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The Evaluation of Technology Startup Role on Indonesian SMEs Industry 4.0 Adoption Using CLD-ABM Integrated Model

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Abstract: The role of the Association of Southeast Asia Nations (ASEAN) small and medium enterprises (SMEs) as the regional socioeconomic stabilizer is inseparable from endogenous multisector collaboration. Indonesian SMEs struggled with Industry 4.0 adoption due to the lower digital infrastructure (DI) and digital literacy (DL) index. This study aims to develop a provisional model to explore the role of technology startups (TS) in covering the DI and DL of SMEs. The evaluation was through a simulation model of Indonesian SMEs' collaboration with the government and TS. The developed model is a concurrent real-time integration of an agent-based model (ABM) with a causal loop diagram (CLD). The simulation results imply that SMEs' collaboration with TS leads to the early adoption of Industry 4.0 that balances the business competition environment. The model also shows that exponentially rising government aid can help the SMEs into late adoption of Industry 4.0. However, SMEs are still unable to sustain the business competition. Thus, the integrative simulation model is a state-action planning model with each state result bounded to the previous state result. The initial input parameters determine the model behavior. Thus, the model is a good resiliency planner for SMEs' Industry 4.0 adoption.

Keywords: Industry 4.0; SMEs; agent-based simulation; causal loop

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1. Introduction

The small and medium enterprises (SMEs) are the economic backbone for the future of Indonesia and the Association of Southeast Asia Nations (ASEAN). Even more, the golden age demography bonus makes Indonesia have to provide enough employment to ensure the economic stability of the people [1]. Therefore, the established SMEs in Indonesia (Indonesian SMEs) have a role to ensure regional stability. The economic dependency on foreign countries is not an available option for a nation to maintain its socioeconomic stability. On the other hand, people's dependence on government aid will force the country to enter such a situation. Furthermore, the economic dependency of a country on other countries in the same region may reduce regional stability [2]. Hence, collaboration is needed to maintain regional stability. This study analyzes the impact of technology startups (TS) on Indonesian SMEs Industry 4.0 adoption.

Financial, technical, and human resource barriers hinder the adoption of Industry 4.0 by Indonesian SMEs. Most developing countries struggle with three major restrictions of Industry 4.0 adoption [3,4]. The specific issues of Indonesian companies on Industry 4.0 adoption are lack of ICT infrastructure, financial constraints, management support, technical expertise, and privacy concerns [5]. The Indonesian government resolves the issues by creating special regulations for Industry 4.0 adoptions [6]. However, the regulations only focus on Industry 4.0 knowledge and organizational culture empowerment. Hence, the regulation does not provide financial or technical empowerment for the SMEs. Therefore, this study explores the possibility of SMEs' Industry 4.0 adoption through collaboration with TS.

The multisector collaboration of a nation's public and private sectors is necessary to build a robust financial structure. System modeling approaches can model these relationship dynamics, for example, the use of the Bozeman collaboration model to evaluate the economic impact of scientific research collaboration. The corresponding provisional model assesses research collaboration effectiveness among interdisciplinary scientists [7]. The expansion of the model also successfully declassifies public and private sector employees' job satisfaction [8]. However, semistructured interview data were the basis of both models. In contrast, this study constructs a provisional model based on information feedback.

Collaboration modeling belongs to nonphysical system modeling. Thus, the system complexity is high because it consists of various entities. In consequence, modeling the social system through conventional statistics requires some assumptions. There are risks of assumption exaggeration and oversimplification that lead to bias [9]. Correspondingly, the discrete event simulation (DES) approach that relies on statistical distribution is not fit to model human collaboration dynamics in medium-level abstraction. Instead, modeling the entity behavior through simple logic called the agent-based model (ABM) is more representative. It is possible to construct data-driven ABM by arranging the agent logic from historical data [10]. This study employs data-driven ABM to simulate the collaboration between Indonesian SMEs and technology startups (TS) in adopting Industry 4.0.

