must genuinely comprehend the core issues that lie beneath the surface issues. The working approach for this study consists primarily of gathering data from the hospitality business and all connected documentation. The approach for this investigation is given in Figure 1 after confirming the subject and starting with the industrial analysis.

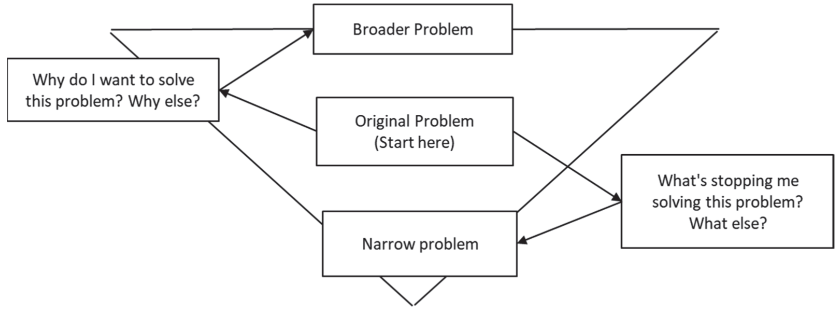

Figure 1. Problem hierarchy analysis structure [41].

3.2. TRIZ Methodology

The methodology used in the study is called Teoriya Resheniya Izobreatatelskih Zadatch (TRIZ), and it was created by a Russian engineer and inventor named Altshuller in 1946. TRIZ was a process developed by Altshuller, who reviewed over 200,000 patents and synthesized the information, resulting in 40 invention principles that became the foundation of TRIZ in 1950 [41]. TRIZ is a systematic paradigm that converts a specific problem into a general issue, outlines a generic outcome from patents, and returns to the original problem. TRIZ includes problem hierarchy analysis, substance-field analysis, evolution trends, 40 innovative concepts, and resources. The key challenges were first identified using a problem hierarchy analysis. The 40 principles were then used to identify the best improvement solution or approach and develop a solution plan that simplified and improved the accuracy of procurement chores while still meeting fleet maintenance and servicing demands.

Forty Principles and Contradictory Matrix: The core premise of TRIZ is to follow the rule of the 40 innovative principles represented in over 200,000 patents. One of the major principles in TRIZ is the contradiction, which is used to formulate challenges and signal a truly unique approach. The resolution of contradictions is a basic TRIZ idea. In TRIZ, there are two types of paradoxes: technical and physical contradictions. When using TRIZ, one of the contradictions is that if we enhance one system parameter, at least one other value will deteriorate. The 40 principles are then applied to resolve the technical inconsistencies. TRIZ normally addresses problems using a two-dimensional contradiction matrix. The matrix row reflects what is keeping things from becoming better, and the column expresses what we wish to improve [41].

In a system, a technical contradiction occurs when one parameter, "A", is modified, while the other, "B", is changed at the same time, for example, in a car system, power vs. fuel consumption and weight vs. strength. The contradiction matrix and the corresponding innovative concepts can be used to solve technical contradiction situations. The TRIZ approach was used to find solutions after understanding these concepts. By eliminating the contradiction, it improves one parameter, "A", without hurting the other parameter, "B". The problem solving by contradiction matrix in TRIZ methodology is presented in Figure 2 [42].

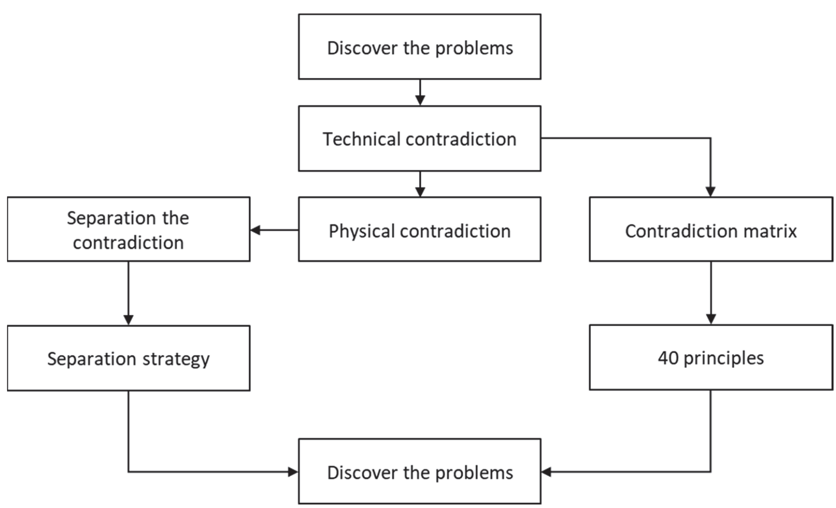

Figure 2. The problem solving by contradiction matrix in TRIZ methodology.

4. Case Study

4.1. Current State

The Evergreen Group was founded in 1968. Over 50 years, it has grown into a large corporation with investments in various industries and nations, including shipping, hospitality, and airlines, among others. The Evergreen Group decided to diversify its business from shipping to include air transportation, hotels, and leisure services as part of its expansion strategy. Evergreen International Hotels was formed to allow international tourists to enjoy better Evergreen Group service by satisfying clients from Evergreen

Eva flights and differentiating imported goods from shipping techniques. With a global presence and a diverse range of services, the Evergreen Group provides domestic and international customers with quick and dependable sea, land, and air freight services as well as safe, comfortable, and convenient air transportation.

Parallel to its booming airline industry, it has built up a huge transportation network and constructed a chain of worldwide hotels over the last 50 years. Evergreen Laurel's name honors the aesthetic heights attained by Europe's poet laureates, whose work continues to inspire humanity. All Evergreen International Hotels ensure a comfortable, warm, safe, and clean stay as a guarantee to guests. Evergreen International Hotels is a large hotel chain with Keelung, Taipei, Taichung, Tainan, Chiayi, Yilan, Paris, Penang, Bangkok, and Shanghai locations.

All the case study data come from the Evergreen hotel of Taiwan's Evergreen corporation. This is a real project to help hotels survive during the COVID-19 situation. This study is focused on limiting canceled booking, increasing new booking from customers by replacing some old processes and strategies in the hotel, and reducing the cost to run a hotel's business during difficult times. The following four-step coordination process is shown in Figure 3 and described as follows.

1. All of the bookings of customers will be divided into two types: canceled booking and new booking. Because the COVID-19 situation suddenly became worse, many companies in Taiwan were frozen from February 2020. In the hotel tourism industry, many from January 2020 were still saved in the hotel's booking system. The Evergreen hotel aims to keep the old customers and boost the number of new customers booking for next months. Therefore, the finance department has to analyze and report to the company daily about the recent situation and the emergency plan to apply in the hotel to reduce the cost for at least six months. The plan should clarify the requirements of the three maintenance levels, such as safe, effective, and stable, and the review of requirements for investors should be completed in one month before the target year.
2. Marketing and finance officials are guided to submit their requisitions to relevant project managers. All acquisition requests need to be updated every day, appointing dedicated personnel to each request and reviewing the department's integrity of the requests submitted. The review outcomes are returned to the requesting departments for review, revision, and confirmation. After analyzing that in March, Taiwan decided to close the borders to decrease the number of disease cases in the world. Going out of the country for traveling became so difficult that hotels have decided to focus on domestic traveling. That meant, from June to August in 2020, a large number of domestic customers can book the hotels for traveling. Because of the chance, the hotel has to prepare and create a safe environment for new customers (cleanness, privacy, safe distance, etc.) and change the time to arrive for the canceled booking of customers.
3. The finance office must give the results of investors to the company to review and decide which company could become the partner of the Evergreen hotel, could support the hotel during the no-benefit period, and support the hotel in the busiest time in one to two months.
4. All the new benefits of canceling the rooms' rules and booking rooms will be posted on the internet to attract customers. The number of canceled bookings will be controlled with the customer care office or hotel's hotline and saved with its code. Marketing and finance plans will be sent to all potential investors to attract cooperation by email and directly operated by executives and high-level companies. Failed SOP failed is collated into a list and returned to the original requesting department for review: unaccepted canceled bookings will be passed to the booking department to review and reported to the front desk to help customers choose their other options.

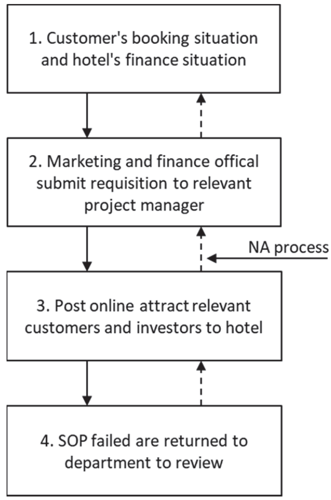

Figure 3. The current process of booking rooms before improvement.

4.2. Problem Description

This study adopted the problem hierarchy analysis (PHA) to analyze the research problem, which is expanded, narrowed, and repeatedly analyzed to formulate an efficient flowchart for improving the performance of the Evergreen hotel during the pandemic crisis. The flowchart was then used to analyze demand and process descriptions (Figure 4).

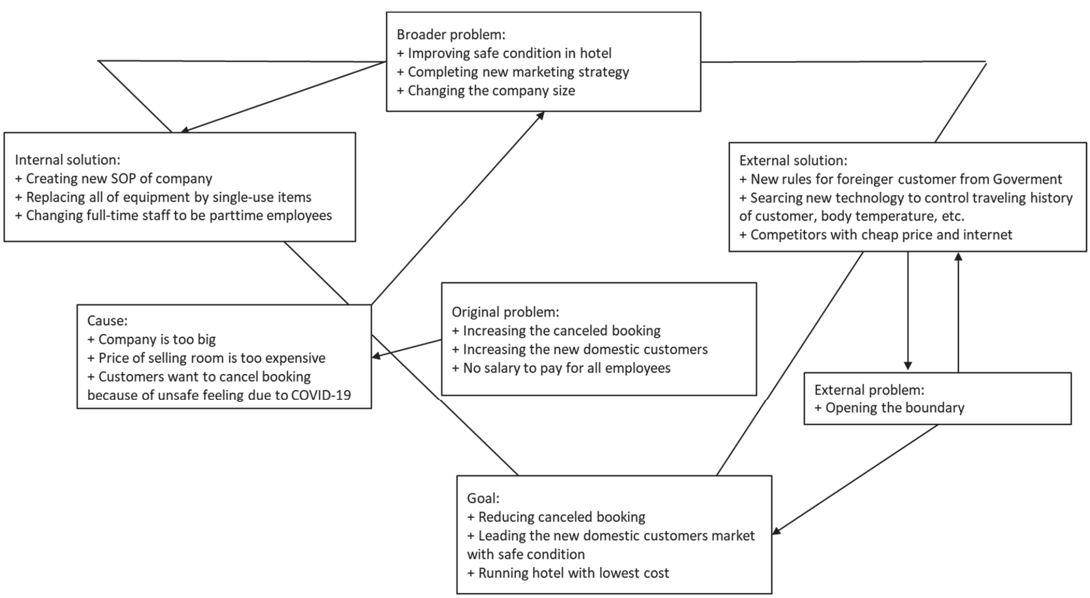

Figure 4. The problem hierarchy analysis of the Evergreen hotel.

The TRIZ problem hierarchy analysis of Figure 4 was adopted to elucidate the following aspects of the process:

- **The original problem:**

Because of COVID-19, almost all hotels in Taiwan could not be safe for travel, so the number of bookings for hotels suddenly decreased during March, April, and May of 2020. Thus, many big and medium hotels were closed and interrupted because of canceled booking, and no customers could travel. Therefore, many companies encountered trouble with finance to run the business with unpredicted ending times for the restrictions.

- **Cause:**

Having many canceled bookings should be solved with flexible methods; zero new and old bookings from foreign customers, which play an important role in the hotel's benefits, will affect the hotel seriously, especially Evergreen 5-star hotels.

- **Broader problem:**

Hotels need to improve their safe condition and create a completely new strategy.

- **Internal Solution:**

Creating a new SOP plays an important role in hotels during the COVID-19 period. The old SOP process now needs to add a safer process, such as all the equipment and items for customers should change to single-use and be sprayed by disinfectant water.

Hotels need to create a safer environment with new cleaning levels during working times, add screenings to check body temperature, and make wearing a mask a mandatory condition during the COVID-19 pandemic for areas such as hotel check-in desks, where people might gather together. Therefore, providing personal protective equipment (PPE), such as face masks and gloves, could be a new service of hotels to keep staff and guests protected or ensure the distance (1.5 to 2 m) between two people will be applied at any given time.

For the safety conditions, employees should divide into two shifts day and night, and unnecessary staff should be changed to part-time work or fired during the period. According to a review of the research, isolation can be mitigated by having a strong social support network. Video conversations and virtual meetings allow social interactions despite physical distance [43,44].

- **External Solution:**

Security: With the new rules to protect customers and employees of hotels, travelers and guests need to perform all safety and hygiene measures as a priority, with strict cleaning protocols to deal with the coronavirus, such as filling out a form of history traveling information for two weeks; measuring body temperature at two times, namely at arriving and leaving the hotel; and performing disinfection before touching any equipment or people in the hotel.

Flexibility: When customers decide to book hotels, there should be more flexibility and importance. All the new policies need to be updated consecutively to adapt to unpredicted changes, such as time for business meetings or staying, that will need to be delayed because of sudden travel restrictions. Giving the flexibility conditions for the customer, they could gain more confidence in facing the fear of isolation situations, the closing of borders, and transportation cancellations.

Hospitality: The hotel must have a good relationship with online travel agencies, which display clear and simple updated information of the new policy for COVID-19 on the listings of hotels. The hotel must explain the information, such as the time to answer hotel inquiries, the hotel's current COVID-19 cases, safe transfers from the airport to the hotel and vice versa, museum tickets, etc.

- **Goal:**

Hotels could prepare well with investors with many canceled bookings, and new bookings could be transferred to June 2020. This study revealed that revising domestic traveling could be the trend of the years, and opportunities could come from this point. Therefore, project managers should verify the sources and price for marketing for bookings and investors should modify or supplement necessary and unnecessary plans. Moreover, project managers' business analysis abilities and knowledge toward the detailed plan should be fostered to improve the efficiency of hotels.

5. Results Analysis

5.1. Application of 40 Principles of TRIZ

TRIZ is a problem-solving strategy focused on logic and data rather than intuition, helping the project team solve challenges more creatively. The TRIZ 40-principles method was adopted in this study to identify the causes of the related problems and the possible solution for improving the hotel's performance in the COVID-19 period. In order to analyze the feasibility of the suggested principles obtained from the matrix of contradictions, they were crossed with the existing approaches. The selected principles were proposed for acceptance and were executed by the hotel. The objective is to determine contradictions for the problem and match them with appropriate parameters from the 39 engineering parameters and 40 innovative principles defined in the matrix [45]. A brainstorming session identified the following major contradictions in the system, where # denotes the TRIZ engineering parameter number. A contraction matrix was created for the 29 solutions as tabulated in Table 1.

Table 1. The contradiction matrix of the paper.

Improving Parameters	Worsening Parameters					
	Duration of Action of Moving Object: 15	**Temperature: 17**	**Power: 21**	**Loss of Information: 24**	**Object-Generated Harmful Factors: 31**	**Adaptability or Versatility: 35**
Stress or pressure: 11	19, 3, 27	35, 39, 19, 2	4, 6, 2		3, 5, 1	1, 15, 29
Stability of object's composition: 13	13, 27, 10, 35	35, 1, 32	32, 35, 27, 31		35, 40, 27, 39	35, 30, 34, 2
Duration of action of moving object: 15		19, 35, 39	19, 10, 35, 38	10	21, 39, 16, 22	1, 2, 5, 13
Object-affected harmful factors: 30	22, 15, 33, 28	22, 33, 35, 2	19, 22, 31, 2	22, 10, 2		35, 11, 22, 31
Ease of operation: 33	29, 3, 8, 25	26, 27, 13	35, 34, 2, 10	4, 10, 27, 22		15, 34, 1, 16
Ease of repair: 34	11, 29, 28, 27	4, 10	15, 10, 32, 2			7, 1, 4, 16

In the evaluation stage, the suggested principles obtained from the contradiction matrix were cross-referenced with the actual approaches to analyze the feasibility of the suggested principles. After discussing with the hotel management team, some inappropriate approaches were eliminated. The segmentation principle (#1), taking out (#2), blessing in disguise (#22), and cheap short-term living object (#27) were adopted to enhance the number of bookings for hotels during the COVID-19 period. Upon the discussion the hotel management team, this study came out with some actions for improvement, and the hotel management team agreed to follow and execute these actions. The details are listed below.

The segmentation (#1): The target is divided into several independent parts. All the types of the booking will be divided into two groups. Specifically, the requested cancellations are priority cases that need to be solved as soon as possible. Subcategorizing categories facilitate price negotiations and reduce the ability of canceled bookings. The booking system will monitor and control the new booking to help customers update to the new price and new rules during COVID-19 time. Therefore, the company makes this object easy to disassemble, such as eliminating the full-time staff and cooperating with potential investors to share and maintain the benefits together. All of the staff passed the requirements to be kept by hotels, and the entire will be transferred to part-time staff. After a miniature business model, hotels could cooperate with investors in the same situation to cover all hotels. The plan helps hotels survive during COVID-19 with lower costs to run the business and enough staff with good skills during the summer vacation and holidays without training costs.

Taking out (#2): The company changes an object's structure from uniform to non-uniform, changing an external environment (or external influence) from uniform to non-uniform, such as flexible working hours. Because of protecting the safe environment during the risk of COVID-19, all employees are arranged in differential working shifts and could not change flexibly. Therefore, hotels open or recommend their factory or distribution, entertainment centers near hotels, such as shopping malls, cafeterias, bakeries, and convenience stores, to customers to control the schedule of customers efficiency.

Blessing in disguise (#22): The company uses the method named loss-leader strategy for increasing sales. Evergreen is a 5-star hotel, and almost all the benefits are from foreign customers, so it uses expensive equipment and luxury items to service customers. However, in a complicated situation, the company needs to decide to change all the old habits. To keep the standard of 5-star hotels that can still compete with many small hotels, some items inside hotels are replaced with items at cheaper prices. Using protection environment trends, Evergreen will change to items made of recyclable materials or reduce the use of expensive but unnecessary items during the time. Moreover, eliminating the fear of change by introducing fear of competition is effective. Evergreen decided to share 20 to 50% benefit with the investor named Tai-Xie to raise the competitive environment in a work place with two targets, in which our employees will work with higher productivity and reduce the cost to run the business in this time. Approving the other company's access inside Evergreen's own company is harmful because it will constitute two systems running together in a company but will lead to benefits, also.

Cheap short-term living object (#27): The target of hotels is to replace an expensive object with multiple inexpensive objects that will not compromise certain qualities, such as service life, for instance, too much. Moreover, all the big spaces inside hotels must be divided into closed and small spaces to adapt to government rules and let customers have their own space to protect customers' health. During COVID-19, hotels would like to attract short-term customers to stay in hotels, so they must control and limit the contact between people and people in the large areas and practice sterilization as a routine.

5.2. Verifying the Efficiency of Study

A flowchart of the improved booking and HR system for cutting cost and gaining a new segment market of the Evergreen hotel during the COVID-19 period is illustrated in Figure 5 and described as follows:

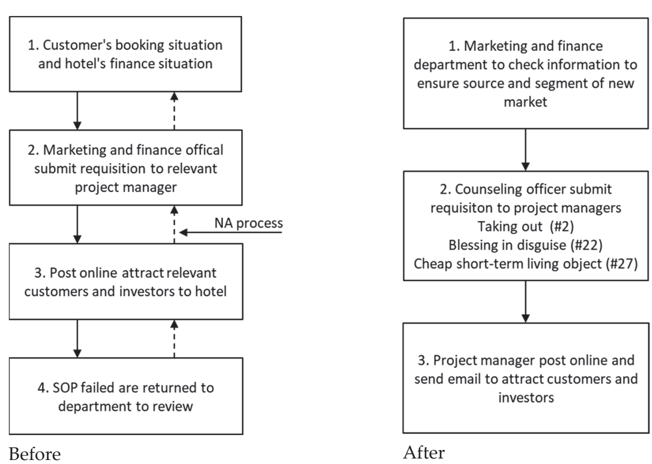

Figure 5. The process of booking rooms before and after improvement.

1. Before submitting a requisition, the requesting departments, such as the marketing and finance department, should cross-reference the coordination and procurement of the canceled and new customers' or investors' information to ensure the market sources. This process enables the requesting departments to revise system information immediately, saving at least three working days to revise management information by #1 segmentation.
2. The counseling officer submits the requisition to project managers in segments based on the requesting department: the requesting department allocates the procurement cases to dedicated projects depending on the department type. Moreover, subcategorizing spare-part categories facilitates price negotiations and quotes: #2 taking out, #22 blessing in disguise, and #27 cheap short-term living.
3. Projects are then posted online, and emails are sent to attract customers and investors. Procurement plans are formulated and submitted to the department for tender listing and procurement one month before the target year.