The growth of Indonesian TS changes the economic ecosystem. TS promote technology disruption that widens access to advanced technologies. Through some cooperation with the Indonesian government, TS focus on helping SMEs sustain themselves [11]. Indonesian startup global growth ranked fifth with 2229 listed startups in 2021 [12]. The growth is due to venture capitalist funding and an active startup growth campaign involving young technology talent. The expected outcome of TS collaboration with SMEs is to maintain prosperity with increasing population. This study models the dynamics to achieve the expected outcome.

Indonesian TS has rapidly grown while facing some major obstacles. The obstacles were digital technology infrastructure and digital literacy of the available human resources. The technology problem is a global problem since European SMEs also experienced the same digital resource problems [13]. However, funded TS have access to use giant technology company infrastructure. Most Indonesian TS use low-cost, exclusive subscription plans from cloud service providers such as Amazon, Google, Facebook, and Microsoft [14]. Numerous training programs can overcome the digital literacy problem in the Indonesian TS ecosystem. However, outside the TS ecosystem, Indonesia's digital literacy index is 3.49, which is low [15]. Indonesia has a decacorn, 13 unicorns, and hundreds of startups in the Serie-B and Serie-A funding stage, but thousands of Indonesian TS remain in seed and preseed funding [16]. This study analyzes the TS growth impact on Indonesian SMEs' Industry 4.0 transformation process.

The analysis of SMEs' Industry 4.0 adoption requires the integration of system variables with the detailed entity variables. The high-level model and medium-level abstraction model connection allow the integration of both system variables. The medium-level abstract model provides a detailed model of an entity's behavior in a system. The highly abstract model provides a general entity relation. The relation depicts the way an entity affects the states of the overall system [17]. This study applies high-level abstract modeling to understand the effect of TS and government support on Indonesian SMEs Industry 4.0 transformation. The evolution of the high-level abstract model states every time-step unit can be analyzed using dynamical systems (DS). DS analyzes the changes in a system with predefined general variables [18]. Meanwhile, the construction of ABM for SMEs business competition introduces detailed factors. This study aims to construct an integrated simulation model to analyze the contribution of the growing TS to Indonesian SMEs' adoption of Industry 4.0 technology.

The DS and ABM simulation integration enables in-depth system analysis with a general perspective. DS is a top-down modeling tool that models a system at a high abstraction level [19]. DS relies on information feedback from an entity to another entity. The most common tool to construct a DS model is the causal loop diagram (CLD) and stock and flow diagram (SFD). CLD excels at qualitative model building that only involves binary relationships represented by positive (+) and negative (−) at the arrowhead [20]. The information loop is either reinforcing (positive–positive/negative–negative) or balancing (positive–negative). Both CLD and SFD allow DS to model the complex and nonlinear behavior of a system into a simple relationship structure [21]. SFD excels at quantitative system modeling that allows the system flow estimation according to inflow and outflow quantity [22]. The SFD's ability to quantify flows makes it suitable for data-driven DS [23]. However, CLD integration with a bottom-up model such as ABM has enabled its utilization of quantitative problems. The corresponding integration scheme utilization was to explore the complexity of the construction waste management problem [17]. The flexible CLD can act as a logic gate for the bottom-up model result based on high-level interactions (ABM on top DS) or low-level interactions (DS on top ABM). This study proposes a real-time interaction model that allows the ABM model and DS concurrently to feed input and output data.

This study evaluates the digital technology disruption by the TS that targets SMEs as their customer. This study extends through interabstraction integration the provisional model built by [7,8]. To construct a high-level abstraction model, the integration scheme replaces ABM with a medium-level abstraction model and CLD-based DS. This study reports the first real-time ABM and CLD concurrent simulation. Therefore, this study adds real-time interaction capability to the ABM-CLD integration scheme built by [17]. The first implementation of the proposed integrated model is to solve the problems described by [13]. The model represents the problem ([13]) as the integration of SME business competition behavior as the bottom abstraction layer and the SME Industry 4.0 development environment as the top abstraction layer. The materials and methods section presents the integrated model construction and the definition of simulation parameters. The results section showcases the ABM, CLD, and the simulation parameter analysis results. The discussion section discusses the technical aspect of the integrated model as a decision support tool to maintain a balanced manufacturing SME business competition environment for multiparty users (SMEs, government, TS, investors, and funders) followed by the analysis and interpretation of the simulation results.

2. Materials and Methods

The provisional model that relates SME business competition was built by integrating DS and ABM. The DS technique used was quantitative CLD as previously implemented by [24]. The CLD employs a simultaneous equation to process quantitative variables. The CLD was constructed to model SMEs–government, SMEs–TS, and TS–Government relationships. Information is exchanged between the entities in the DS model, which connected in real-time with the ABM model. The information processed by ABM on each simulation step was fed to the CLD to be processed.

The historical data determine the CLD simultaneous relationship and ABM model behavior. The Indonesian TS and SMEs data were collected from several open data providers. The SMEs data were collected from the Indonesia open government service, and the Indonesia SMEs growth projection data were obtained from the World Bank data [25,26]. The SMEs data were obtained from the ASEAN SMEs policy index [27], Indonesian SMEs growth data [28], and Indonesian SME's Industry 4.0 readiness data (4IR) data [29]. The TS data were collected from databooks and some previous studies through Mendeley open data. The TS data were Indonesian startup growth index, Indonesia startup classification, and Indonesia startup funding, collected from [30]. The cost components were calculated from the collected panel data. Hence, the variables were comparable due to unit homogenization as cost. The data collection was for the Industry 4.0 adoption and current SMEs operation model construction and simulation.

The ABM simulation was performed using the Python programming language with the help of the MESA module. MESA is an open source ABM simulation module licensed under Apache 2 [31]. The simulations consist of three scenarios applied on high-level abstraction CLD of SMEs Industry 4.0 adoption. The model describes the business operations of the SMEs and the competitors to gain profits. Obtaining profits requires a set of operations that need operational costs. The simulation run was in 50 steps, with each step representing a year. The simulation agents were the SMEs, the competitors, and the profits to be gained by the SMEs and the competitors. The model construction assumed the competitors (the large companies) are always capable to take over the SMEs market. In opposition, the SMEs Industry 4.0 adoption removes the first assumption. Based on the data and the underlying assumptions, the simulation parameters are defined in Figure 1. The parameters were the initial population of the SMEs and the competitors, the growth rate, and the profit gained from the customers. The second scenario, shown in in Figure 1b, is related to the exponential growth of government aid, which is assumed to double the growth rate. The third scenario, shown in Figure 1c, reflects the balance competition by equally setting the "gain from customer" variables due to the SMEs Industry 4.0 adoption.