5.3. Results Validation

Figure 6 shows the number of rooms sold out and the marketing segment for each month of 2020 following the COVID-19 situation. Before COVID-19 broke out (January and February of 2020), the average that the Evergreen hotel could reach was 1456 rooms (18.6% of the total of rooms). March to May of 2020 was the worst time of COVID-19 for hotels, with 825 rooms per month (12.8% of the total of rooms) booked by customers. From June to October of 2020, because of applying the new strategy for booking rooms, the percentage of orders increased dramatically, with 3107 rooms per month (40% of the total rooms). November and December of 2020 were two months that show a stable time after the improvement period of the hotel, with 2472 rooms per month reserved to customers. From this chart, it is observed that the rooms were sold out after using TRIZ innovation methodology and still increased following by month during 2020.

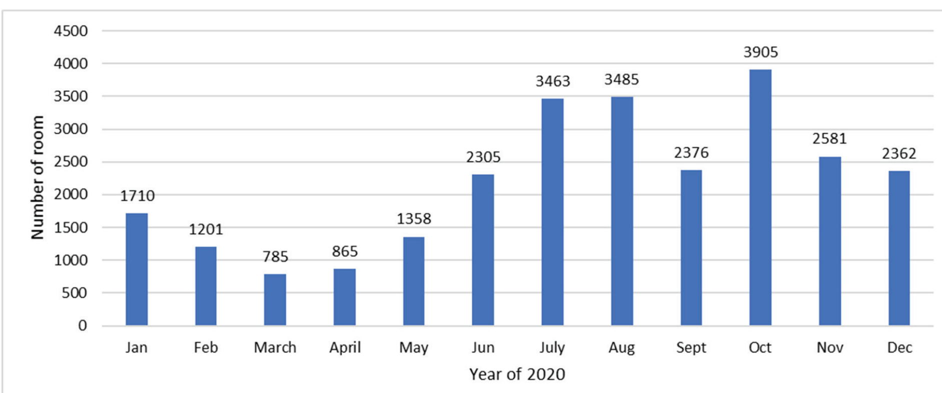

Figure 6. The number of rooms booked in 2020.

Figure 7 shows the situation for booking rooms following the year's quarters (2020). From the chart, although the hotel was affected by the COVID-19 situation, the Evergreen hotel recovered and even reached a better situation for 2021 with an increasing percentage covering four quarters. Before improving by applying TRIZ, the hotel reached 16% and 19% total of rooms from booking by customers; however, in Q3 and Q4, Evergreen reached 40% (more than 21% compared to Q1 and Q2). Therefore, Q4 was when hotels decided to stop using the discount for booking and used the new system to run hotels only; however, the percentage of sold-out rooms was 38% higher than before the COVID-19 situation, which means the new strategy is effective for hotels.

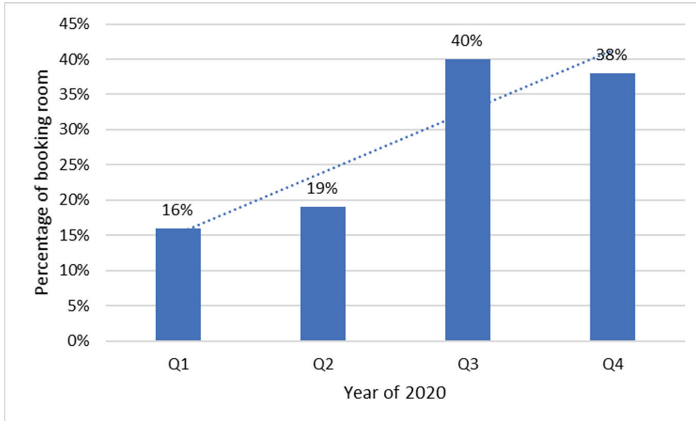

Figure 7. The booking rooms situation of hotel during four quarters in 2020.

Figure 8 shows the situation for booking rooms following the situation COVID-19 in 2020 for the Evergreen hotel. From the chart, before improving by applying TRIZ, the hotel reached 19% of total rooms from booking by customers (January and February of 2020). However, during COVID-19, the number of booked rooms of the hotel calculated and predicted by the marketing department was 13% (March to May of 2020). By realizing the bad situation could appear again in the next months in 2020, hotels decided to improve and change.

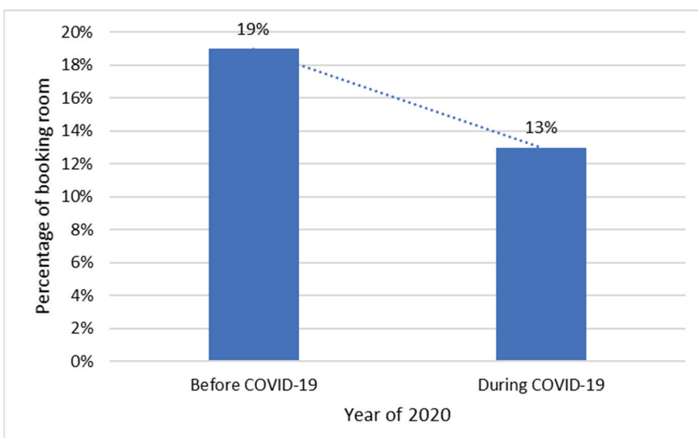

Figure 8. The predicted hotel's booking before and during COVID-19.

Figure 9 shows the percentage of employees of two companies, Evergreen and Taixie company, during and after COVID-19's emergence. With realization of the world's situation during COVID-19, combination and cooperation are the best solutions for the existing difficult time. From July until December of 2020, the percentage of employees of Taixie company made up approximately 40% to 55% depending on the situation of the disease in Taiwan.

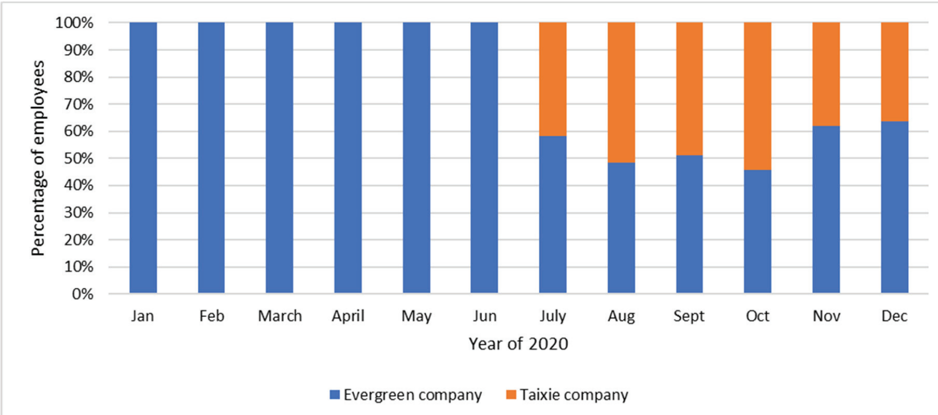

Figure 9. The percentage of employees of Evergreen and Taixie company in 2020.

Figure 10 shows the rate of hotels before and after the COVID-19 pandemic when applying the TRIZ method in the Evergreen hotel from the websites of Agoda.com and booking.com. The rating after improving is 8.5 scores higher than before, at 8.3 scores. From the chart, the effects of the hotel's new strategy were accepted by customers.

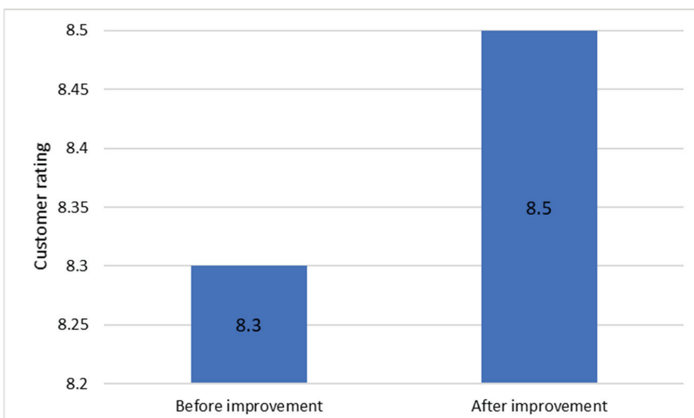

Figure 10. The rating of customers before and after improvement in 2020.

6. Discussion and Conclusions

The quantity of booking plays an important role in the net income of the Evergreen group's 10 hotels located in Taiwan. However, COVID-19, as an uncontrolled factor, made hotels need to change flexibly with the new strategy and control system in the booking system and elucidate the latest model to run business to cover the difficult time. During the early COVID-19 period, booking processes were often inefficient because of canceling and an unsafe hotel environment. Besides marketing problems, human resources in hotels were a difficult solution. The main purpose of the TRIZ methodology in this paper was to identify and fix the mistake in the system of hotels in the marketing and HR department. The analysis results can serve as a reference to execute, improve, and simplify operating processes, enhancing efficiency.

Regarding solving the tourism industry decision-making problem under the COVID-19 pandemic, according to the findings of [10], it was advised that the "quality management" of the international travel "bubble zone" be prioritized as a decision-making criterion during the pandemic. Another article [46] aimed to improve the community's psychological perspective to aid in the revival of the area's tourist business. The community must be aware of the current situations and must be able to innovate to support their family from numerous online micro-retail company gaps. This paper proposed some innovative recovery strategies to assist the tourism industry in anticipating the impact of COVID-19 during the pandemic by implementing several business recovery strategies, such as recognizing lost tourism business basics, reviving the business and running it normally and effectively, understanding the changing cultural character of tourists and new business identities, and determining the business position. Based on the impact of the influencer market on consumers of the tourism industry, the study of [47] found that most of the participants are not influenced by social media influencers in terms of deciding where they would travel.

In our study, the results showed that the CCP efficiency was increased from 19% to 40% after applying the TRIZ solution, yielding an improvement rate of 21%. The customer rating was improved from a 8.3 to 8.4 score after conducting the improvement. Aside from that, changing the hotel structure with a partnership with the Taixie company assisted Evergreen in reducing various cost pressures to manage the business and recover after a difficult period. This improvement in efficiency is directly reflected in the categorization completion rate of planned and unplanned long-term acquisition projects, which are complex and contain extended turnaround periods. This paper can be a useful reference for managers, investors, governments, and policymakers to improve the sustainability performance in the tourism industry.

The contributions in this research can lead to new lines of inquiry in the hospitality area. Several further questions emerge in light of the discoveries presented in this paper. A few of the most prominent are listed. By applying the TRIZ method to the Evergreen hotel with good results, the researcher would like to uncover new research to maintain and improve the outcome after using the TRIZ method during the COVID-19 period. Because of unpredicted diseases in the future, the latest running model of hospitality continuously needs to be changed to fill the large gap. The newest trend in the field will focus on customers' requirements in safety, size of rooms, and 3D experiments, mobile check-in services, robots in hotel and restaurant settings, etc. The research is a reference to guide other hotels in flexibly adapting to the hotel industry's changing and difficult times.

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The Impacts of Digital Technology on Service Design and Experience Innovation: Case Study of Taiwan's Cultural Heritage under the COVID-19 Pandemic

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Abstract: The aim of this research is to identify the digital technology impact and experience innovation of cultural heritages in the context of the epidemic. The authors created an analytical framework and used a qualitative exploratory multi-case study of three cultural heritages in Taiwan. The findings indicate that digital technology has facilitated further innovations in cultural heritages under the epidemic to be closer to consumers' daily life and more connected with the young generation. Compared to traditional cultural heritages, profit-making cultural heritages need sales of its products to sustain operations, while live streaming, which is interactive, is rising as a new way to promote sales. Using multiple digital platforms can maintain consumers' interest in the cultural heritages, encouraging follow-up visits and thus resulting in more traffic online and offline. This paper illustrates the advantages of digital technology in the context of the epidemic, highlighting the innovative technology of live streaming and social platforms introduced that are different from the traditional cultural heritages.

Keywords: service design; digital technology; experience innovation; cultural heritage; COVID-19

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1. Introduction

The majority of COVID-19 cases are caused by interactions in an indoor environment [1]. According to the data of the UN's cultural watchdog, approximately 85% of heritages have been temporarily closed due to the epidemic [2]. Especially, the use of digital tools in cultural heritages is receiving increasing attention [3]. However, cooperation between cultural heritage and technology is currently limited [4]. Research on cultural heritage management is mainly from the perspective of demand (visitor satisfaction) and the ability to protect cultural heritage [5]. Due to the demand for service improvements generated by COVID-19, much cultural heritage around the world still needs to supplement their strategic approach to digital transformation [6].

The global epidemic has a substantial social and economic impact on cultural heritage. The innovation of digital media has given the cultural heritage industry a new opportunity to continue interacting with visitors and creating value. This study adopts a multiple case study approach to extend the concept of experiential innovation to cultural heritage using service design as an entry point including the space service design and setting up digital platforms. This research surveyed three cultural heritages in Taiwan. These three properties represent revitalised and commercially viable cultural heritage. By the following research questions: (1) How do Taiwan's cultural heritages use digital platforms to interact with consumers? (2) How can the service design change the customer experience? (3) How does digital technology impact innovation on visitors' experiences during COVID-19?

The number of international tourists visiting Asian countries has increased annually. For example, the percentage of international tourists visiting Asian countries increased from approximately 15.5% in 1995 to 24.9% in 2016 [7]. Specifically, according to statistics from the Tourism Bureau of the Ministry of Transportation, the number of tourists in Taiwan exceeded 10 million for the first time in 2016, and the trend of tourist growth is expected to continue [8,9]. The Taiwanese government also noticed the crucial role of tourism expansion in economic development and is eager to promote tourism internationally [10].

2. Theoretical Background

This section reviews the literature in service design, digital platforms, and experience innovation theory. We try to explain the relationship between service design and customer experience in cultural heritage and how digital technology can act as an enhancement to them to solve the plight of cultural heritage. Then, the third part of this section explains the research model, which presents the impact of digital technology during COVID-19 on cultural heritages.

The impact COVID-19 has had on the service industry is major, and transformative research is needed to address the sustainability and benefits of the customers, employees, and service organizations in travel-related industries [11]. The asymptomatic cases in Taiwan made the low infection rate a thing of the past, and it remains unknown how these cases occurred and how many more cases there are [12]. Many precautions and prompt responses have been taken against the virus in Taiwan, such as wearing masks and avoiding mass gatherings [13]. Digital technology, while used to identify the epidemic and its transmission, serves as a temporary alternative to the "physical entity", facilitating greater social participation in the cultural heritages and playing an even more significant role in the future [14]. It allows consumers to interact with brands in new and unconventional spaces through sensory experiences, gaming platforms, or mobile apps [15], and online shopping platforms with technological features provide users better shopping experiences [16]. Based on this, the following discussion will focus on three theoretical bases: service design, digital platforms, and experience innovation.

2.1. Service Design

Service is the basis of creating value, and service design is an exploratory process to build new value relationships among participants [17]. As service innovation brings new service ideas to life, developing a new prospect through new service design methods and models for the design is an important direction for service design research [18]. In addition to the cultural products themselves, cultural managers need to understand that an appropriate service design helps promote the participants' experience and post-consumption behaviour [19]. Service design can guide multiple stakeholders to be involved in platforms and share resources to enhance the value creation [20]. Further explanations of how and when service design is used will help service designers and managers to understand what environments are needed to foster innovation [21].

Integrating local art and culture into sustainable service design can create unique value and experiences for customers. As a means of service design, local value creation creates sustainable added value for local stakeholders [22]. Service design originates from a generation of digital-based network thinking. The customer is transformed into exquisite consumption, and the pursuit of the quality of life, innovative use of technology networks, and people will bring better service quality [23]. Based on this broad vision, the experience can be evoked through products, packaging, communications, store interactions, sales relationships, and events [24]. Technology applications will improve the experience dimensions and engage consumers to actively be a part of and create together the service experience [25]. The platform information will effectively improve the operation efficiency, help adopt customized and flexible services, and boost the service [26]. Online retailers need to pay attention to the customers' shopping experience process, as each factor can influence customer attitudes and willingness to purchase again [27].

Heritage faces the direct impact of the workforce and finances. Their inability to operate forces them to close, postpone, or cancel their services to their audiences. In order to maintain their functions and increase access to cultural heritage, cultural institutions around the world have turned to digital platforms [28]. The social platform pages can interact with customers and generate income directly in the online market. Therefore, management must understand how to design a valuable interactive experience for a new interactive space [29].

2.2. Digital Platforms

With the help of digital technology, the platform provides an environment to link consumers' creative interactions with the experiential outcomes of potential resource capabilities [30]. Advances in digital technology have expanded the horizons of cultural heritage learning and provided new opportunities for information sharing through digital forms [31]. Technology has become the primary means of cultural heritage communication. Such sites that cannot operate offline continue to work online [32]. Managers of these sites recognized the need to better connect objects to the audiences' personal daily lives. Social media and e-commerce, for example, are used to attract and retain customers, especially millennials and the tech-savvy [33].

The innovation of service providers, namely striving to be customer-, technology-, and cocreation-oriented, determines satisfaction and eventually affects customer loyalty for intentions of referrals and recontracts [34]. Technology has the advantage and importance of creating an immersive and positive experience and behavioural purposes [35]. Online connection grants customers access to efficient, convenient, and real-time value. The establishment of social platforms enhances brand competitiveness and brings consumers opportunities to experience products and services [36]. The design of the tourist experience should coordinate different elements of integrating the digital world and the physical space into a unified and comprehensive experience [37].

2.3. Experience Innovation

In response to these market trends, cultural heritages are working to develop experience-based value creation activities that allow visitors to participate in the daily exhibitions and be a part of them [38]. The tourism experience is closely linked to the visitor's perception of the activity and the environment. Social media is a way for them to share a memorable experience with others [39]. Cultural heritage now requires creativity and innovation to develop intangible resources and new visitor experiences [40]. A key aspect of being consumer-oriented is providing added value by offering novel and meaningful services, in which technological innovation undoubtedly plays a vital role [41].

Service innovation and customer satisfaction are essential components of a company's sustainable development strategy [42]. To achieve sustainable development, companies need to provide innovative services constantly. Service design can be used to envision and design new services to achieve change [43]. Technology advances are pivotal to the digital transformation of services and understanding of the digital and data marketplace [44]. Visitors shape the service experience during participation, and technology facilitates new interactions, including on-site and online interactions [45]. The use of technology will improve the experience dimension and actively engage consumers to create the service experience. Such active participation requires experience in management planning and activities initiated for customers [24]. It needs to be further proven how institutions can rely on various digital tools such as live streaming and other social media platforms to stay connected and always be present for audiences who live in different communities around the world [46]. Digitization has become part of the museum's mission, structure, and practice, while the entity and digitization can be practised together as an enhancement of one with the other [47].

3. Methodology

3.1. Case Studies

This study is a qualitative study and will adopt a grounded theory and case study in qualitative research. Through multiple case studies, samples are designed to compare the service design and customer experience of three cultural heritages. The analysis process includes open coding, axial coding, and selective coding [48]. The existing literature recognises that digital platforms can create value for cultural heritage innovation, but it has not been linked to customer experiences, and further research is needed. Therefore, the theory has to be established to prove that the strategy in the research is synchronised with the new phenomenon [49]. Multiple case studies allow the researcher to look into the cases and observe differences between them [50]. In particular, the question of why and how phenomena such as the current plight of cultural heritage are being addressed [51]. Case selection is based on six basic types proposed by Langrish [52]: (1) Comparative: They are Japanese buildings of the same period that have been reused in different forms and contain different scales. (2) Representativeness: There are still in business under COVID-19 and have a creative department. The main consumer groups are tourists. (3) The best practices: All three cultural heritages have won government or NGO/industrial association awards. (4) The ones next door: the researchers are close to the research objects, with access to the survey of the management sector and consumers without the epidemic influence. (5) The "car, look at that": few cultural heritages are commissioned for third-party operations, especially commercial ones. (6) The economic: All three heritages have similar structures (competitors, buyers, etc.) that will allow for generic insights. In the case study, the researcher can collect and conclude from the survey data to understand the phenomenon in the study [53].

3.2. Case Selection

This study uses "intentional sampling" for the selection of interviewees. The data sources include primary and secondary data. The primary data was collected through semi-structured interviews with a total of 11 stakeholders from the management, staff and vendors of the cultural heritage site, experts, academics, and visitors during June and November 2021, which were recorded with permission (Table 1). The interviews covered the heritage operation status, innovation experience activities, the digital platform establishment, and the epidemic's impact (Appendix A). In addition, secondary data from various sources were collected to supplement this study, including interviews in magazines and newspapers, company websites and news and annual reports, government reports such as press releases from the Ministry of Health and Welfare, and reports on the operation of cultural heritages for a supplement.

Table 1. Data sources.

Data Type	Case	Position	Type	Date
Interviews	The Red House	Director	phone interview	2021/6/28
Interviews	The Red House	Merchant full-time staff	Face-to-face interview	2021/11/6
Interviews	Hayashi	Head and Deputy Head of Marketing Planning Department	Face-to-face interview	2021/5/6
Interviews	Jin Jin Ding	full-time staff	Face-to-face interview	2021/10/6
Interviews	Scholars And Tourists	Three Taiwanese residents	Phone interview	2021/5/17
Interviews	Tourists	One Taiwanese residents	Face-to-face interview	2021/11/5
Interviews	Tourists	One Foreign tourists	Face-to-face interview	2021/11/5
Direct observations	Jin Jin Ding The Red House Hayashi		Field Research	2021/10/6 2021/11/5 2022/4/28

Sources: complied with this research.