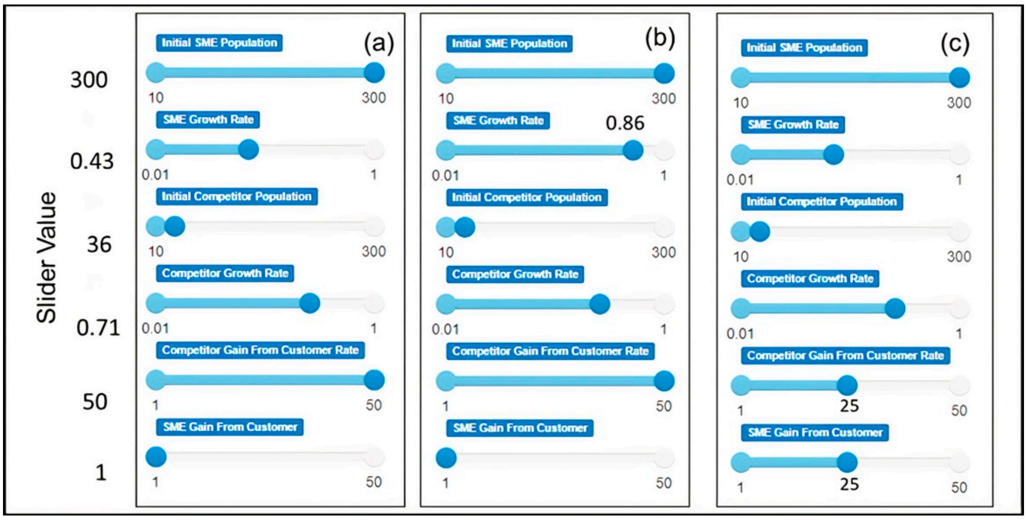

Figure 1. Simulation parameter setup: (**a**) current scenario, (**b**) doubled SMEs growth rate, and (**c**) SMEs with Industry 4.0 adoption.

The relationship model between SMEs and TS was developed based on technology infrastructure and digital literacy problems, as shown in Figure 2. The model components in Figure 2 were determined based on available digital literacy data in [30] and the Industry 4.0 basic infrastructures reviewed by [32]. Refs. [30,32] derive the components used to evaluate the ABM simulation state and transfer to CLD through Equation (12). The DI variable in Equation (12) consists of the sum of Equations (1)–(5) in conjunction with the DI value obtained from Equation (6). The high-speed internet component is critical for production control (PC), inventory control (IC), and facility control (FC) of manufacturing operations. Each manufacturing and management operation generates data stored and processed by computing servers (cloud or dedicated). The data comprise production data (P), supply data (S), and management data (M). The computing servers may be required for physical control (PCtrl) of the production machine or equipment. The form of controls (PC, IC, FC, and PCtrl) can be in the form of intelligent control (AI), internet-of-things (IoT) control, or both that require extra computational resources. The AI may be utilized in the production line, management, or executive level as a decision support system (DSS). The IoT control utilization is for a physical data collector in the production line controlled directly by management input or AI [33]. All the control processes require executor software (Soft). The overall control of the infrastructure components was by digital talents, SMEs employees that received a digital scholarship, or digital training. This model assumed the

SMEs gained infrastructure and digital literacy through a subscription plan to the TS, and the TS gained capital from investments.

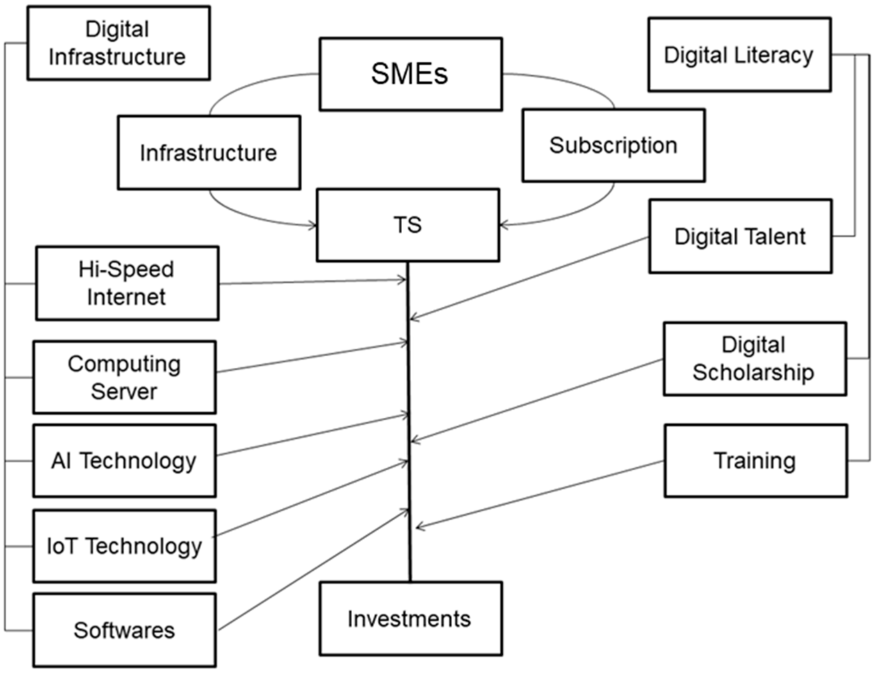

Figure 2. Model derived from major problems.