3.3. Data Collection and Analysis

This study used triangulation on the semi-structured interviews with consumers and the management, secondary sources, and participant observation. The interview is the primary data source for qualitative research. At the same time, participant observation is commonly used in the case study, with in-depth descriptions and analyses of specific phenomena or phenomenon collections to achieve theoretical saturation during the triangulation [54]. By examining the same conclusion reached by different methods or from different observers, the research outcome can be verified [55]. During the period, methodological flaws or data or researcher bias were identified and eliminated [56]. This research collected comparable data materials about relevant phenomena for classification and coding based on grounded theory. The concepts and scopes were extracted and connected to form an approach based on these data [57], as specified in Table 2.

Table 2. Material categories.

Category Code	Second-Order Code	Open Code
Service design	The change of service procedures The involvement of other participants New resources	Physical operation turned online and changes of operation time and items; new resources (epidemic prevention equipment) Exterior partners (tourism program, restaurants and diners), food delivery platforms (food panda and uber eat); new products, epidemic prevention equipment (temperature measure and alcohol machine), and new raw materials
Digital technology application	New technology introduced cooperation function API	Appointment system, message real-name system QR code, and connection to partner commerce platform; use of digit payment, mobile payment, and digital coupons
Experience innovation	New shopping method Dynamic interaction	Live streaming shopping discounts; more interactions on social platforms

Sources: complied with this research.

4. Case Briefing

4.1. HAYASHI

HAYASHI is the only remaining department store in Taiwan and the only department store in Taiwan with a shrine. It is positioned as a cultural and creative department store. Before the epidemic, its monthly visitor flow reached up to 200,000. It won the Design for Asia Awards in 2016 and is currently the most popular must-see attraction and a new landmark in Tainan City. In 2016, it started to operate an online shopping website and entered Pinkoi in 2019. The physical site has been closed since 19 May, and it began to sell products by living streaming on Facebook on 1 June. The digital technology is mainly used in online shopping stores and social platforms, the previous built-in cooperation now changing to be independently run for membership.

4.2. The Red House

It is the only remaining public market building from the Japanese rule period in Taipei, located in Hsimenting. It was later positioned as a cultural and creative colony, hoping that it would be a living cultural and creative place to introduce young Taiwanese cultural and creative brands to more young people and tourists from abroad. In 2019, it welcomed monthly visits from 800,000 people, but the number dropped to 200,000–300,000 in 2020 after the epidemic set off and was ranked the fourth among the major tourist sites in Taipei in 2017–2021. The Red House, an international cultural and tourist landmark, won the 7th Taipei Urban Landscape Awards to revitalize historic spaces. It was shut down on 14 May and currently operates on social platforms with digital technology.

4.3. Jin Jin Ding

Jin Jin Ding is situated on 84 and 86 Jinhua Street tucked inside the Nishiki-Cho Japanese-style dormitories, which previously served as the staff dorm for the execution ground. Built between 1920 and 1930, it has kept the original Japanese-style structure, went through five years of renovation, and reopened to visitors two years ago. It has souvenir and cafe areas with products aimed at middle- to high-end consumers. The main visitor sources are tourists from Japan, Korea, and Mainland China and revenue sources from souvenir sales. Since the epidemic, sales mainly come from residents during festive seasons. Its current digital technology application is the online store and social platforms, independently run by Jin Jin Ding.

Table 3 summarizes the characteristics of the case cultural heritages, including their location, year of establishment, visitor traffic, received award, main customers, etc.

Table 3. Brief profiles of the case companies.

Characteristic	Company		
	Hayashi	**The Red House**	**Jin Jin Ding**
Prosperity	1940	1940–1950	1930
Location	Tainan City	Taipei City	Taipei City
Original purpose	Department Store	food market-Theatrical Theatre	Government Officers' Quarters
Local Cultural Characteristics	Japanese period architecture	Japanese period architecture	Japanese period architecture
Visitor traffic before the COVID-19	100,000–200,000	200,000–300,000	20,000–30,000
Award	Design for Asia Awards	Urban Landscape Awards for historical space revitalization	Historical space revitalization Awards of Taipei City
Digital platform operation	Cooperative	Cooperative	Independent
Main customers	Foreign tourists especially Japanese	Tourists from Japan, Korea and Hong Kong t and local homosexual groups	Tourists from Chinese Mainland and Japan, Taiwan locals

Sources: complied with this research.

5. Research Findings

5.1. Digital Technology and Experience Innovation

5.1.1. Social Platforms Help Cultural Heritages to Maintain Customer Relationship

The use of digital technology has helped Heritage to maintain its relationship with its customers. The management explained the following to us during the interview:

> *"We have been promoting various issues about the hayashi department store, the brand and the product stories to give positive energy during the epidemic. This is why we are promoting different topics about the department store. The department store will promote different topics such as music, literature, art and literature."*

The management of HAYASHI department store explained that they would organise events and post about the department store on different social media platforms to enhance the relationship with customers. Digital technology has helped these cultural institutions open again, and their online activities have increased significantly [26]. Table 4 showed the case company social platform interaction comparison.

Table 4. Case company social platform interaction comparisons.

	Company		
	Hayashi	**The Red House**	**Jin Jin ding**
Social media	FB, IG, Line	FB, IG	FB, IG, Line
Upload frequency before	every two days	every two days	every week
Upload frequency after	Daily	Daily	Three to seven days
Content before the COVID-19	Announcement, publicity, and reply	Announcement, publicity, and reply	Product operation time
New in the COVID-19	live streaming	-	live streaming
Function	Shopping, group buying, membership	-	membership

Sources: complied with this research.

5.1.2. Digital Technology Helps Cultural Heritages Switch Services Quickly after a Shutdown

Cultural heritages have been building digital platforms for a long time, and their development accelerated during the epidemic. Tainan tourism authorities have proposed in their political guidelines to build a digital brand marketing platform and instruct the digital transformation of the tourism industry. A HAYASHI manager said to us:

> *"Since last year's epidemic, HAYASHI has been working hard to develop online shopping, so this year, we go with live streaming and social group management and promotion, which is relatively helpful during the epidemic."*

The Red House has adopted a strategy of "content management" and "in-depth marketing", starting with a Facebook fan page and later opening an Instagram account. As one of the informants mentioned:

> *"All the art and cultural performances have been canceled, but we will use Facebook and Instagram to help the art and cultural units repost, and then introduce the fair and workshop brands."*

HAYASHI uses the most digital platforms among the three cultural heritages, with an official online shopping store, collaborative platforms, and mobile app. The more innovative companies are more capable of using digital platforms to be more agile [58].

5.1.3. Cooperation with Online Shopping Platforms Benefits Cultural Heritages Operation

Cultural heritage needs to work more closely with the other partners to help innovate online shopping platforms. Cultural heritages that cannot build their own online shopping platforms will face more severe financial problems than others during the epidemic. Here are some responses from our interviewees:

> *"For the Red House itself, we cannot make our own online store; most of our brands run independently. We cannot make an online store for something we did not develop."*

Both The Red House and HAYASHI are stores that house brands, but HAYASHI is comprehensive and includes products that it creates. It reaches more foreign customers through platform cooperation and can maintain interactions with Lin's main consumers and tourists. One informant mentioned:

> *"We have been responding to foreign customers through Pinkoi, and we have launched on the Japanese market of Rakuten."*

Joining new platforms will open up more potential opportunities, but it will also prevent the cultural heritages from operating independently.

> *"We don't own the online platform, so we don't have the customer information. That's why we want to develop our membership system quickly."*

> *"We hope to obtain more member data and consumption preferences to help HAYASHI's precise marketing in product development and event planning."*

Jin Jin Ding joined the MOMO e-commerce and Uber Eats during the epidemic and did improve the plight that they could not operate physically. Meanwhile, the collaboration with another cultural institution, Taipei Palace Museum, also brought new jobs for staff on unpaid leave.

With restriction removal and market reopening, there may be a fundamental shift in technology adoption and demand planning, which will let employees take on new front-line roles. Small and medium enterprises can achieve internationalisation goals and work with outside partners through digital platforms, which is an effective means for them to overcome challenges related to knowledge or resource constraints [59,60]. Companies should develop strong relationship networks, select quality partners, and link them to their core R&D teams to develop an integrated platform [61]. New functions added to existing online channels may bring new customers to talk about the unmet needs and thus lead to new sales opportunities [62].

In sum, Table 5 shows the comparison of case company technology adoptions.

Table 5. Comparison of company technology adoptions.

	Hayashi	The Red House	Jin Jin ding
Post	✓	✓	✓
Live steaming	✓	-	✓
Digital membership	✓	-	✓
Self-employed online store	✓	-	✓
Cooperation online store	✓	✓	✓
API	✓	✓	✓

Sources: complied with this research.

5.2. Service Design and Experience Innovation

5.2.1. Technology Updates Benefit Service Improvement

During the epidemic, Jin Jin Ding updated its online store, as the original website was slow, difficult to create orders or find an item, and needed staff assistance for purchases. The brick-and-mortar stores used to be the main channel for customers to buy from, but after the new website was launched with the ordering problems improved, customers switched to online ordering, which made the latter the preferred alternative shopping form during the epidemic. Online shopping is convenient and simple and provides more choices than traditional stores [63].

Cultural heritage actively uses digital technology to innovate the customer experience, particularly linked to festivals and local communities. For example, the Red House used AR technology to organise parent–child events "catch ghosts" in the surrounding community on Halloween. Such events enhance the relationship with the community and have the effect of enlivening the surrounding economy. In terms of outbreak management, in the holiday creative market (regular events during the Red House weekends), suppliers and visitors will need to provide proof of vaccination, and alcohol will be available at the show desk for disinfection. The HAYASHI online shopping network has added brands and products such as fragrances, accessories, and refined daily wear that were previously only available in brick-and-mortar stores. Before entry, precautions like temperature taking at the forehead, hand disinfection, and code identification are required.

5.2.2. Application Programming Interface Connection

The Red House mainly uses its official website and the brand's independent stores connected to social media platforms for online sales. The operator told us that "people see the introduction on our Facebook and turn to their shopping store to purchase". Each cultural heritage has a variety of payment methods. Jin Jin Ding accepts five kinds of digital and mobile payment platforms, and the store staff said that customers use mainly mobile payment such as Apple Pay and credit cards. The Red House uses mainly Line Pay and EasyCard, along with the digital coupon issued by the government. HAYASHI uses a dozen mobile payments such as Apple Pay, Samsung Pay, Google Pay, Line Pay, other digital port payments, and Pi wallet. This month, it also included EasyCard, the first time the payment platform will work with the Tainan department store industry.

5.2.3. The Change of Service Procedure May Bring New Opportunities

The Red House adjusted its business hours during the epidemic. On weekdays, it offers self-service, allowing customers to pay for a drink and have a place to rest and chat, cutting the need for the staff and better-attracting consumers who are affected by the prices. A store owner inside said that the business was not good since the shutdown, but they changed their operation to weekends and the Red House fair and holiday crowds, which helped product sales. During the epidemic, Jin Jin Ding took the initiative to provide customer services such as phone orders and delivery, which increased customers' willingness to purchase again. As for the products, they improved according to customer feedback, such as making package sales into certain combinations for them to choose from, and some products are sold separately. The packaging is up to the customers to select or customise. HAYASHI provides ordering services through calls and Facebook, and customers can choose to pick up the products at the store or have them delivered. Companies need to pay attention to customer relationship management to improve the ability to perceive the customers' asset level in the markets [64].

5.2.4. The Membership System Helps to Understand the Consumer Needs with Zero-Contact

The online store cannot be in physical contact with the consumers, and the latter's shopping references and purchase records help with the marketing of cultural heritages. Such heritages in Taiwan have recently established a membership system on the Line@ social platform. Before the epidemic, Jin Jin Ding mainly depended on Line, e-mail, and phone to inform the old customers of the latest products. After the new official website was launched, it set up its new membership system there. Jin Jin Ding also said that the membership system allows them to promote and let customers purchase without being in the store.

The managing sector of HAYASHI said:

> *"This year, we worked on line@ membership and hoped that we can learn about the customers' purchase information and motive through the backstage data."*

Information on user experiences serves to assess the service quality and expectations [65]. The alignment between the consumers' personal preferences and the brand image will affect how they perceive the brand assets [66].

5.3. Service Design and Digital Technology

5.3.1. Live Streaming Is a New Trend in Cultural Heritage

Live streaming brings up a new way to interact with cultural heritage. During the epidemic, cultural heritages use social platforms to sell their merchandise, but their customer crowds still hesitate to embrace this way of promotion. The Red House 108 annual report mentioned adopting a visual way of communication to cater to the young generation and seek greater publicity through online media and live streaming. According to HAYASHI's feedback, they adopted such a practice for the first time with limited coverage, so the sales volume did not hit a peak right away, but the interactions with followers and their recognition of the brand turned out to be pretty good. Different from other department stores' sales, Jin Jin Ding has more means to communicate with the customers, and they also leave personal contacts from Line or e-mail. One informant said:

> *"Since the beginning of the epidemic last year, hayashi department store has been working hard on online shopping. Therefore, this year, with live streaming and social media operation and promotion, it is relatively good to help in the epidemic."*

Live streaming marketing can help companies to maintain business or even growth during the epidemic of COVID-19 [67]. However, the effects may be affected by the customer group.

5.3.2. Discount Activities Design Helps Improve Customer Experience

The three cultural heritages have all launched events such as set sales, discounts, coupons for membership registration, and exclusive discounts on certain platforms, which helps to attract customers to the online shopping platforms. HAYASHI also had many discount events in their online and offline stores.

> *"HAYASH shopping website has set up specially discount service for anti-epidemic area. At the end of May there was group purchase in limited time for people in the middle and north part who missed Tainan to bring these fine products home at the discounted price."*

Jin Jin Ding presents different coupons and discounts to different members according to their previous consumption amounts. It is also building itself on different shopping platforms with events to attract customers. With digital and paper discounts issued by the Taiwan local government, stores in the Red House also issued different coupons to boost sales. One of the respondents said that it was their biggest discount ever.

> *"Now the products we sell are 50% off for the second item they buy, the biggest discount ever and the long-shirts are the new products and they don't have this discount."*

According to the consumers' common responses, the cultural innovation products are mostly sold at relatively high prices, and they would buy there once at most. Promotions help customers to accept the prices, and the improved shopping experiences and satisfaction will make them more willing to revisit [68].

5.3.3. Content Promotion and Online Events Help with Network Traffic

During the epidemic, staff at the Jin Jin Ding brick-and-mortar stores explained and promoted the online ordering to the customers that visited, which led to a surge in online sales during the Mid-Autumn Festival. The other two cultural heritages preferred activity on social websites. HAYASHI changed its paper DM to an online one on social platforms to promote its products. There are also discounts that need interactions with people, for example, putting the store number on Line@ to obtain a "HAYASHI exclusive discount". These limited digital coupons are issued every weekend. Those who own a five-time coupon with the HAYASHI official Line account get an extra discount. Log in to HAYASHI for a consumption invoice, and there will be a lottery for hotel accommodations and dining coupons that are worth over USD 10,000. A respondent said that the consumers took active part is this. Online interactions allow consumers to constantly connect with the cultural heritages, and the service design should include meeting their emotional needs (including artistic events) [69]. Here are some quotes from the informant.

> *"Since the epidemic HAYASI started to spontaneously promote on social websites its daily details, brand and product stories for, so as to tell people about their physical events like music, literature and art for them to look forward to one day they can visit again when the shutdown is removed and there is no safety concern."*

The findings above responded to the positive influence [24,25] brought about by experienced innovation. The digital technology interaction model presented in this research (Figure 1) can be used to explain how cultural heritages use digital technology to connect with consumers during this epidemic. Their management is affected by the operation; the service design, procedure improvement, and experience innovation can maintain or establish a connection with consumers. The use of digital technology allows both parties to interact on social platforms and online shopping stores when they wish to, allowing consumers who are unable to leave their homes to gain an experience and connect emotionally with these cultural heritages. When physical interactions are absent, the management sector and consumers continue to interact and create value to the social platforms and online store created by digital technology. This model can also be applied to discuss cultural circuits Champ and Brooks [70]. Relevant research on cultural circuits have been complied, including areas of public relations, tourism, and so on. Those applied to management goals witness interpersonal relationships in a wide range of experiences, including the process of representation, identity, production, consumption, and regulation. This model of a cultural circuit can apply as long as the processes of understanding the cultural circuit are dynamic and see how, when, and why they emerge; how they are related; and when the archetypes change [71]. Put our model in the cultural circuit, and we can identify the five aspects of performance, identity, production, consumption, and regulation [72]. The influencing process is dynamic and is involved with the manager's experience innovation. The epidemic has influenced the process and enhanced the speed of technology applications and the entity limitations.

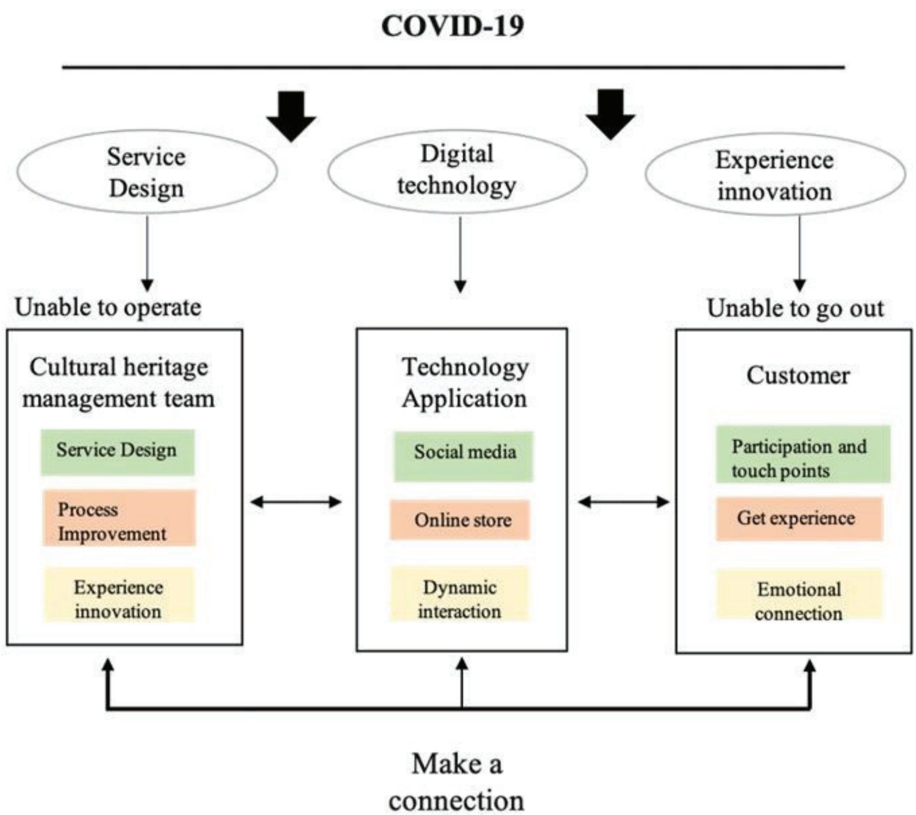

Figure 1. Digital technology interaction model.

6. Discussions

During the COVID-19 epidemic, we have integrated virtual and reality customer experiences through service design, which is conducive to the practice of heritage cultural innovation. When there is a creative department, there are connected places local artists and craftsmen have the opportunity to supply, which can bring the power of stabilising society. Consider the importance of local traditions and culture in service development to increase profits while maintaining local cultural values [73], and shift the focus of art from elegant culture and historical value to materials and commodities that can be touched in daily life. The role of traditional art threatens the economy, but now, it also benefits from the renewal of the industrial structure. Readjust the relationship between art and society, become a new cultural intermediary for consumers and producers, go deep into their personal daily life, and connect the related industries [74].

Different digital platforms can bring about other benefits to cultural heritage. Facebook and Instagram, for example, can interact with customers through texts and posts, while Line can establish a convenient and simple membership system. Cultural heritages can run their own online store to obtain their membership data, and cooperation with other online retailers helps to expand customer sources and establish their own platform in the preliminary stage. Increasing the inspiration and participation caused by interactions is conducive to enhancing the interest in new knowledge and attracting the younger generation and potential customers [75].

This research responds to its multilateral platform function [20,30]), and here are the two propositions:

Proposition 1: *Cooperation with multiple platforms helps cultural heritages create new chances*.

Proposition 2: *Marketing events on different platforms will improve customer engagement*.

After the transformation of heritage, the atmosphere and service design of the whole field allows consumers to experience historical and cultural value by buying these cultural and creative commodities for experience and innovation. They can continue to feel historical value and educational significance after returning home. The way of industrial, artistic creation can further establish contact between heritage and tourists, interact through collective memory, and provide tourists with unique opportunities to experience pleasure and feel the effects of psychological well-being [76,77]. The results above echo the advantages of the proposed service design. Based on this, we have two propositions:

Proposition 3: *Optimising the service procedure and products in the product design helps cultural heritages to build emotional value during the epidemic*.

Proposition 4: *Analysis of the membership data helps the cultural heritage management team to have closer ties with the consumers*.

Service providers and consumers have shown passion and doubt about the use of technology, which might be negative in customers' experiences [63]. Klaus [78] concluded that the lack of interactions is the reason why some customers are not willing to buy online. The interpersonal communications and fine relationships will affect middle- to high-end customers' choices. It has been proven that the information technology of living streaming has a positive influence on customers' purchase decisions [79]. By emphasising the process and relationship of value creation, it is conducive to the coexistence of non-profit, commercial, and social enterprises in the organization and the realisation of the objectives and vision of cultural and art organisations [80]. Here are the propositions for the article:

Proposition 5: *The effect of experience innovation is influenced by customer engagement and where they come into contact*.

Proposition 6: *Cultural innovation products sold on a live streaming platform triggers new experiences for customers*.

7. Conclusions and Suggestions

7.1. Conclusions

This paper introduces the strategies and measures adopted by Taiwan's cultural heritage during the COVID-19 crisis, with particular reference to the use of technology and the establishment of digital platforms. The closure of the museum from 2020 to May 2021 has created a widespread damaging effect on cultural heritage. Cultural heritage has created new market opportunities during the epidemic through the ability to stay engaged with consumers through digital technology and through online shopping. Three main findings can be concluded: (1) The epidemic has facilitated cultural heritage's further innovation to be closer to the consumers' daily life of consumers and connect more with the younger generation. In order to adapt to the changing epidemic environment, digital technology has provided cultural heritages with a new channel to get in touch with consumers. (2) The use of digital technology helps to improve the quality of service and serves as a catalyst for innovation during the experience. Live streaming is a new trend in cultural heritage. (3) Online shopping stores help them to continue to serve the consumers, and cooperation with multiple platforms helps develop more opportunities. The online operation and the physical shops create a two-way diversion effect.

7.2. Theoretical Contribution

Based on the service design point of view, the research has observed a change from physical to online services, enhanced the relevant theory for the cultural heritage industry, and provided cases of measures taken against the COVID-19 restrictions.

(1) The research has identified the relation between the service design and consumer experience, especially under the COVID-19 impact. To be specific, the research also confirms that, during the epidemic, cultural heritages can use digital technology to interact with customers and build new chances in the market through online shopping stores.
(2) The research has stressed digital technology's advantage during the epidemic, especially the innovative introduction of live streaming and social platforms compared to traditional cultural heritages. This is in line with the current e-commerce development and has broadened the literature scope.
(3) Based on the above, the research has constructed a concept framework. It indicated that service design, experience innovation, and digital platform can be involved in the consumer interaction process to highlight the experience innovation influence and connect with customers. Digital technology brings new services and products, which are constantly creating value and being delivered to consumers. Additionally, the research also revealed the influence of the membership system. The cultural heritages change situations where they cannot be in direct contact with customers to understand or provide the proper services. The current discussion focused on the cost of membership and not its function in maintaining relationships with consumers.

7.3. Practical Implications

This research helps the cultural heritage industry learn about the transforming path and innovation strategy against the epidemic and sort out the ways of online operation.

(1) The global epidemic has lasted until today and is full of uncertainties. It has become a significant trend for companies to turn digital, and it is expected that people's shopping habits are changing fundamentally to become online. Brick-and-mortar stores need to think about introducing digital technology to interact with consumers for them to stay interested.
(2) Different social platforms do not have the same customer crowds, but companies can choose how to interact accordingly. Additionally, the managing sector should consider services and products related to the epidemic. It would inspire the company to renovate, as well as boost sales. Cultural heritages need a series of measures to help

consumers to confront the changes brought about by the epidemic (cancellation of courses and performances and changes to or a refund of online purchases). This is one thing service design should think about during an epidemic.

(3) Cultural heritages revitalised need to review how to combine their cultural resources with daily life and recreate opportunities to continue interactions with customers. This paper has offered new references for the transforming industries, with more opinions on maintaining a connection with consumers [81,82].

7.4. Future Research Directions

The COVID-19 situation may go up or down, but there might be new dilemmas for the cultural heritages, for example, the lack of products or delivery staff. The managing sector should be more flexible and responsive in innovating against epidemic changes. At the same time, the spread of COVID-19 has limited our contact with the outside world to online, and there will be competition among the cultural heritages. It requires further discussion about staying competitive in the area. Live streaming is a new way of shopping and is still in the preliminary stages in terms of cultural heritage. This is now mainly popular in Asia and especially in China. Future research can pay more attention to this respect.

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Appendix A Interview Outline

For the management teams:

(1) What kind of culture and spirit do you wish to show the consumers?
(2) What's the main age and ethnic group are the consumers? Which country are they mainly from? Is there ethnic consumption difference online and offline?
(3) What measures do you take to confront the epidemic? What difficulties do you have during the epidemic?
(4) As the old houses cannot receive visitors at the moment, what measures have been taken for consumers to understand local culture and brand history?
(5) How many social platforms do you run on now? How do these platforms help you communicate with consumer interaction?
(6) What are the current projects available on the online shopping store? Is such long-term operation functional against the epidemic impact?
(7) How do you present cultural innovation on such delivery products?
(8) Do you run your store on the online store? Does membership help? What discounts are available for the members?
(9) What's the impact of the new round of epidemic on Taiwan? How is it compared to last year?
(10) What new measures were adopted after the shutdown?
(11) I see that you have live streaming. How do customers respond to that? Does it promote product sales?
(12) How do you maintain your connection with customers during an epidemic?

For Consumer:

(1) What do you think is the most prominent feature?
(2) What do you expect to feel in the environment, for example, experience events, commodities, and ambience? Is the experience in line with your expectation?
(3) How do the staffs serve and present themselves?
(4) Is there any inconvenience in the environment?
(5) Do you visit more or less than before? Do you gain any new experiences or feelings? Have you used the online platform?

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systems

Article

Fresh Product Supply Chain Analysis in Cauca, Colombia — A Hass Avocado System Dynamics Approach

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Abstract: In recent years, agriculture has become an essential activity in Colombia, despite the challenges faced by farmers due to low yields and insufficient resources to improve their main activities, such as irrigation systems, agricultural practices, and industrial machinery. This Hass avocado approach has been addressed in previous research considering system dynamics simulation to evaluate farmers' behavior strategies and improve their competitiveness. However, these studies typically examine a single strategy effect and avoid multiple integrated strategies. Other studies focused on the complex interactions between different factors in the production chain and their feedback effects on farmers' productivity and cash flow. For these reasons, this research provides a comprehensively dynamic model and evaluates long-term strategies and their effects on supporting and improving small farmers' productivity and profitability. A system dynamics methodology was used to model complex systems processing Hass avocado farmer association data and explore their effects on competitiveness for long-term sustainable and profitable agriculture. This research proposes optimal scenarios for small farmers, including strategies such as low-interest credit access, logistics practices, and government technical support. The scenarios provide a proactive tool for decision makers and promote rural farmers' development, aligning high-quality fresh product supply and demand.

Keywords: system dynamics; agriculture value chain; farmers behavior; fresh products production

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1. Introduction

According to the United Nations, the demand for food will increase by 70% between now and 2050 for the predicted world population growth from 7.7 million to 9.7 million [1]. For this reason, researchers focus on improving crop productivity and competitiveness in the space available [2]. One solution is intensive agriculture development, but this method has negative implications for soil degradation, deforestation, and climate change. Experts are seeking new and better ways to produce food for the human species [3]. One of the most widely accepted proposals is "smart agriculture", which entails balancing new agriculture and livestock to increase productivity while maximizing resources and minimizing environmental impact [4–6]. Among smart agriculture's fundamental principles is to produce more food with fewer resources through Good Agricultural Practices (GAP) that limit forest depredation, reduce carbon footprint, and create income opportunities for small-scale producers in rural areas [7]. Likewise, sustainable development is essential to address food production scarcity, allowing organizational and technological changes and focusing on actual and future necessities [8]. However, the challenge in developing countries is identifying fresh product demands (such as root and tubers (potatoes, sweet potatoes, yams, cassava), fruit and vegetables (banana, orange, apple, avocado, tomato, grape), and others [9–11]) with significant resource constraints to achieve sustainable agricultural development, poverty reduction, and economic growth.

Avocado production is a prime example of intensive agriculture, with global production projected to reach 12 million metric tons by 2030, more than triple its 2010 level [12]. In response to the rapid growth in international demand, avocados are expected to become the most-traded primary tropical fruit by 2030 [13]. Colombia is a major player in this market, with its 54,000 hectares accounting for 6% of the global planted area and making it the third-largest producer. It also ranks fourth in production, comprising 11% of the total produced worldwide, with an output of over 540,000 tons [14]. However, the increase in avocado production has compounded challenges related to consolidating the supply chain, achieving added value and market diversification, ensuring adequate technical support, and gaining certification in traceability, quality, and safety of production [14,15]. These challenges have led to precarious production systems lacking in technical, economic, and social sustainability [16], as well as future environmental problems such as deforestation, loss of biodiversity, and significant water scarcity [17].

Currently, System Dynamics (SD) models applied to agriculture allow for the comparison of social, economical, productive, and environmental elements, as they adopt a global perspective rather than focusing on minor details [18,19]. These engineering techniques are ideal for application in the specific scenario of Hass avocado production in the study region, where not only environmental conditions play a fundamental role but also soil and climatic elements, good agricultural practices, and the producer's economic potential, among other factors [20].

Given that the Hass avocado production chain plays a fundamental role in the improvement and economic development of the study region, it is important to identify the most determining factors to consolidate the production chain in the long term with crops with better yields in productivity and fruit quality. To do this, small producers should not only consider the factors that affect the crop, but also identify the factors that affect the other links in the production chain. The SD approach allows for this and helps predict the organization's future based on variables. Additionally, since SD helps to investigate which variables need to be changed to improve the system's behavior, it can be helpful in understanding complex problems [21].

Most research that has addressed strategies to increase productivity and profitability has evaluated them separately, such as [22], which proposes to increase avocado productivity through high-density planting [23], which evaluates the impact of access to credit on the profitability of smallholder maize farmers, and [24], which analyzes the effect of cooperative organization of smallholder banana farmers in Kenya. Some of these researches have used the SD approach, but these studies only examined the effect of a single strategy and did not study the effect of multiple integrated strategies. Therefore, this research aims to provide a dynamic model to comprehensively assess the long-term effect of different strategies aimed at supporting and improving the productivity and profitability of Hass avocado cultivation by smallholder farmers, such as access to credit, implementation of good agricultural practices, farmer association, government support with technical assistance, and fertilizer supply.

This study seeks to answer the following research questions: (1) What financial shortfall do small producers face due to low production yields? (2) If producers can access credit to invest in improvement programs, what effect will it have on the average yield in tons per hectare, cash flow, and cumulative net profit? (3) How much does it cost small producers to implement good agricultural practices and become certified in their use, and what effect does this have on their cash flow? (4) If small producers decide to join an association, what effect will this have on crop productivity and profitability? (5) Should the State invest in the Hass avocado production chain? How and how much should it invest to ensure the long-term sustainability of the supply chain?

The study aimed to investigate the impact of various policies and actions on Hass avocado productivity. To do this, it developed a management model that adopted a systemic approach to capturing the complex interactions within the system. It constructed the model using a system dynamics methodology, which uses official data from regional producer associations. This approach allowed the researchers to systematically analyze the effects of multiple factors on avocado productivity and identify potential areas for improvement.

2. Related Work

Agricultural production chains are complex systems influenced by various factors [25]. The system dynamics approach can be used to study the behavior and consequences of these complex interactions. This approach allows for the analysis of nonlinear behavior over time using flows, feedback loops, table functions, and time delays with differential equations [26]. The system dynamics approach was initially applied in fields such as industrial management [27], urban dynamics [28], and population growth under resource constraints [29]. However, it has since been applied in other fields, including psychology, climate change, nature, and agriculture [30].

In the context of agriculture, the system dynamics approach has been used to evaluate the environmental and economic effects of eco-agriculture in the Kongtong district of China [31]. The results of this study indicated that the current agricultural system has various disadvantages, including slow development of organic agriculture, methane emissions, and high energy consumption. The study recommended specific government policy actions, such as promoting new energy sources and subsidizing power generation, to address these problems. Additionally, Waters et al. [32] applied an SD model to study the interaction between economic drivers and different production systems in the United States. Their results showed that a production system based solely on crops has the greatest potential for sustainability. Birthal and Hazrana [33] used a dynamic approach to rainfall data to assess the impact of climatic disturbances on Indian agricultural productivity. Their results indicated that these phenomena impair productivity, highlighting crop diversification's importance to pre-adapt climatic shocks.

Prior research on agricultural production in South America has predominantly focused on improving competitiveness in the sector [34,35]. Hakim et al. [25] utilized an SD method to build a partnership model in a complex and dynamic red chili supply chain in Indonesia's Bener Meriah Regency to improve the bargaining position of farmers. Another Indonesian study [26] demonstrated the problem of inconsistency in the quality and availability of cocoa beans within an integrative supply chain model. This lack of infrastructure, poor post-harvest management, and low-quality human resources all contributed to the weak competitiveness of the cocoa industry. A study on the fruit sector in Colombia utilized traceability technologies to investigate dynamic behavior [36]. The results indicated the importance of traceability technology and its relationship with investment capacity and quality. A potato supply chain analytical hierarchy approach in Peru and the grant contribution number 068-2021-PROCIENCIA (Opportunities for Small Potato-producing Units in the Challenges of COVID-19 Economic Reactivation—A Multidimensional Approach) evaluated packaging impact using a mixed methodology approach. These potato researches generated improvements, such as overall cost reduction, optimal fill rate operations, and organizations' strategic and functional decision articulation based on a cost-competitive strategy [37]. Finally, a study on the coffee sector in Colombia [38] evaluated the impact of investment policies and economic support on Colombian coffee growers and their cash flow. The results showed that the resources provided to small producers must be sustainable for long-term investment policies.

However, minimal empirical evidence is available in avocado production with SD methodology. Aroca's relevant study in [39] concludes agrifood supply chain entails complex relationships. Therefore, understanding actors' interactions and variables are essential. Aroca's study presented a dynamic model to simulate structures and interaction links taking into account economic, social, and environmental variables. For these reasons, the lack of production empirical evidence, and the gap with SD simulation, this research applies SD methodology with different avocado production scenarios such as association membership, good agricultural practices, access to credit, and government support. The production yield of each scenario is obtained over 15 years.

3. Materials and Methods

This paper presents the concept of SD and applies it to agriculture—specifically, to the Hass avocado, a high-demand product worldwide. Different scenarios were simulated, such as good agricultural practices, access to credit, producer associativity, and government support. These contribute to understanding which elements may be crucial to improving avocado production at the environmental and socioeconomic levels.

The primary references were some elements of the system dynamics framework [40]. As background, several studies presented by Suryani supported the current research on how system dynamics could apply to sustainable agriculture [41,42]. The choice of scenarios for the model simulation was informed by the literature review, since different studies have found that certain elements are fundamental to improving productive capacity. The primary materials used in the research were VosViewer [43] for the literature review, and Vensim [44], which allows scenario-based simulation, for the model simulation process. In addition, R studio [45] was employed for graphing and inferential analysis, and PAST [46] for the remaining data analysis. First, the development of the model involved the structuring of a causal diagram to indicate the main internal and external variables that make up the production chain and the cause–effect relationship between each of them. Second, the Forrester diagram was structured, which takes the variables of the causal diagram and compares them by means of equations that recreate real behavior. Finally, the policies to be evaluated are formulated by means of simulation scenarios [47]. The software used for the simulation was the Vensim PLE software package, a visual modeling tool that allows SD models to be conceptualized, documented, simulated, analyzed, and optimized. The simulation model was supported with the data, variables, and equations, and the methodological structure is better detailed in Figure 1. The following subsections detail the simulation execution process.

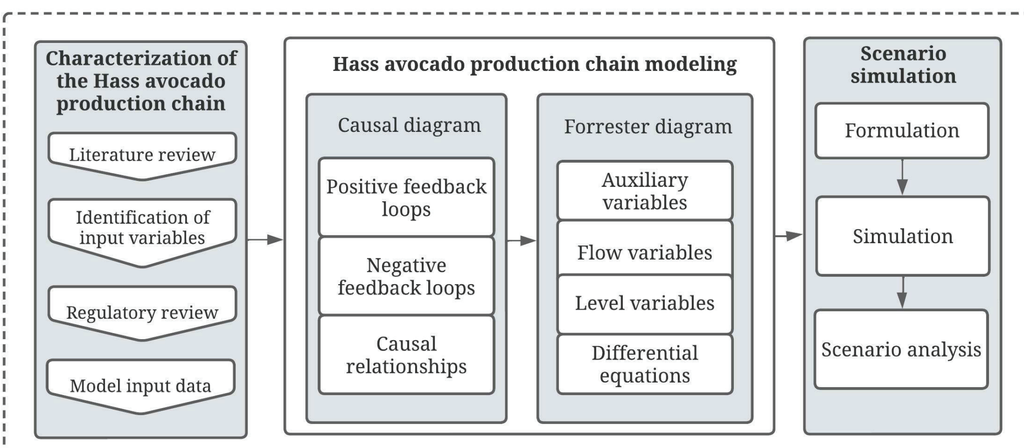

Figure 1. Methodological structure of the study development.

3.1. Problem Map

Figure 2 presents a map that demonstrates the identification of problems and solutions, as well as the underlying structure of these problems, according to the cited journal article [48]. This work aims to evaluate the input parameters in the upper part of the graph, which include the current status, access to credit, adherence to good agricultural practices, producers' association membership, and government support. The lower part of the graph showcases the variables that can be analyzed through simulation, including crop yield, cash flow, accumulated profit, and financing needs.

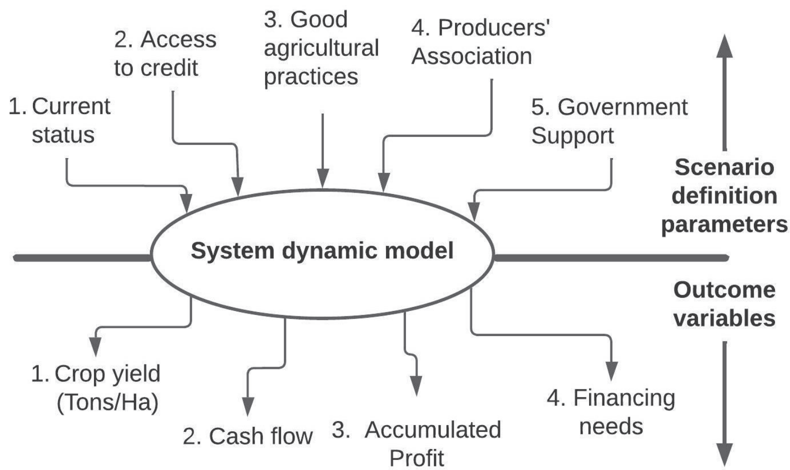

Figure 2. Problem map linking the research input variables to the simulation scenarios.

3.2. Study Region

The Cauca Department, with an area of 469,628 hectares suitable for Hass avocado cultivation, is Colombia's second most suitable department for producing this variety. However, to date, only about 1000 hectares of Hass avocado have been planted—less than 1% of the department's potential area. In addition, a yield of 5.4 tons per hectare has been identified, which is low compared to other Colombian departments such as Antioquia and Valle del Cauca, whose outputs range between 10 and 14 tons per hectare [49]. This deficit in production has been identified because of various studies conducted by entities that support the agricultural sector, such as education and research centers, the Government of Cauca, the Colombian Agricultural Institute (ICA), the Colombian Association of Fruits and Vegetables (ASOFRUCOL), and the Colombian Agricultural Research Corporation (AGROSAVIA). These studies have identified key factors contributing to the deficit, including the cost of fertilizers, limited financial access, scarce technology and technical assistance, and low levels of association membership and access to export certificates such as good agricultural practices [50,51].

In response to these findings, the national government has implemented support and investment policies for the avocado sector in Cauca to improve competitiveness. This study aims to identify and evaluate simulation strategies that enable small Hass avocado producers to improve their competitiveness through factors such as access to credit, good agricultural practices, association membership, and government support.

3.3. Description of the Model's Variables

In this section, the decision variables in the model and the reason for their choice are detailed. The model seeks to understand how farmer support strategies influence their productivity performance and cash flow.

3.3.1. Crop Performance

This variable refers to the productive capacity in tons per hectare in a year. Figure 3 shows that the production yield depends on the number of trees per hectare, fruits per tree, and the increase in productivity, which in turn depend on multiple factors. The present research found that the factors that most influence agricultural productivity are the association membership producers, access to credit, implementation of good agricultural practices, technical help, and reinvestment strategies in crop improvement programs [52,53].

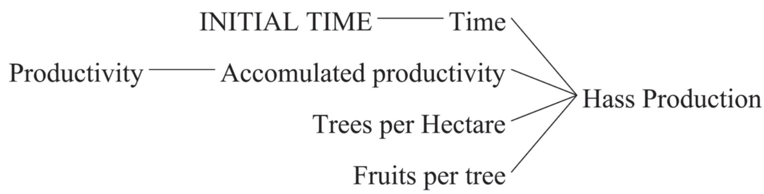

Figure 3. Production influence diagram.

3.3.2. Farmer's Cash Flow

This variable, denoted as "difference between producer's annual income and expenditure", is a measure of the profitability of an avocado producer. The sales volume, or quantity of avocados sold, has a direct impact on the producer's income. Additionally, the price per kilogram of avocados can vary depending on the location of the sale, with domestic sales typically commanding a lower price than international sales. In order to sell avocados abroad, producers must obtain certification from the Colombian Agricultural Institute (ICA) for good agricultural practices. This certification guarantees the quality and safety of the avocados, and is necessary for entry into foreign markets. The price per kilogram of avocados in domestic trade is typically 0.75, while international prices are approximately 1.75 per kilogram. Production costs and the size of payment installments for credit can also affect the producer's expenditure, and may influence the producer's decision to reinvest in improvement programs. Figure 4 depicts the variables that impact profit for avocado producers.