The detailed impact of the TS on SMEs assessment was using Industry 4.0 adoption cost. The costs were operational cost (*OC*), digital infrastructure cost (*DC*), human resource cost (*HC*), and digital service subscription cost (*SC*). The subscription price was assumed to have been set by TS based on its expense-over-profit multiplied by the initial price (*I*) (see Equation (6) in Table 1). Each TS profit consists of investment (*INV*) and income (*INC*), while the expense covers human resource (HC_{TS}), operational (OC_{TS}), and infrastructure costs (IC_{TS}). Each cost-relationship mathematical model was built based on digital resource utilization (see Table 1). The cost utilization control was using the amount factor (A_f), usage factor (U_f), and existence factor (E_f). The A_f represents the amount of a discrete or continuous resource, U_f represents the usage of a resource (continuous), and E_f is a binary (0 or 1) variable that marks the existence of a resource.

$$3\begin{bmatrix} A_{fPC} \\ A_{fIC} \\ A_{fFC} \end{bmatrix}\begin{bmatrix} U_{fPC} & U_{fIC} & U_{fFC} \end{bmatrix}(OC + DC + HC) \tag{1}$$

$$(OC + HC)\begin{bmatrix} \frac{OC+DC+HC}{OC+HC}A_{fP} & A_{fM} & A_{fS} \end{bmatrix} \times \begin{bmatrix} U_{fP} \\ U_{fM} \\ U_{fS} \end{bmatrix} \tag{2}$$

$$SCA_{fAI}U_{fAI} \tag{3}$$

$$CSA_{fIoT}U_{fIoT} \tag{4}$$

$$(HSE_{HS} + CSE_{CS} + AIE_{AI} + IoTE_{IoT})SCU_{fSoft} \tag{5}$$

$$\frac{OC_{TS} + HC_{TS} + IC_{TS}}{INC + INV}I \tag{6}$$

Table 1. Detailed model of SMEs Industry 4.0 adoption cost.

Cost Component Equations	
Adoption Technology	**Adoption Cost**
High Speed Internet (HSI)	Equation (1)
Computing Server (CS)	Equation (2)
AI Technology (AI)	Equation (3)
IoT Technology (IoT)	Equation (4)
Software (Soft)	Equation (5)
Subscription Price Setting	
SC	Equation (6)

The DS simulation was employed to observe system behavior on the high-level abstraction side. The DS simulation compared the initial condition (SMEs Industry 4.0 adoption without TS collaboration) and TS collaboration with SMEs. The DS simulation was performed using Vensim® PLE software. The high-level abstraction model was constructed using CLD focused on SMEs Industry 4.0 adoption capability and measured by SMEs competitiveness. The CLD variables and the simultaneous equation are listed in Table 2. The variables were concurrently updated with the ABM. The units for all the simultaneous variables listed in Table 2 were currency. The government aid was a predefined variable obtained from [28]. The digital inf cost was the total infrastructure cost and the digital HR cost was the total human-resource-related cost obtained from Table 1.