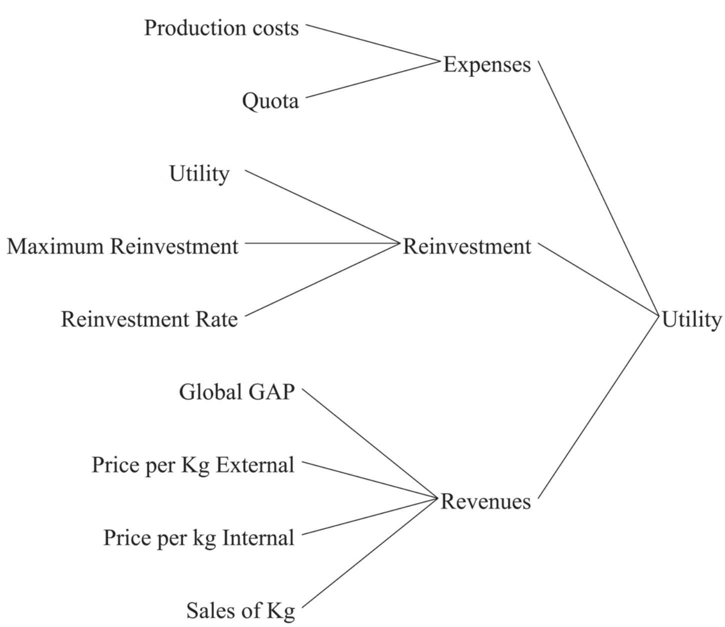

Figure 4. Utility influence diagram.

3.3.3. Description of the Model's Variables

Table 1 presents the variables used in the simulation model, along with the corresponding equation and variable type. The production variable is a flow variable representing the number of avocados produced in a period. Factors influence it such as the number of fruits per tree, the number of hectares planted, and the accumulated productivity over time. The average yield is calculated by summing the production of each period and dividing it by the number of years simulated (15 years in this case). Demand is modeled as a function of production, with an annual increase of 3%. Sales are only considered adequate when sufficient inventory is available. The price of avocados in the domestic market is modeled as a random variable, following a uniform distribution between 0.68 and 0.90 per kilogram. The price is between 1.58 and 2.04 per kilogram for the international market.

Table 1. Simulation model variables.

Variables	Equation	Type
Accumulated Pdn (A)	Production Ton (pt)	Level
Inventory (I)	Hass Production-Sales in Kg	Level
Accumulated productivity (AP)	Productivity (P)	Level
Utility (U)	If then else (Revenues-Expenses (EX)-Reinvestment) > 0, (Revenues-Expenses-Reinvestment), 0)	Level
Maximum Amount (M)	If then else(Financing Needs (FN) > 0, Financing Needs, 0)	Level
Balance (B)	- Quota (q)	Level
Production Hass (h)	(Fruits per tree (Time)*Trees per hectare*0.18) * (Accumulated production)	Flow
Average yield	If then else (Accumulated production > 0, Accumulated production/Time, 0)	Auxiliary
Demand	Hass production*15*(1 + 0.003)	Auxiliary
Sales (S)	If then else (Demand > Inventory, Inventory, Hass Production)	Flow
Revenues (Re)	If then else (Global GAP > 0, External kg price*kg sales*kg sales, Internal kg price*kg sales)	Flow
Internal price	Uniform random (0.68, 0.9)	Auxiliary
International price	Uniform random (1.58, 2.04)	Auxiliary
Profit	If then else ((Income-Expense-Reinvestment) > 0, (Income-Expense-Reinvestment), 0)	Level
Production costs	If then else (Producer Association > 0, (((Fertilizers + Labor + Plant Material + Equipment (Time) + Technical Assistance) * $(1 - 0.28)) -$ Supporting State)	Auxiliary
Reinvestment (Rei)	If then else (Profit > 0, if then if (Profit $\geq$ Maximum investment, Maximum investment, (Profit) * Reinvestment rate), 0)	Flow
State Support	2252.54	Auxiliary
Financing needs	If then else (Periodic cash flow < 0, -Periodic cash flow, 0)	Auxiliary
Interest rate	If then else (Producers' Association > 0, (0.0175 + 0.05), 0.0175 + 0.07))	Auxiliary
State investment	If then else (State Support > 0, 0.01, 0)	Auxiliary
Access to credit	If yes (Loan > 0, 0.07, 0)	Auxiliary
Application of GAP	Uniform Random (0.03, 0.08, 0)	Auxiliary
Producer Association	Random Uniform (0.06, 0.077, 0)	Auxiliary
Government support	If then else(Reinvestment > 0, Reinvestment*2×10^{-8}, 0)	Auxiliary
Productivity (P)	Fixed lag (Access to profits + Producer Association + Global GAP + Investment status + Productivity increase through reinvestment, Lag, 0)	Flow
Utility (U)	Sales revenue - Production costs	Level

The decision to reinvest profits is based on the profit level: if the profit exceeds the maximum reinvestment amount, the producer will reinvest the maximum amount. Otherwise, the producer will only invest 20% of the profit, provided that the profit is positive. Government support is represented by a fixed amount of 2262.54, representing the maximum amount of support provided by the state to cover production costs. Financing needs are calculated as the cumulative negative cash flows in the current scenario. Access to credit, implementation of GAPs, producer association membership, and government support are auxiliary variables closely related to the scenarios considered in the simulation. These variables are discussed in more detail in the Results section. The values in the equation represent the percentage increase when these strategies are implemented. The simulation evaluates them based on the assumption that the producer has implemented these strategies.

3.3.4. Description of the Model Level Equations

The level equations and their mathematical notation are known as state variables because they only change with time; they ultimately determine the system's dynamic behavior. Equations (1) to (6) represent the behavior of the level variables. Equations (1) to (6) describe the behavior of the level variables. Equation (1) is used to calculate the accumulated production. Equation (2) models the behavior of the accumulated inventory, accounting for production and sales. Equation (3) measures the accumulated increase in productivity. Equation (4) describes the behavior of the accumulated flow of profits. Equation (5) allows the identification of the maximum debt level. Equation (6) calculates the decrease in debt over time, accounting for periodic payments made by the producer.

$$\frac{\mathrm{d}A}{\mathrm{d}t} = pt; \tag{1}$$

$$\frac{\mathrm{d}I}{\mathrm{d}t} = h - s; \tag{2}$$

$$\frac{\mathrm{d}P}{\mathrm{d}t} = P; \tag{3}$$

$$\frac{\mathrm{d}U}{\mathrm{d}t} = \begin{cases} Rev - Ex - Rei; & \text{IF } (Rev - Ex - Rei) > 0 \\ 0; & \text{IF } (Rev - Ex - Rei) \leqslant 0 \end{cases}; \tag{4}$$

$$\frac{\mathrm{d}U}{\mathrm{d}t} = \begin{cases} FN; & \text{IF } (FN) > 0 \\ 0; & \text{IF } (FN) \leqslant 0 \end{cases}; \tag{5}$$

$$\frac{\mathrm{d}B}{\mathrm{d}t} = -q; \tag{6}$$

3.4. Structure of the Causal Diagram

Causal diagrams are graphical representations of variables connected by arrows, indicating causal relationships between the variables [54]. They allow us to understand the possible routes of association between causes and effects and other alternative routes that may produce biases in the association [55]. In the context of this research, the low productivity of the agricultural sector has a significant impact on the farmer's cash flow, as typical scenarios tend to involve more cash outflows than inflows. Thus, the cash flow is affected by the farmer's income and expenses: demand, sales, and product price per kilogram influence revenues. The product's price is lower if sold in the domestic market. By applying good agricultural practices, farmers can produce high-quality avocados, which adds value to the product and allows the producer to sell on the international market at a higher price. The farm's production volume is influenced by the productivity index, which increases as a function of investment in improvement programs, such as implementing irrigation techniques, phytosanitary control, or applying good agricultural practices.

Producer association membership also positively impacts productivity and is related to production costs, as association members can achieve cost reductions. In addition, member producers may have easier access to credit with lower interest rates than independent producers. Figure 5 shows the causal relationships between these variables and the positive and negative feedback loops. In this study, a positive feedback loop was identified, represented by the symbol (+) surrounded by a circle with an arrow pointing in the direction of the loop. Two negative feedback loops were also identified, represented by the symbol (-) surrounded by a circle with an arrow pointing to the left to indicate the direction of the loops.

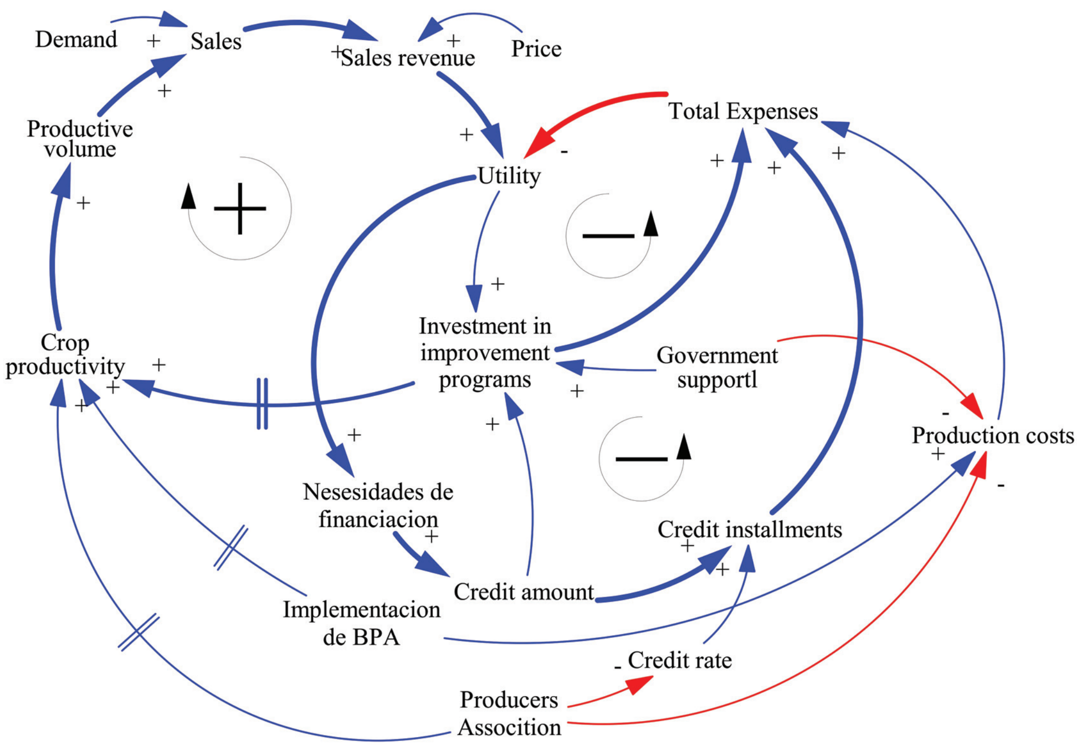

Figure 5. Causal diagram describing the relationship between the different research variables.

3.5. Construction of the Forrester Diagram

The Forrester diagram, illustrated in Figure 6, represents the interdependent variables and parameters involved in the production chain of Hass avocados, from production to marketing per kilogram of fruit. This model employs a cause-and-effect analysis to evaluate the relationships between policies and investment strategies in crop improvement programs and the benefits of these initiatives. The Forrester diagram is a precursor to developing a system of first-order differential equations, as described in [56].

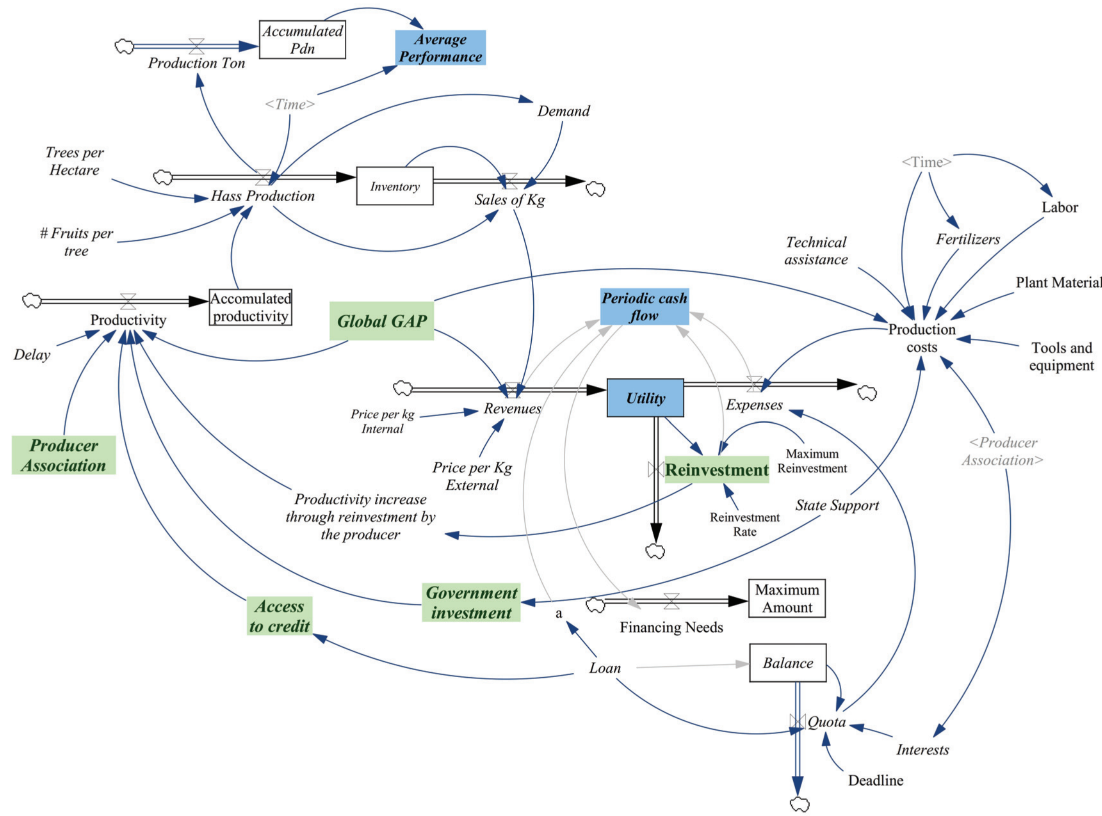

Figure 6. Forrester diagram for the Hass avocado production chain in the Cauca department.

4. Results and Discussion

In system dynamics, a simulation is defined as the experiments conducted in a model—rather than a real system—through simulation scenarios, making it possible to observe the effects that the adoption of a new strategy or a new form of organization will have on the real system [57]. In this study, five scenarios were modeled to evaluate various strategies aimed at improving the productivity and profitability of the Hass avocado production chain, with a simulation time of 15 years and a time interval of one year. These scenarios can be used to evaluate the behavior of the proposed strategies within each scenario and can be replicated for other production chains and permanent crops managed by small producers.

The first scenario simulates the current situation of small Hass avocado growers. The second scenario introduces the option of access to credit for investment in crop improvement or new planting projects, allowing for the identification of benefits gained by producers through such access. The third scenario incorporates the implementation of GAPs to evaluate the associated costs and impacts. The fourth scenario examines the effects on the system's behavior when independent producers decide to join an association. Finally, the fifth scenario considers government investment in small producers to identify government support's economic and performance impacts on crop development.

The financial results obtained from the simulation were validated with the findings of other research, such as those of [58], who conducted a pre-feasibility study for the production of Hass avocados in another region of Colombia. These results show that the investment is recovered within six years, which differs by one year from the results of the present study. This difference can be attributed to the present study focusing on small producers who still need machinery and cultivation technology, leading to a longer recovery. The results of the present study were also compared to those of producers in leading avocado-producing countries such as Mexico, who can recover their investment within four years, as reported in [59]. However, the profits obtained are subject to debate, as the area studied in the Colombian reference study is 4 hectares. In comparison, the area studied in Mexico is 25 hectares and the present study only considers the production of 1 hectare, leading to variations in profits and investment recovery time.

4.1. Scenario 1—Current Situation

Scenario 1 represents the current performance of the production chain, and Figure 7 shows the indicators used to measure its performance: average crop yield per year, annual cash flow, annual financing needs, and cumulative net income.

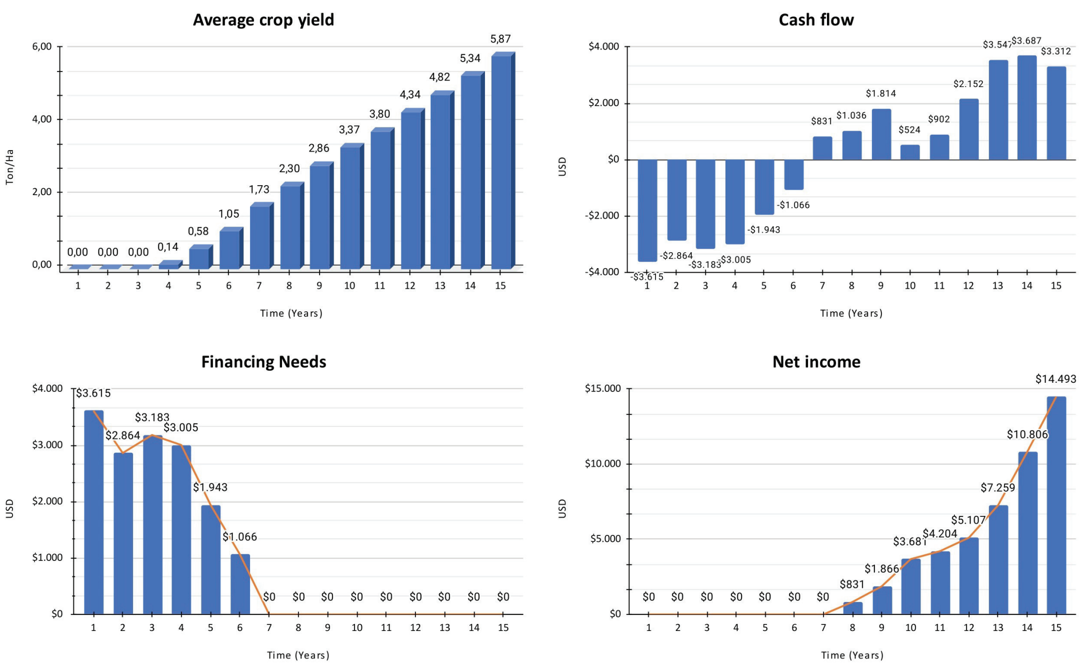

Figure 7. Results were obtained for the current scenario for the different variables studied, representing the current state of the Hass avocado supply chain in the Cauca department.

In this scenario, the average yield for the previous year's harvest was 5.87 tons per hectare, which is low compared to other countries, such as Mexico, where yields reached 18 tons for the same year. This production deficit negatively impacts the cash flow indicator, as the first few years exhibit more cash outflows than inflows. Despite this, the small producer becomes profitable in the seventh year, achieving a total profit of USD 831. The cumulative net cash flow indicator shows that the cumulative net income between the seventh and fifteenth years amounts to USD 14,493. Finally, the financing needs indicator reveals a cash deficit in the first year of USD 3615, which decreases to USD 1066 by the sixth year. If these financing needs were covered through access to credit, an improvement in production yield could be expected. This option of access to credit is evaluated in Scenario 2.

These results indicate that small Hass avocado producers in the southwestern region of Colombia face economic challenges. One potential solution to these difficulties would be for producers to acquire a significant initial working capital to invest in technical and technological improvements, enabling them to achieve profitability in a shorter time frame. Another option for adding value to Hass avocados would be to implement technology in the production process and obtain certifications such as an appellation of origin. In the case of other products, such as dairy, obtaining an appellation of origin has been shown to improve the profitability of small producers, as reported in [60]. An appellation of origin serves as a unique marker of a specific geographic location where high-quality products are produced, directly linking the quality of these products with that location. Obtaining this status would add value to Hass avocados produced in the region, making them more competitive in the market and increasing their sales value.

4.2. Scenario 2—Access to Credit

The second scenario evaluates the performance of the production chain when small producers have access to credit. With access to credit, small producers can cover the financing needs observed in Scenario 1 and invest in machinery and other means of upgrading crop production. The results indicate that access to credit increases yields by 0.838 tons per hectare, representing a productivity increase of 7%. Figure 8 illustrates the behavior of the average annual yield, cash flow, and cumulative net profit indicators under this scenario.

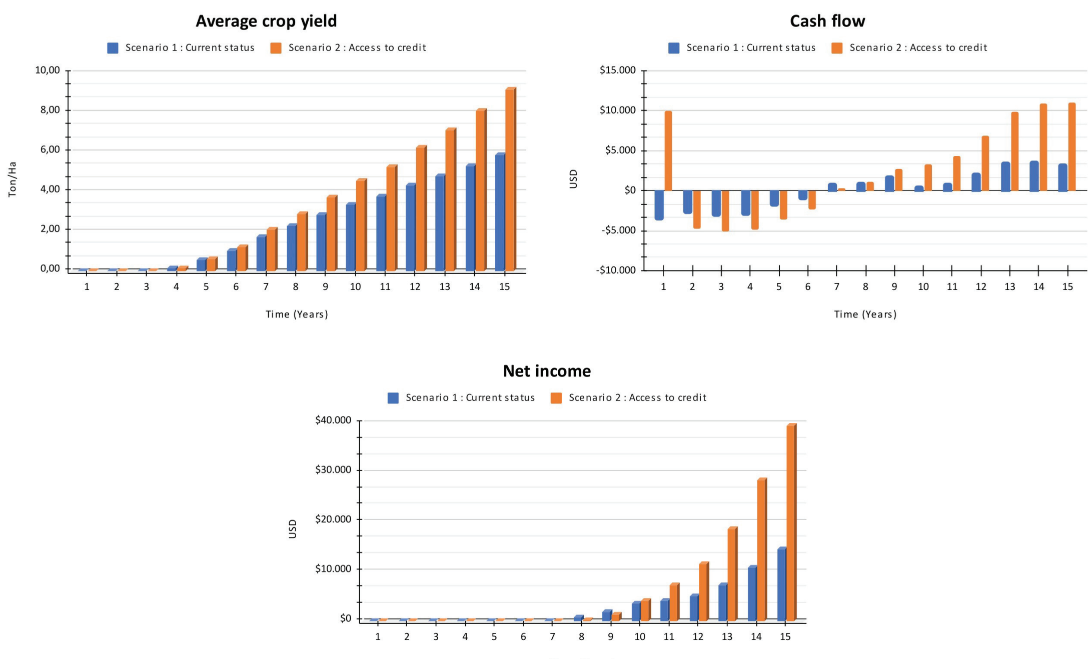

Figure 8. Results obtained for the scenario where small producers obtain credit for the cultivation and production of Hass avocado in the Cauca department.

The average annual yield graph reveals that the increase in yield between the current scenario and the scenario with access to credit, with year 15 as a reference, is approximately 50%, going from 5.8 to 8.1 tons per hectare. The cash flow indicates that the outflows in the first few years are higher due to the need to pay credit installments during this period.

However, the cumulative net income indicator over the 15-year simulation period shows an increase of 176%, from USD 14,493 to 40,000 per producer. This suggests that producers with access to credit can pay their debt plus interest and achieve higher profits than those without such access. It is also noteworthy that Scenarios 1 and 2 are similar during the first four years of cultivation, indicating that credit support strategies must be durable and flexible to prevent economic bottlenecks in the early years. In addition, the performance improvement is significant from the tenth year onwards, providing significant benefits to producers in these later years.

The results of the second hypothesis are supported by other cases in which small producers have easy access to credit. For instance, the federal government has improved public financing and specialized services in Brazil to help small producers increase their productive capacity. It has also implemented a strategic plan to strengthen technological and product differentiation capabilities, resulting in producers with more significant economic capacity and contributing to the consolidation of the sector in the country, as reported in [61]. Similarly, Onakoya et al. in [62] have studied the impact of small-scale enterprise financing on Kenya's economic growth, concluding that this developing country has achieved favorable economic results. These studies suggest that the simulation for Scenario 2 in the present research may be accurate, indicating that providing loans to small producers and improving the socioeconomic context would benefit the avocado sector.

4.3. Scenario 3—Implementation of Good Agricultural Practices

Obtaining certification for GAPs, which focus on producing safe and high-quality food, enables avocado producers to be more competitive in the market. Certified producers typically find that the primary advantage of adopting GAPs is access to more and better markets. Additionally, GAPs improve the safety of farm workers and end-consumers through the implementation of good management practices for inputs and agrochemicals, as well as traceability systems. The main disadvantage of GAP certification is the increased production costs associated with implementing and maintaining these practices, as discussed in [53].

Figure 9 shows the impact of implementing good agricultural practices compared to the previous scenarios.

After GAPs, the average yield of avocado production increases to nearly 11.5 tons per hectare, allowing for a larger quantity of higher-quality fruit that can be sold at higher prices in international markets. This results in an accumulated benefit of approximately USD 160,000 for the producer.

Initial cash flow may be lower compared to current scenarios but recovers more quickly than in previous scenarios, with a significant increase in income. This suggests that GAPs play a crucial role in improving avocado productivity and have the potential to enhance sector profitability in the future.

The final graph illustrates the relationship between financing needs and production costs. When GAPs are implemented, production costs increase, and the green line representing financing needs also increases in the initial years because of the implementation and maintenance of GAPs and sustainability measures. These actions during production ensure the quality and safety of the product, as well as labor, social, and animal welfare, and protect human health and the environment in the Hass avocado sector. Implementing these practices would bring benefits not only to the sector but also to the surrounding social context of production.

Scenario 3 supports the hypothesis that implementing good agricultural practices yields medium- and long-term benefits for the production of food for human consumption, confirming that making an initial investment in technical upgrades or implementing contract farming allows farmers to reap more significant benefits from production and also helps the country remain competitive in the global market (a requirement for Global GAP certification), as reported in [63].

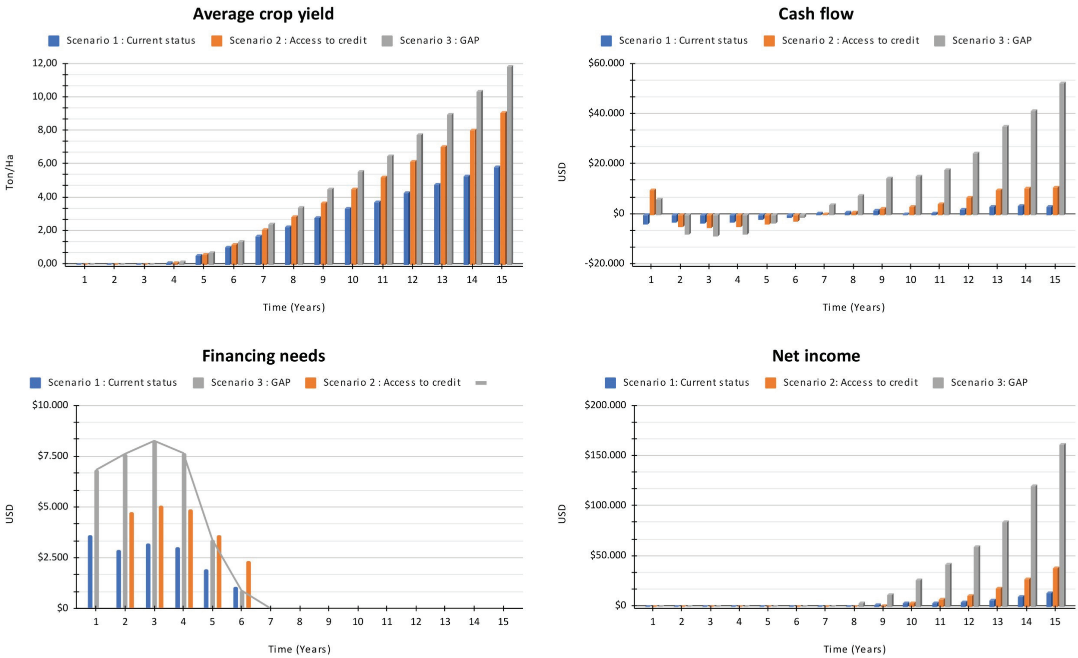

Figure 9. Results were obtained for the scenario where GAP investment is made, improving production methodology and technology implementation.

4.4. Scenario 4—Producer Association Membership

Scenario 4 analyzes the benefits of producers joining an agricultural association or forming one among themselves. Besides cost advantages, association membership enables producers to obtain credit at lower interest rates. According to FINAGRO's services portfolio, the interest rate for independent producers in 2021 was 8.7% per annum, while the rate for association members was 6.7%, with increased flexibility and accessibility of credit.

Figure 10 compares the performance of an agricultural association with other scenarios. The yield graph indicates an increase to 15 tons per hectare. In terms of cash flow, expenses are lower than in the previous scenario. By belonging to an association, associated costs are lower compared to the current scenario, along with the inherent advantages of membership, such as increased access to markets and the ability to participate in policy dialogue aligned with their interests. As it reduce costs through the association, financing needs are also reduced, allowing for investment in improvement programs with lower debt and interest rates.

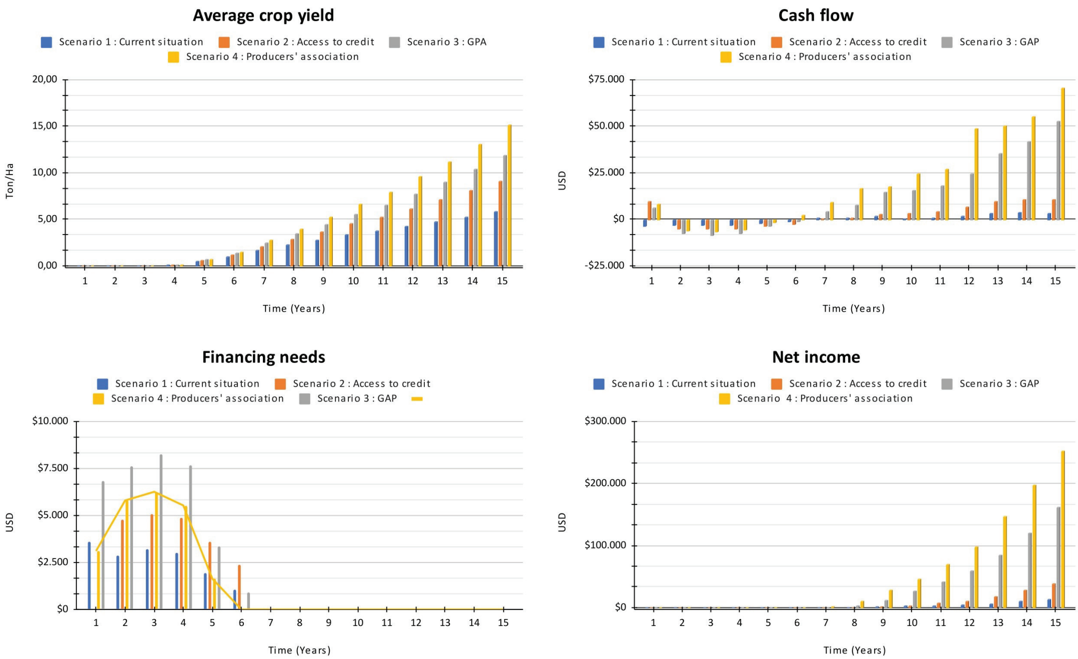

Figure 10. Results obtained for the scenario where producers have a civil association supporting them technically and technologically.

4.5. Scenario 5—Government Support and Investment

Figure 11 shows a scenario in which the government invests in improvement projects for small-scale Hass avocado growers. The current government support provided to farmers, including planting materials, certified seeds, technical advice, and some inputs and fertilizers, was considered.

This scenario exhibits a much greater competitiveness, reflecting the situation in other leading avocado-producing countries, with an average yield reaching 16 tons per hectare and an accumulated profit exceeding USD 300,000 over 15 years. This would directly address rural poverty and significantly improve the quality of life for producers.

The graph representing financing needs shows that, with government support, these needs are practically non-existent; producers would not have to go into debt because the state would assume those costs, resulting in no outflows in the cash flow and profits being generated as soon as it yield the first harvest. The high-income levels would reinvest in the crop and harvest.

The results align with other findings in the literature [64], indicating that government support policies for agriculture contribute to increasing the price of agricultural land and, subsequently, to improving the competitiveness and sustainability of agricultural production and reducing associated risks. This shows that the government should be a key player in the Hass avocado production chain, and its participation as a guarantor in assisting less profitable productive sectors with inputs such as technical upgrades or improving their cash flow is vital for the industry's consolidation in Colombia.

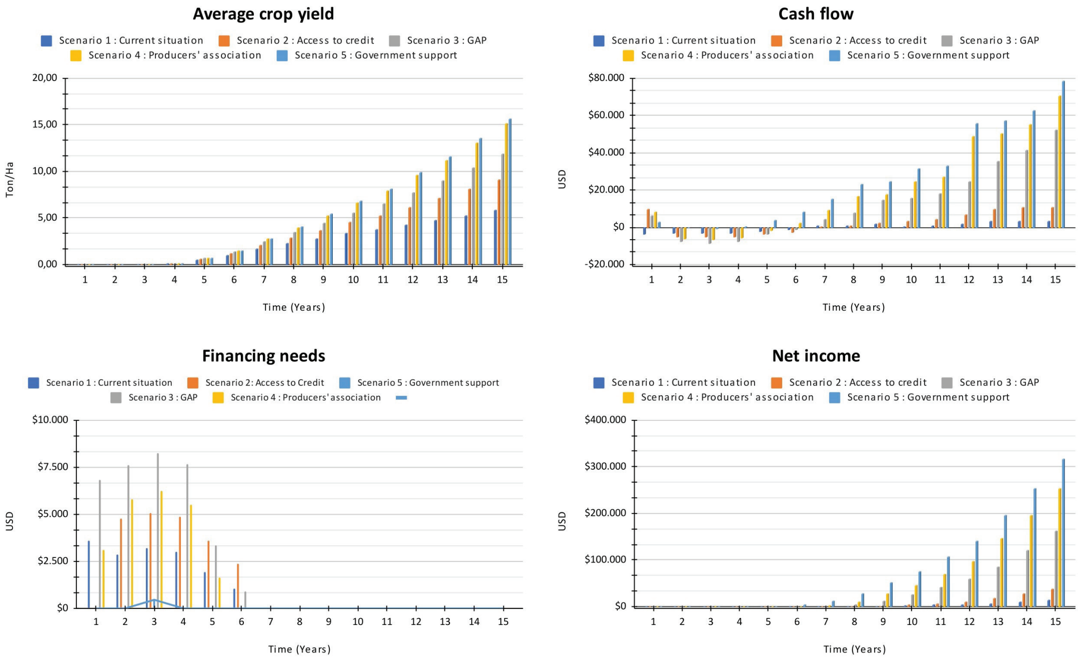

Figure 11. In this scenario, the producers enjoy the technical and economic support of central government, and achieve excellent Hass avocado production results at a similar level to other leading countries.

5. Conclusions and Further Work

This research presents the simulation of different scenarios using system dynamics for the Hass avocado production chain in the southwestern region of Colombia, considering factors such as cash flow, good agricultural practices, and association membership. The study's main result is that strategies such as access to low-interest credit, collaborative logistics, and government support in providing technical advice and agricultural inputs are essential measures for promoting developed agriculture that can respond to demand with high-quality products. The study also shows that low yields result from small producers' lack of financial support for investing in crop improvement and modernization programs.

The research identifies the need for financial institutions to provide better credit instruments for avocado production. Since this crop generates income only after the third year, producers may need more resources to cover loan payments during the first two years. Good agricultural practices play a crucial role in determining a farmer's productivity and cash flow. Although implementation and maintenance of these practices incur high costs, the results show that this improvement strategy is profitable and creates a sustainable production chain model over time. Finally, association membership is also a crucial strategy in reducing the costs of acquiring technology and inputs and adding value and efficiency to marketing, which translates into better economic and capital benefits for the members. It could also scale these actions up to other crops currently being consolidated in the market.

As a follow-up study, it could conduct an analysis to forecast the behavior of Hass avocado prices over the years, considering exchange rates, consumption, and production rates worldwide and modeling this data to obtain more reliable results for decision making. Extending the model to other production chains with their respective characteristics and contexts would provide government agencies and associations with further information to take action for the benefit of the production chain.

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Abbreviations

The following abbreviations are used in this manuscript:

SD	System Dynamics
ICA	Colombian Agricultural Institute
GAP	Good Agricultural Practices

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Review

A Literature Review of Social Commerce Research from a Systems Thinking Perspective

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Abstract: The paper aims to investigate social commerce systems from a systems thinking perspective. It proposes to model the social commerce process and outlines how Following, Communicating, Purchasing, and Sharing are systematically connected with each other in the social commerce process. The paper describes an exploratory review study using the systematic literature review method, including 384 social commerce research papers, which were published from 2011 to 2021. The data are refined by documentary analysis, including Study Selection Criteria and Quality Assessment processes. The paper systematically develops a conceptual framework for understanding social commerce. Previous research on social commerce mainly focuses on one or more particular key success factors (such as trust) in social commerce, and a few of them investigate social commerce as an integral business system. This review provides a more comprehensive basis for future social commerce research.

Keywords: social commerce; e-commerce; social media; business model; network steam

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1. Introduction

Social commerce has developed rapidly in practice and gained widespread attention in the information systems (IS) discipline. Since it was introduced in 2005 by Yahoo, social commerce has quickly become an effective tool for engaging customers of major e-commerce companies, such as Amazon, Groupon and eBay [1]. It is known that the first academic article that used the "social commerce" term appeared in 2006 [2], while some studies believe that social commerce research can be traced back to the late 1990s [3]. Nevertheless, there is no doubt that social commerce has received widespread attention and the number of social commerce publications has increased tremendously in the past ten years. In practice, the formal adoption of social commerce occurred in 2009 when Flowers.com started the first online store on Facebook [4]. It is predicted that by the end of 2021, a social network sponsored by these internet companies will be able to generate nearly USD 3.5 billion in revenue worldwide [5].

Despite the rapid development and adoption of social commerce, the current understanding of social commerce is still scattered and limited [1,5]. Social commerce research is in the early stages of development since there is little theoretical work on how social commerce operates and little is known about the social commerce business cycle. Furthermore, the current understanding of the distinction of social commerce from e-commerce includes the use of social media as a tool to connect customers, considering social commerce as a new marketing mode of e-commerce. We believe that this understanding of social commerce could be further re-considered.

Systems thinking is a research paradigm that emphasizes the interactions between different components of a system. For a particular problem, systems thinking is a conceptual framework that considers the problem in its entirety [6]. Systems thinking examines the relationships between various components in a system and emphasizes the understanding of the mechanisms among these components. In a social commerce context, system thinking considers social commerce as a system and provides an integral perspective to depict complex components such as trust. This can enhance the understanding of social commerce initiatives to respond to the needs of business organizations.

In order to provide a more comprehensive understanding of social commerce theory for academics, this study conducts a systematic literature review to explore the social commerce business model from a system thinking perspective and puts forward a possible theoretical explanation of why social commerce is essentially different from e-commerce. To achieve the main objective of this review, we propose three major research questions as stated below:

1. What is social commerce?
2. What are the key components of social commerce?
3. What does a social commerce system look like and how do its internal mechanisms make it different from e-commerce?

Overall, the contributions of this research are as follows. First, through the analysis of 300 studies, this review proposes a more detailed social commerce components (SCCs) model compared to previous studies. This will deepen our understanding of the social commerce business model. Secondly, this paper provides a possible explanation of why social commerce is an important transformation of e-commerce. The authors propose that the network stream distribution mechanism is the key difference between social commerce and e-commerce. Lastly, this research develops a framework that includes the entire social commerce business cycle. This can be a cornerstone and starting point for future social commerce research.

The remainder of this research is structured as follows. Section 2 explains the research method used in this review; Section 3 reveals the statistical results; Section 4 reports and analyzes the answers to the research questions; finally, Section 5 presents the three main conclusions of this research.

2. Methodology

In this paper, a systematic literature review is conducted to describe the trend of social commerce in research and explore the social commerce business model. Meanwhile, this review is used to answer the research questions proposed in Section 1 by collecting and analyzing all the previous works in the social commerce research field that fit the pre-specified eligibility criteria.

A systematic literature review is a tool for identifying, evaluating and interpreting all available research relevant to a particular research question, topic area or phenomenon of interest [7]. Systems thinking focuses on the understanding of the mechanisms among different components of a system [6]. In the social commerce context, system thinking considers social commerce as a system and provides an integral perspective to depict complex components such as trust. In this study, we apply systems thinking and use a systematic literature review to examine social commerce with the following objectives:

- To propose a conceptual framework of social commerce systems;
- To explain why social commerce is a distinct business paradigm from e-commerce by examining previous social commerce studies;
- To identify research gaps in current social commerce research for future study.

2.1. Review Protocol

As shown in Figure 1, we design the review protocol of this paper mainly in two stages.

Stage 1 is designed to obtain the raw material of this study, which consists of identifying the research questions and determining the search strategy. We define the search strategy as searching the keywords "social commerce", "s-commerce", "social e-commerce" and "social electronic commerce" in Google Scholar/AIS/IEEE and other databases to cover as many social commerce studies as possible.

Stage 2 is designed to refine the data that we collected with multiple criteria, which will be addressed in detail in Section 2.2. At the end of Step 2, we obtain 300 formal published studies as our research database and enter information such as the title, author, publication year, journal name and so on into Zotero software for further processing.

From the systems thinking point of view, we attempt to categorize all components of social commerce systems studied in all publications identified by this review protocol. This enables us to further investigate the relationship among different components of social commerce systems and propose a conceptual framework of social commerce systems.

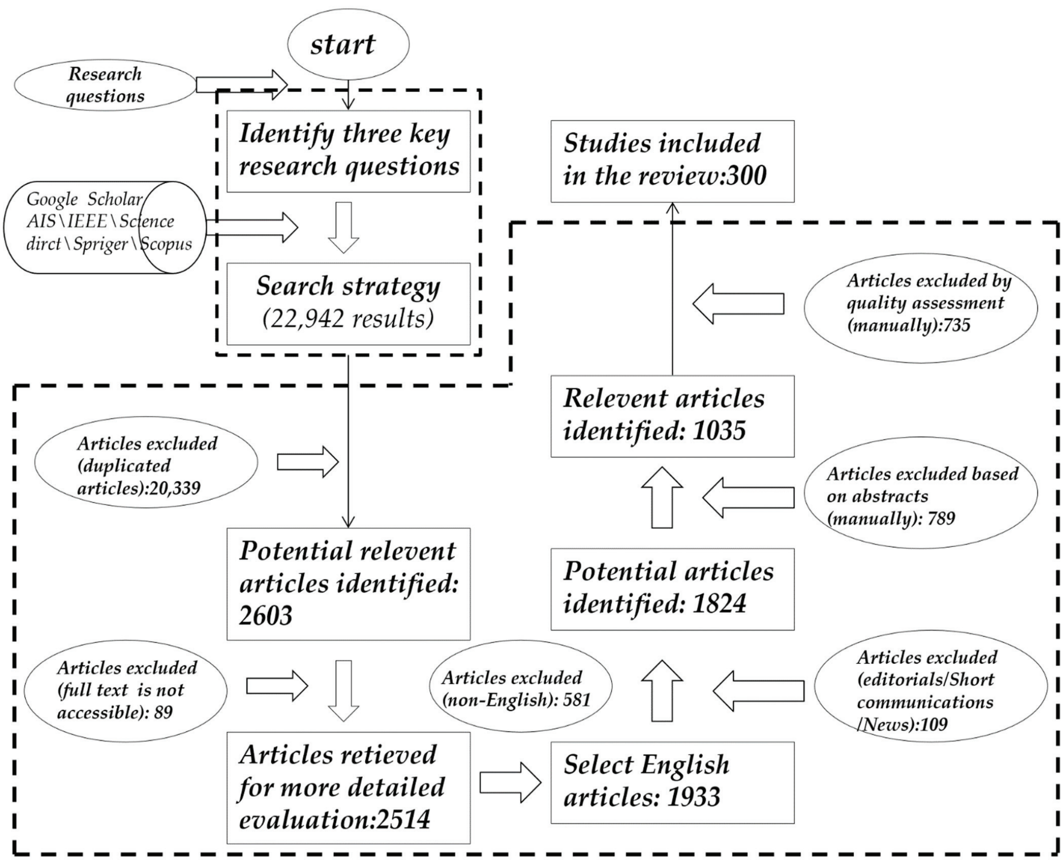

Figure 1. The review protocol.

2.2. Study Selection Process

In this section, we propose our selection criteria according to the research questions and present the quality assessment process of study selection.

2.2.1. Study Selection Criteria

The primary reason for identifying selection criteria is to make sure that the selected articles are relevant and related to the social commerce research field. We develop a set of selection criteria as shown in Table 1. In Stage 2, we filter the studies collected in Stage

1 with these criteria and exclude 22,642 articles. Thus, 300 research papers remain in our database.

Table 1. Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
Full text	Full text is not available by current database
English studies	Non-English studies
Published within the selected period of time (2009–2019)	Outside the selected time
In the domain of social commerce	Duplicated studies
Research articles	Research in progress Editorials Short communications News

2.2.2. Quality Assessment

There is no generally accepted definition of 'Quality', but according to [8], a research's quality relates to the extent to which the study minimizes bias, as well as its validity. Thus, we develop a quality checklist to evaluate the studies:

- QA1. To what extent is the article subject associated with social commerce? (−1—low, 0—medium, 1—high)
- QA2. Is the research methodology specified in the article? (−1—no, 1—specified)
- QA3. Is the data collection described in the article? (−1—no, 1—described)
- QA4. Are the results of data analysis explained in the article? (−1—no, 0—yes, but not well explained, 1—well explained)

Each article receives a score from −4 to 4 in this quality assessment. Every study receives a label based on the total score: −4–0 for low quality, 0–2 for medium quality and 2–4 for high quality. Articles filtered by the low-quality label are excluded (735 articles), and 300 articles remain to answer the research questions (86 studies with the high-quality label and 214 studies with the medium-quality label).

3. Data Extraction and Synthesis

The primary goal of this section is to extract the data and analyze the information of the selected studies in each stage. As shown in Table 2, most studies in this field appeared in the context of "social commerce", and some studies also used the term "s-commerce". "Social e-commerce" and "social electronic commerce" are rarely used.

Table 2. Search results.

Key Words	S-Commerce	Social Commerce	Social E-Commerce	Social Electronic Commerce
search in title	45	1110	53	1
search in all areas	7940	13,100	674	19

Search date 25 October 2021 by Google Scholar.

After the selection process, we sum up the publication year distribution of the 300 articles, which is presented in Figure 2. Although we have excluded studies that do not meet the criteria, we can still observe a clear increasing trend of social commerce academic publications. This increasing trend shows no sign of slowing down in 2021 since we do not include all the publications of 2021 (the search date is 25 October 2021). In particular, in 2019 and 2020, the number of social commerce publications is much higher than in previous years. Thus, we believe that social commerce research is still in an early stage and its volume will continue to experience a high level of growth.

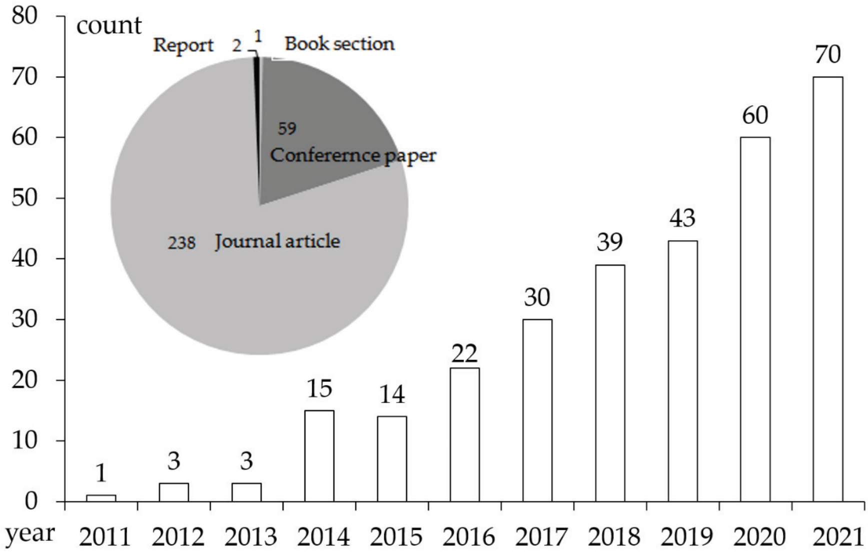

Figure 2. Social commerce contribution trend from 2011 to 2021.

Figure 2 also shows the type distribution of the social commerce publications. Almost 80% of them are journal articles and nearly 20% are conference papers. There are also two reports and one book section article in our database. Thus, journal articles and conference papers make up the major part of our research material. While most of the conference papers appeared early, journal articles in social commerce generally appeared after the year of 2016. This shows that social commerce, as an emerging research subject, has been more and more accepted by some major academic journals.

Table 3 shows the top 20 journals that publish most studies in social commerce. Most of them are top information management journals, such as the *International Journal of Information Management*, *Electronic Commerce Research and Applications*. Some of them are marketing and consumer behavior journals, such as *Decision Support Systems* and the *Journal of Retailing and Consumer Services.* It is evident that the social commerce subject was first recognized as a subset of e-commerce and a new tool for marketing.

Table 3. Journals related to social commerce.

Journal	Articles
International Journal of Information Management	20
Electronic Commerce Research and Applications	16
Information and Management	14
Computers in Human Behavior	11
Journal of Theoretical and Applied Electronic Commerce Research	6
Technological Forecasting and Social Change	6
Decision Support Systems	5
Electronic Commerce Research	5
International Journal of Electronic Commerce	4
Internet Research	4
Journal of Retailing and Consumer Services	4

Table 3. *Cont.*

Journal	Articles
Electronic Markets	3
Information Sciences	3
Journal of Business Research	3
Journal of Internet Commerce	3
Journal of Strategic Marketing	3
Modern Applied Science	3
Pakistan Journal of Commerce and Social Sciences	3
Sustainability	3
Asia Pacific Journal of Marketing and Logistics	2

4. Results

In this section, we address the three research questions and answer them based on the results of Section 3.

4.1. What Is Social Commerce?

Social commerce originated from e-commerce [9]. Online shopping, known as e-commerce today, emerged at the beginning of the 20th century. E-commerce needs to provide not only online business infrastructure, but also tools similar to the traditional offline commercial activities, such as word-of-mouth (WOM) advertising, bargaining, emotional implication, social shopping, etc. [10–13]. The reason for this is that the offline commercial activities are essentially emotional activities in which buyers are critical because they convey ideas, impressions or feelings about products [14]. Through these ideas or opinions, customers become the link between sellers and other potential buyers and have shown a great influence on this online business ecosystem in recent years. Thus, the customer's opinion is a central issue in online marketing and serves as an important signal of purchase decision making with previous transaction phenomena, such as repeat purchase and brand loyalty [15,16]. Reports show that people are more willing to make a purchase decision based on other customers' recommendations, especially when these recommendations come from the people who they are familiar with [17]. Thus, the concept of so-called social commerce becomes more and more popular.

The concept of social commerce mainly has two sources. First, social commerce is based on e-commerce. Without e-commerce, social commerce can only be a concept, which cannot be applied in commercial activities [18]. It is believed that e-commerce provides the fundamental ICT foundation of social commerce [19–21]. Secondly, social shopping is the other critical source of social commerce. Social shopping is the prototype of social commerce before social networking based on the Internet became available [11,22,23]. Some studies also conclude that the two sources of social commerce are online shopping and social networking, which is in line with our understanding [24].

In 2005, the first bloggers started to notice the upcoming changes in e-commerce and created the term "social commerce". Rubel first defined social commerce as follows: "Social commerce can take several forms, but in sum it means creating places where people can collaborate online, get advice from trusted individuals, find goods and services and then purchase them. It shortens the research and purchasing cycle by creating a single destination driven by the power of many" [25]. The first formal definition of social commerce was given by [26]. They believe that social commerce is based on an e-commerce platform that can enable customers to collaborate with each other. Several early studies are found, as shown in Table 4. These definitions mainly focus on three aspects:

- E-commerce—emphasizing that social commerce comes from e-commerce and considering social commerce as a new type (application) of e-commerce;
- Social media—considering that social media is the basis of social commerce and social media plays an important role in social commerce adoption;

- Web 2.0—arguing that it is the Web 2.0 technology that makes social commerce a reality and Web 2.0 is the technology foundation of social commerce [27].

Table 4. Some early definitions related to social commerce.

Definition	Factors			Source
	EC	SM	W2	
Social commerce focuses on interpersonal relations (recommendations, feedback, information, etc.) that are influencing a business transaction before, while or after it happens.		*		[26]
A new application in online marketplaces, where business organizations leverage social media or Web 2.0 as a direct marketing tool to support customers' decision-making processes and buying behavior.		*	*	[28]
Social commerce integrates the customer directly into these processes by using new technologies, applications or functionalities and the existing willingness of the customers to participate.		*	*	[29]
A form of social media, encouraging consumers to actively engage in the marketing and selling of products in online marketplaces and communities.	*	*		[30]
Social commerce is the use of social media, in the context of e-commerce, to assist with buying and selling products and services online.	*	*		[18]
Social commerce can be briefly described as commerce activities mediated by social media. In social commerce, people engage in commerce or intentionally explore commerce opportunities by participating and/or engaging in a collaborative online environment.		*		[31]
A new concept that enables customers to have an active position in cyber space. It is a development in e-commerce based on a network of buyers and sellers. It is more commonly found in social and interactive forms of e-commerce.	*		*	[32]

EC: E-commerce; SM: Social media; W2: Web 2.0.

Since its introduction, the definition of social commerce has constantly evolved. As shown in Tables 4 and 5, early studies consider social commerce as a subset of e-commerce and believe that social commerce is a new kind of collaborative buying or social shopping [23]. However, as the importance of social media is gradually being recognized, some studies point out that social commerce is more than collaborative buying and social shopping. Social commerce actually is a new form of incorporating "social layers" into e-commerce or linking retail sellers to social media sites [20,31,33]. In general, with the deepening of social commerce study, researchers have incorporated e-commerce, social media and Web 2.0 technology into their studies and focused on specific components of social commerce. Essentially, the following components have been repeatedly examined:

- Follow. These studies focus on how eWOMs make potential customers become brand followers/fans or users [34,35].
- Trust. These studies try to examine how trust is generated between sellers and buyers or among them in a social commerce context [36].
- Share. These articles focus on how eWOMs transfer and spread on a social commerce platform or user communities [37].

Transaction. These studies seek to explain how UGCs on a social commerce platform lead to generating customers' intention to buy or how customers' purchase decisions are made in a social commerce context [38].

Table 5. Some representative definitions of social commerce.

Category	Components	Definition	Title	Sources
e-commerce	Share; Exchange	A kind of e-commerce in which users can share and exchange the shopping experience and can make an intelligent business decision.	Social Commerce: A New Electronic Commerce	[21]
social media	Trust	A new online business model incorporating social network sites.	Determinants Influencing Consumers' Trust and Trust Performance of Social Commerce and Moderating Effect of Experience	[39]
e-commerce	Share	A new form of e-commerce that integrates online shopping and social networking.	Reputation Management in Social Commerce Communities	[40]
e-commerce	Trust; Share	Social commerce encapsulates both seller and buyer networks, as well as the platforms where shopping activities and the related interactions take place.	Website Features that Gave Rise to Social Commerce	[31]
social media/Web 2.0	Transaction; Share	An Internet-based commercial application, leveraging social media and Web 2.0 technologies, which supports social interaction and user-generated content in order to assist consumers in their decision making and acquisition of products and services within online marketplaces and communities.	From E-commerce to Social Commerce: A Close Look at Design Features	[34]
social media/ e-commerce	Follow; Like; Transaction	A subset of electronic commerce that involves using social media to support social interaction and user contributions, to assist in the online buying and selling of products and services.	Social Commerce Emerges as Big Brands Position Themselves to Turn "Follows", "Likes" and "Pins" into Sales	[35]
social media/ e-commerce	Share	Integrated e-commerce and social media can re-sort the user's social relationships, and effectively motivate the product spread and form a virtuous circle.	Evolution of Knowledge Sharing Behavior in Social Commerce	[41]
social media/ e-commerce	Share	A new stream in e-commerce where social factors are the determinant of this phenomenon and consumers are empowered to generate content using social media through online communities, forums, ratings, reviews and recommendations.	Social Commerce: The Transfer of Power from Sellers to Buyers	[42]
social media/ e-commerce	Transaction; Share	A new generation of e-commerce that treats social media and social networks as a carrier, promotes online trading and information exchange related to commercial activities.	The Influence of Sharing Evaluation Information on Consumer Buying Behavior in Social Commerce	[38]
social media	Share; Communication	Originated from the idea of knowledge sharing about goods and/or services among customers.	Why Customers Participate in Social Commerce Activities?	[43]
social media/ e-commerce	Transaction; Share; Follow	Refers to the delivery of e-commerce activities and transactions via the social media environment.	Social Presence, Trust and Social Commerce Purchase Intention: An Empirical Research	[44]
social media	Trust	Uses social media to facilitate social interaction and members' contributions, whose users can share their shopping experiences with other members and seek their opinions and recommendations.	Understanding Social Commerce Acceptance: The Role of Trust, Perceived Risk and Benefit	[36]
social media/ e-commerce	Transaction; Share	A new phenomenon of e-commerce that utilizes social media platforms and applications to conduct e-commerce activities.	The Antecedents of Trust in Social Commerce	[45]
social media/ e-commerce	Share; Trust	An emerging trend where the seller and buyer are connected to the online social media network.	The Influence of WOM on Customer Loyalty to Social Commerce Websites	[46]

Table 5. *Cont.*

Category	Components	Definition	Title	Sources
social media/ e-commerce	Follow; Like	A subset of electronic commerce that involves social media as a base platform to assist online buying of selling products and services.	Follower's Quality Factor in Social Commerce	[47]
social media/ e-commerce	Share; Trust	A type of e-commerce platform that enables users to participate in the selling, buying, comparing and sharing of information about products and services in an online marketplace.	An Investigation of the Drivers of Social Commerce and e-WOM Intentions: Elucidating the Role of Social Commerce in E-business	[37]
social media/ e-commerce/ Web 2.0	Follow; Like; Share	An Internet-based commercial application that makes use of Web 2.0 technologies and social media and supports user-generated content and social interactions.	A systematic review on social commerce	[48]

Other components, such as Exchange, Communication and Like, are also examined in previous studies. However, these components can be integrated into the components listed above.

Although there is no standard definition of social commerce, the opinions among researchers have actually tended to be consistent: in other words, social commerce is a subset of e-commerce activities that incorporates or is realized by social media and social networks. In this study, we follow this definition temporarily and examine other questions listed at the beginning.

4.2. What Are the Key Components of Social Commerce?

As shown in Section 4.1, recent research in this field focuses on particular aspects or components of social commerce, such as trust, purchase decisions, etc. We count the keywords of social commerce in the database and display them in Figure 3. Previous studies can be classified into four main categories or components.

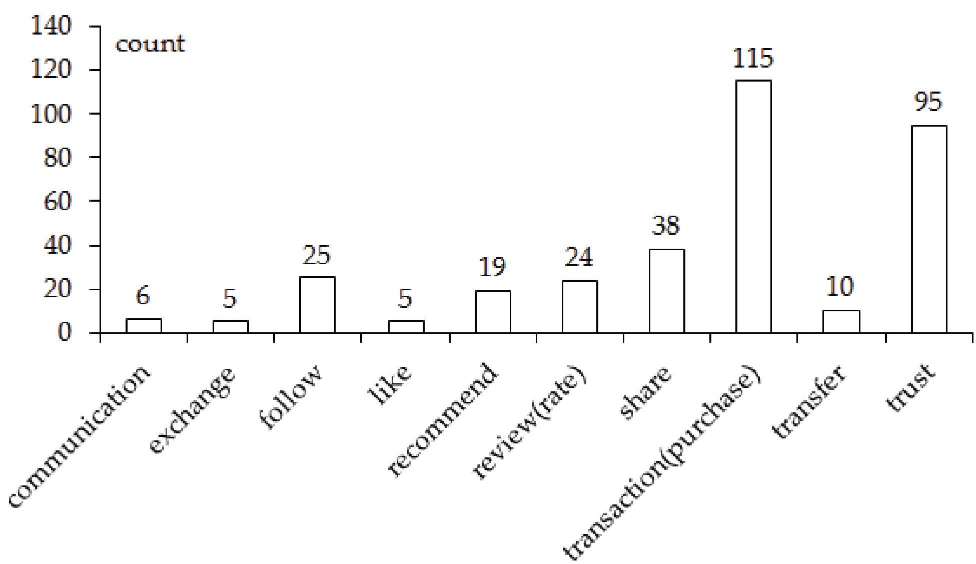

Figure 3. Distribution of some of the most frequent key components. Notes: The vertical axis shows how often these components appear in titles, abstracts and keywords.

4.2.1. Following

Following is one of the key components of social commerce and can be considered as the starting point of the social commerce eco-system [49]. This component is also examined as **Like**, which indicates that a person has become a potential customer and is beginning to pay attention to the products and services that a company provides [34]. As shown in Figure 4, previous studies indicate that social commerce users start following a particular product or service after being exposed to WOM or UGCs on social media; then, they tend to either communicate with others (become UGC creator) or go directly to purchase the products or services (become customers).

Several studies focus on this particular component [35,47,49,50]. In general, Following is an intermediate component between Sharing and Communication (Transaction). It is Following (Like) that causes a WOM become a purchase intention [51]. Early studies consider Facebook and Twitter as social media or SNS, which draw people's attention by UGCs (including WOM) and transform this attention into purchase intention by leading them to an e-commerce platform such as eBay or Amazon [47]. However, some rising content media such as TikTok have not been fully examined in a social commerce context, while businesses based on these content platforms have already become an important tool for companies to gain customers in the real business world [52]. The mechanism of **Following** can be summarized as follows:

- Sharing—Following: Studies analyze how UGCs (including WOM) affect potential customers' behavior, especially how to attract potential customers' attention to particular products and services. Hairudin et al. (2019) analyze how a follower's quality affects followers' behavior in a social commerce context and identify five key factors, including social sharing, that affect customers' behavior [52].
- Following—Communication: Studies in this field focus on how followers communicate with each other and generate content that can be used by companies to promote products and services [34]. In particular, Hofer and Aubert (2013) used data collected on Twitter to analyze how bridging and bonding social capital affect communication among followers and these social capitals can be used by companies to generate UGCs in order to build brand loyalty [53].
- Following—Transaction: Studies tend to examine how purchasing intention is generated among followers/fans [50,54]. Jung (2014) conducted empirical research on how social commerce website design affects followers' purchase intention and results show that the information characteristic generally has a more significant impact on purchase intention than the visual property [49]. However, few studies can integrate other components such as **Trust** to exclude influences caused by factors outside the model.

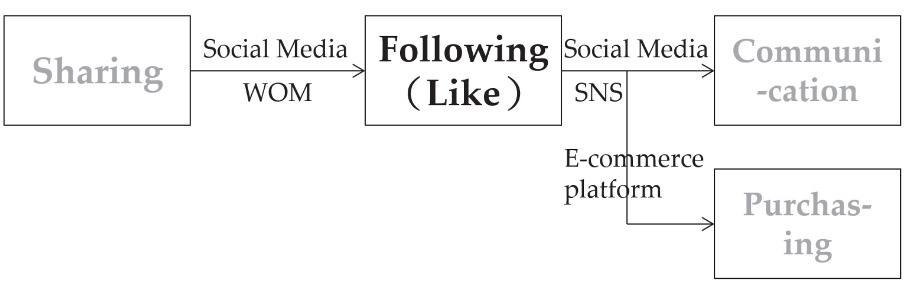

Figure 4. The mechanism of Following in social commerce [34,50,52].

4.2.2. Communication

This study combines **Trust** and **Communication**, which frequently appear in previous research as one component. The reason for this is that it is widely believed that trust comes from regular communications among users in a social commerce context [46] and communication is also the prerequisite of creating trust either among users or between buyers and sellers [43].

There are plenty of studies that focus on Communication and Trust. In general, the following questions are frequently examined in previous research. The first is how trust is generated or how communication among users can be promoted [39,54–57]. This question is considered to be important because communication and trust are critical factors that have a great influence on purchase decisions [58]. The second is to what extent this trust affects users' purchase intention [59,60]. The last is how WOMs and UGCs affect the formation of trust [61,62]. Based on these research topics of previous studies, we can construct the mechanism of **Communication** (**Trust**) as shown in Figure 5.

A few studies have compared the role of social e-commerce and traditional e-commerce in promoting sales. Taking Facebook as an example, Wongkitrungrueng and Assarut (2020) discuss the role of social commerce in promoting sales through streaming video. Their conclusion points out that, unlike traditional e-commerce, social commerce has important advantages in building trust and improving user participation.

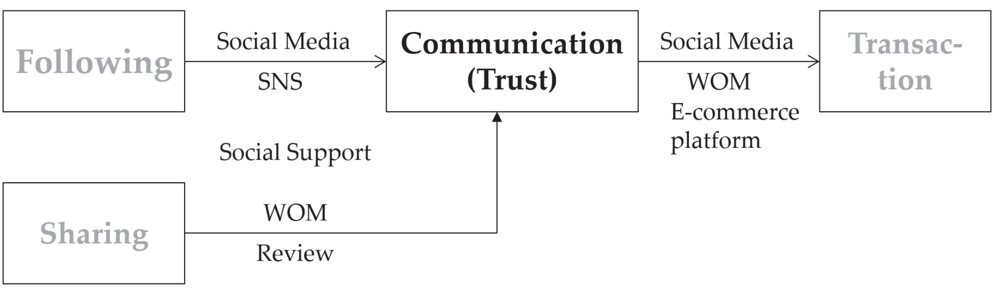

Figure 5. The mechanism of Communication in social commerce [39,43,56,61].

The main importance of the mechanism of communication can be summarized as follows.

- Following—Communication: As mentioned in Section 4.2.1, studies in this field focus on how communication and trust are built among followers. Moreover, several studies examine the factors that affect the formation of trust among followers. Alhulail et al. (2018b) conducted empirical research and point out that reputation, satisfaction, WOM and social presence have a positive effect on trust [63]. Yahia et al. (2018) also examined a similar topic and concluded that the social habits, reputation and price advantage of users have positive impacts on trust formation, while product differentiation generally weakens the formation of trust and communication [64].
- Sharing—Communication: Studies focusing on this topic seek to explain how UGCs such as customers' reviews influence users' behavior (Trust/Communication). Patrick et al. (2017a) examine the relationship between content shared among users (as well as that between social commerce vendors and users) and find that the perceived security and general credibility of the content have a more significant positive impact on users' trust than susceptibility to reviews and persuasiveness [61]. Similar studies are conducted by [65,66].
- Communication—Transaction: These studies seek to examine how communication and trust are transformed into a purchase decision. WOM [67], informational support and community commitment [68,69] are the main factors that transform trust and communication into a purchase decision. Moreover, Makmor et al. (2018) further confirmed that trust acts as an intermediate variable that connects social supports (emotional and informational) and purchase intention (transaction) [70].

4.2.3. Transaction

Transaction or **Purchase** is the core component of the social commerce system. Studies in this field generally focus on the following aspects. The first is how a transaction is realized in the social commerce context [71,72]. This topic is also examined in terms of how a customer's purchase decision is made under the effects of social media and WOM [73,74]. The second is which factors affect customers' purchase intention [75–77]. This includes customers' online behavior [78], social presence [60,63] and self-identification [79]. Lastly, some studies also focus on how customers behave after their purchase [80,81]. This kind of research generally examines customers' sharing behavior, which can lead to more attention among users [82]. According to these previous studies, we can construct the mechanism of **Transaction (Purchase)** shown in Figure 6.

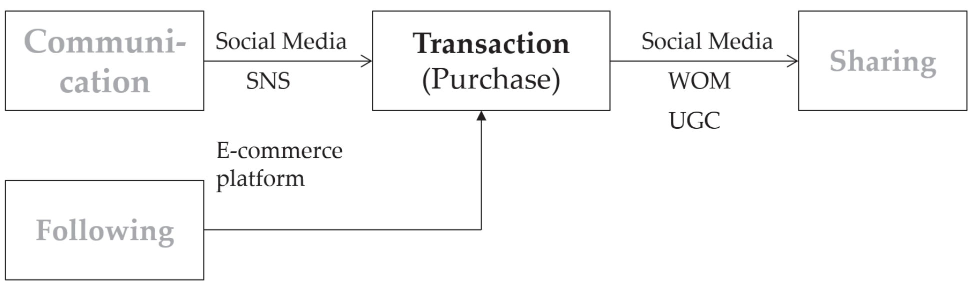

Figure 6. The mechanism of Transaction in social commerce [71,73,75].

As shown in Figure 6, the main mechanisms of the **Transaction** component can be summarized as follows.

- Communication—Transaction: As mentioned in Section 4.2.2, research on this topic examines how trust and communication among users are turned into a transaction. Moreover, from the perspective of transaction, several studies conclude that peer influence [83], brand relationship [84], perceived ease of use [85–87] and IT affordance [88] are also important factors that promote transaction.
- Following—Transaction: As examined in Section 4.2.1, studies in this field seek to explain how a purchase is generated among users. Moreover, some studies examine this question from the perspective of the culture dimension. For example, Yin et al. (2014) pointed out that intimacy among followers contributes to trust-building and both of their positive impacts on purchase intention show distinct effects in different cultures [89].
- Transaction—Sharing: Studies focusing on this question attempt to examine how customers' sharing behavior is determined [90]. For example, Ko (2018) points out that commercial desire is more influential for social sharing intentions on SNS [91]. Generally, brand co-creation [92], technical support [93] and social relations (such as guanxi) [94] are the key factors that promote customers' sharing behavior after a purchase in a social commerce environment.

4.2.4. Sharing

Sharing is the last key component found in social commerce research. In these studies, we integrate the concepts of share, recommend, spread, review and rate as the **Sharing** component because research in this field generally focuses on customers' behavior after a purchase, which can still be utilized in a social commerce system.

Studies that focus on Sharing mainly try to explain the following four questions. The first is how customers' rate/review/recommend (known as the "3Rs") behavior is determined after a transaction [92–95]. The second is how the WOM and UGCs created by customers' sharing behavior affect other users' purchase intention [96,97]. The third is how social commerce users decide to create or share content based on Trust or Communication with other users [90,98]. The last is how potential users are turned into followers or fans by UGCs or WOM generated by sharing behavior [47,89]. According to the analysis above, we can construct the mechanism of **Sharing (Review)** shown in Figure 7.

Some studies use qualitative and quantitative methods to examine the impact of KOLs' sharing behavior on sales volume in the social commerce context [99,100]. The results show that KOLs, as social media influencers, communicators and innovators, can promote innovative behavior and further promote an increase in sales volume. However, some research also showed that the moderation effects of celebrities' authenticity are insignificant [101].

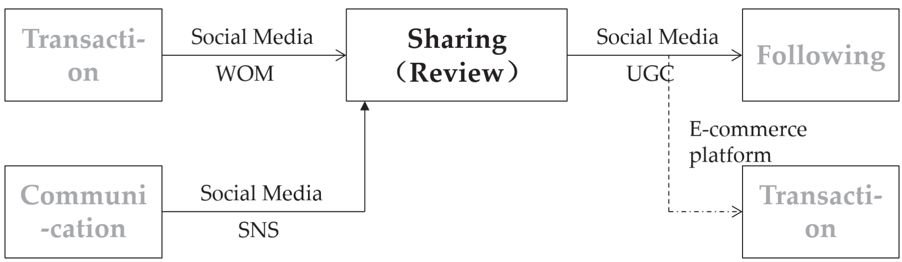

Figure 7. The mechanism of Sharing in social commerce [89,90,92,93].

The main mechanisms of the **Sharing** component can be summarized as follows.

- Transaction—Sharing: As mentioned in Section 4.2.3, studies in this field focus on the influential factors that determine users' sharing behavior after a transaction.
- Communication—Sharing: Studies in this topic try to explain how UGCs and WOM generated from Communication and Trust affect users' post-purchase behavior. It is believed that perceived trustworthiness [85], social capital bonding [96,102] and individual capital (such as reputation and the enjoyment of helping others) [103] are the key factors that promote users' sharing behavior.
- Sharing—Following: As mentioned in Section 4.2.1, studies in this field analyze how to attract potential customers' attention to particular products and services by UGCs (including WOM). Moreover, from the perspective of Sharing, several studies focus on explaining the relationship commitment, which has a positive impact on users' following behavior, such as customer loyalty [97,104–115].
- Sharing—Transaction: Studies focusing on this question seek to examine how sharing behavior promotes other users' purchase intention. For example, Chen et al. (2019) conducted empirical research to explain how product recommendations on social media affect users' urge to buy impulsively [106]. Results indicate that purchase intention influenced by recommendations is determined by affective trust in the recommender and affection toward the recommended product. This conclusion is also supported by other previous research, such as [107]. However, the results presented by [97] showed that online consumer reviews do not have a direct influence on users' intention to buy. Thus, the question of whether there is a direct relationship between **Sharing** and **Transaction** still needs further investigation.

4.3. The Conceptual Framework of Social Commerce Systems

Thus far, we can answer the third question proposed in this research. Based on the discussion in Section 4.2, a concrete conceptual framework of social commerce can be built. Figure 8 integrates Figures 4–7 as a typical social commerce business cycle and the sub-graphs I–IV represent Figures 4–7, respectively.

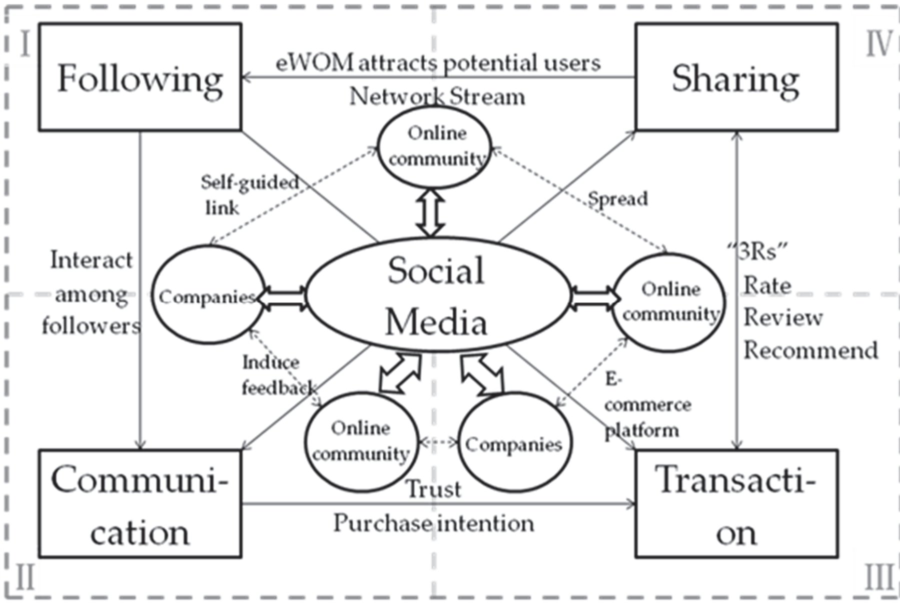

Figure 8. A systems thinking view of social commerce systems.

A typical social commerce business cycle (closed loop) consists of four components: Following, Communication, Transaction and Sharing. Social commerce completes the connection between buyers and sellers through social media and can be summarized as a closed loop as follows: social commerce users, including potential buyers and sellers, generate an online community based on the same value identification driven by social media; continuous and in-depth interactions in SNS build long-lasting relationships among users; trust attached to these social relationship can be turned into purchase intention according to previous studies; social commerce transactions are realized by a mutually accepted payment system, which is built by the e-commerce platform; buyers share the "3Rs" on social media and sellers improve products and services based on buyer's feedback. Based on the experience after the transaction, WOM is formed and continues to attract new potential followers (network stream).

We can draw some internal mechanisms of social commerce from Figure 8.

First, as shown in sub-graph I–II, new followers generate an online community in a social network, which can be considered as the starting point of social commerce. Interactions among users, including potential buyers and sellers, promote the formation of customer loyalty to particular brands. Moreover, this process also can be induced by company players and its feedback is an important source of product and service improvement.

Secondly, as shown in sub-graph II–III, communication on a social network generates trust among users and trust can strengthen the herd mentality before a purchasing decision is made. As shown in previous research, an online community formed by social media can amplify the conformity among users, which has already been used by many brands as an effective marketing tool.

Thirdly, as shown in sub-graph III–IV, transactions led by trust will be realized by a payment system built by the e-commerce platform and the "3Rs" will be more actively produced by social commerce users compared to traditional e-commerce transactions. This is mainly because, in the social commerce context, the transaction is a kind of social activity rather than a purely business activity. Once a transaction or a brand becomes the subject of an online community, the "3Rs" will continuously be created until the end of the brand life cycle.

Lastly, as shown in sub-graph IV–I, the e-WOM generated by the "3Rs" will attract more potential followers and continue this social commerce business cycle. The potential new online followers are also called a network stream or traffic in some previous studies [110,111]. Streaming is a concept in physics that indicates the amount of fluid flowing through a section of a closed pipe or open channel per unit time. Internet economics and e-commerce theory use this concept to refer to the online views or clicks of a specific network channel per unit time. In this study, we use this concept to refer to the number of page views (PVs) and unique visitors (UVs) on a social commerce website.

Sub-graph I–IV constructs the complete social commerce system. In this model, Following, Communication, Transaction and Sharing are the key components of social commerce, which are also the main steps that social commerce users perform. Social media, the online community and the e-commerce platform are the main supporting components, which are the infrastructure of the social commerce system. Moreover, followers, fans, customers, KOLs, cyberstars and companies are the main players on the social commerce platform.

We can thus obtain the answer regarding the difference between social commerce and e-commerce. The main difference between social commerce and e-commerce is shown in Figure 9. In the traditional e-commerce context, an e-commerce platform has decisive power in allocating a network stream through the search engines that they develop. This centralized mode of network stream allocation has caused e-commerce platforms to become huge, such as Alibaba and Amazon, which benefit from these "economies of scale" [108,109]. Although e-commerce platforms and social media still play a critical role in the social commerce context, they have no decisive power to allocate a network stream, i.e., social commerce users (buyers and sellers) connect with each other on their own. This fundamental difference is an important sign of social commerce as a new kind of online business.

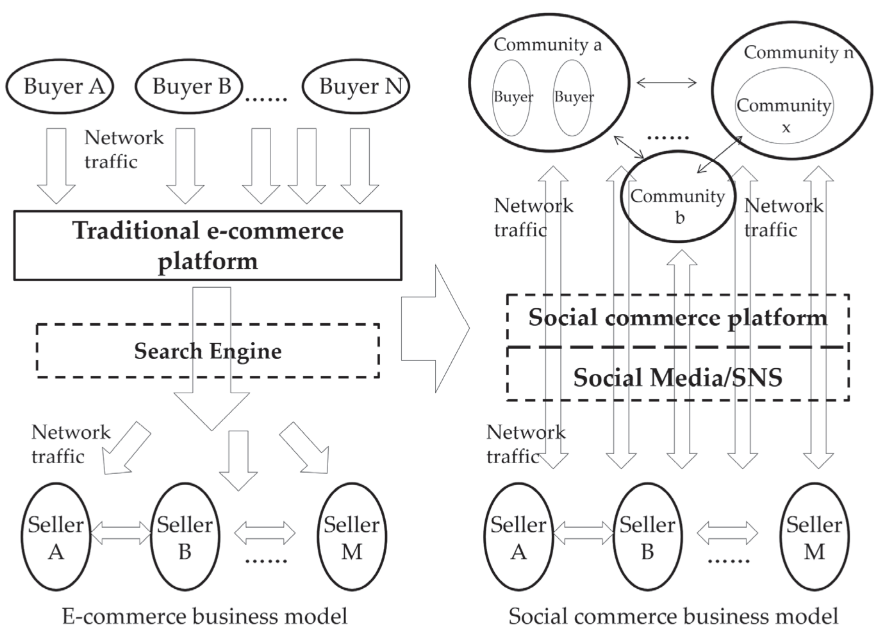

Figure 9. The transformation from e-commerce to social commerce.

5. Conclusions

As shown in the Results section, in the social commerce context, systems thinking considers social commerce as a system and provides an integral perspective to depict complex components. From the systems thinking point of view, we categorize all components of social commerce systems identified in previous publications to further investigate the relationships among different components of social commerce systems and propose a conceptual framework of social commerce systems. Some interesting conclusions can be drawn from this study. First, social commerce is an important evolution from e-commerce. Many previous studies consider social commerce as a subset of traditional e-commerce [21,110,112,116]. However, in this study, we believe that social commerce is a new form of online business that is essentially different from the traditional e-commerce that we are familiar with. Future research can be conducted from the perspective of social commerce as a new form of online business rather than a subset of traditional e- commerce.

Secondly, social commerce is changing the foundation of online marketing. As has already been widely accepted, e-commerce represents a paradigm shift as a "disruptive" innovation that is radically changing the traditional ways of doing business [113]. Social commerce may be a "disruptive" innovation that is changing the traditional e-commerce methods of doing business, rather than an alternative means of online marketing. Social commerce is an emerging trend in which sellers are connected by online social networks [114], and this has changed the core of marketing from brand recognition to community recognition and from brand management to relationship management [84,114]. This shift in social commerce has turned traditional online marketing into e-marketing or digital marketing, which is completely data-driven. Further marketing studies should not ignore this fundamental change brought about by social commerce.

Lastly, social commerce will promote the implementation of a C2B model. The most important aspect for companies engaging in business activities in the social commerce context is relationship operation. The core of relationship operation is to achieve continuous and in-depth interaction with customers in order to establish emotional relationships and value recognition. In this process, users' in-depth involvement in product development, design and improvement is the prototype of a demand-driven production and operation model (C2B). In this model, companies need to be "closer" to their users, and start the initial integration of crowd-funding, crowd-creating and crowd-sourcing. The distinction between producers, communicators and consumers in the traditional economy will become blurred in social commerce, in which online community participants are "active producers", "faithful consumers" and "enthusiastic communicators" at the same time. It can be seen that in the social commerce context, consumers and their communities are the promoters of business activities, and the C2B model is easier to be implemented under the influence of SNS and social media. Future research should start from the specific mechanisms of how social commerce promotes the C2B model.

6. Discussions

This study proposes a social commerce business model framework by conducting a systematic literature review. The main contributions of this paper are as follows.

Compared to research focusing on social commerce constructs, this study proposes a more detailed SCC model. Previous studies generally consider social commerce as composed of a social component and commercial component [117–119] and try to establish a social commerce model by examining how a particular factor, such as trust, is affected by social support [120]. Based on previous studies, this paper integrates current key factors that are involved in social commerce and builds a more comprehensive model that includes Following, Communicating, Purchasing and Sharing. This model can deepen the current understanding of social commerce systems.

Compared to previous literature review studies of social commerce, this paper focuses on explaining why social commerce is an important transformation from e-commerce. Previous studies focus on social commerce adoption [121,122], social commerce characteristics/topics [2,4,48,80] and consumers' behavior [123–125]. Based on these studies, this paper further proposes a network traffic distribution mechanism as the key difference between e-commerce and social commerce, and this makes social commerce an important evolution of e-commerce.

Compared to other social commerce frameworks or conceptual model research, this study develops a theoretical framework that includes the entire social commerce business cycle. Previous studies are relatively scattered and mainly focus on one or two particular components of social commerce, such as trust and social commerce adoption [110,126,127], the influencing factors of online marketing [114], customer satisfaction [128], social commerce website design [129–131] and C2C social commerce [132–134]. Based on previous works, this study constructs a more integral social commerce theoretical framework that contains all social commerce activities examined before. This provides a more comprehensive basis for future social commerce research.

The main limitation of this study is that the transformation of social commerce has not fully been examined through real business cases. In reality, this transformation process may be unclear, as some traditional e-commerce platforms are also integrating social elements, such as Alibaba's live-broadcast shopping. However, as mentioned in this paper, the network traffic distribution mechanism is fundamentally different between social commerce and e-commerce. Based on this limitation, more in-depth research in the future can be started by conducting more detailed social commerce case studies to provide more concrete real business evidence.

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