$$\text{SIMULTANEOUS}(\text{First Aid} \times (\text{Government Aid} \times 0.01), \text{First Aid}) \tag{7}$$

$$\text{SIMULTANEOUS}(\text{SME}'\text{s Investment} \times \text{SME}'\text{s Competitiveness}, \text{Initial Investment}) \tag{8}$$

$$\begin{gathered}\text{SIMULTANEOUS}(\text{Government Aid} + \text{SM E}'\text{ s Investment} - \\ \text{“SME}'\text{s Industry 4.0 Adoption”}, \text{Government Aid} + \text{SME}'\text{s Investment})\end{gathered} \tag{9}$$

$$\begin{gathered}\text{SIMULTANEOUS}(\text{IF THEN ELSE}(\text{SM E}'\text{ Capital} \geq \\ \text{Minimum Digital HR Cost}, \text{Digital HR Cost}, 0), 0)\end{gathered} \tag{10}$$

$$\begin{gathered}\text{SIMULTANEOUS}(\text{IF THEN ELSE}(\text{SM E}'\text{ s Capital} \geq \\ \text{Minimum Infrastructure Cost}, \text{Digital Inf Cost}, 0), 0)\end{gathered} \tag{11}$$

$$\text{SIMULTANEOUS}(\text{Digital Infrastructure} + \text{Digital Literacy}, 0) \tag{12}$$

$$\begin{gathered}\text{SIMULTANEOUS}(\text{DELAY1I}(\text{“SME}'\text{s Industry 4.0 Adoption”} + \\ 1, \text{ Final Simulation Year}, \text{ “SME}'\text{s Industry 4.0 Adoption”}), 0)\end{gathered} \tag{13}$$

$$\begin{gathered}\text{SIMULTANEOUS}(\text{Venture Capital} + \text{Angel Investors} + (0.2 \times \text{SME}'\text{s Capital}) - \\ \text{Digital Infrastructure} - \text{Digital Literacy}, \text{Venture Capital} + \text{Angel Investors})\end{gathered} \tag{14}$$

$$\text{SIMULTANEOUS}(\text{Initial Capital} + \text{Initial Capital} \times \text{Growth}, \text{Initial Capital}) \tag{15}$$

$$\text{SIMULTANEOUS}(\text{Inital Investment} + \text{Initial Investment} \times \text{Growth}, \text{Initial Investment}) \tag{16}$$

Table 2. Causal loop simultaneous equations of the SMEs Industry 4.0 adoption cost.

Initial SMEs System	
Variable	**Simultaneous Equation**
Government Aid	Equation (7)
SMEs Investment	Equation (8)
SMEs Capital	Equation (9)
Digital Literacy	Equation (10)
Digital Infrastructure	Equation (11)
SMEs Industry 4.0 Adoption	Equation (12)
SMEs Competitiveness	Equation (13)
SMEs with Tech. Startups System	
Technology Startup	Equation (14)
Venture Capital	Equation (15)
Angel Investors	Equation (16)

The DS simulation was driven by the medium-level abstraction ABM simulation result. The variable values in Equation (7) to Equation (16) were based on the output of the ABM simulation result for each time step. The MESA ABM simulation and Vensim® DS simulation were run simultaneously through a Python script intermediary. The concurrent real-time connection between ABM and CLD was achievable through multithreading. The Vensim® model (.mdl file) and dataset (.vdhl) were read by Python through the PySD module. The Pandas module modifies the dataset for the simulation. The variable analysis used the Vensim® slider basic I/O.

3. Results

3.1. Medium-Level Abstraction Analysis

The ABM simulations of SMEs competition with three different scenarios project the future state of each agent. The initial and termination states of the simulation are shown in Figure 3. The grid represents the market for SMEs and competitors to perform their business operations. The green grid indicates the availability of profits that are available to be gained by the occupant agents. The orange shop icon portrays the SMEs, and the tall building icon portrays the competitors. Figure 3a,b depict the first simulation scenario's initial and termination state representing the model maintaining its current simulation state. Figure 3c,d represent the initial and termination state of the doubling growth rate scenario by exponentially increasing the government aid to the SMEs each year. However, both scenarios failed to maintain a balanced competition. The inexistence of SMEs at the termination state indicates the corresponding failure (see Figure 3b,d). Meanwhile, the balanced competitive model indicated in Figure 3e,f shows the ability of SMEs to compete with larger competitors as they adopt Industry 4.0 early with a collaborative strategy.

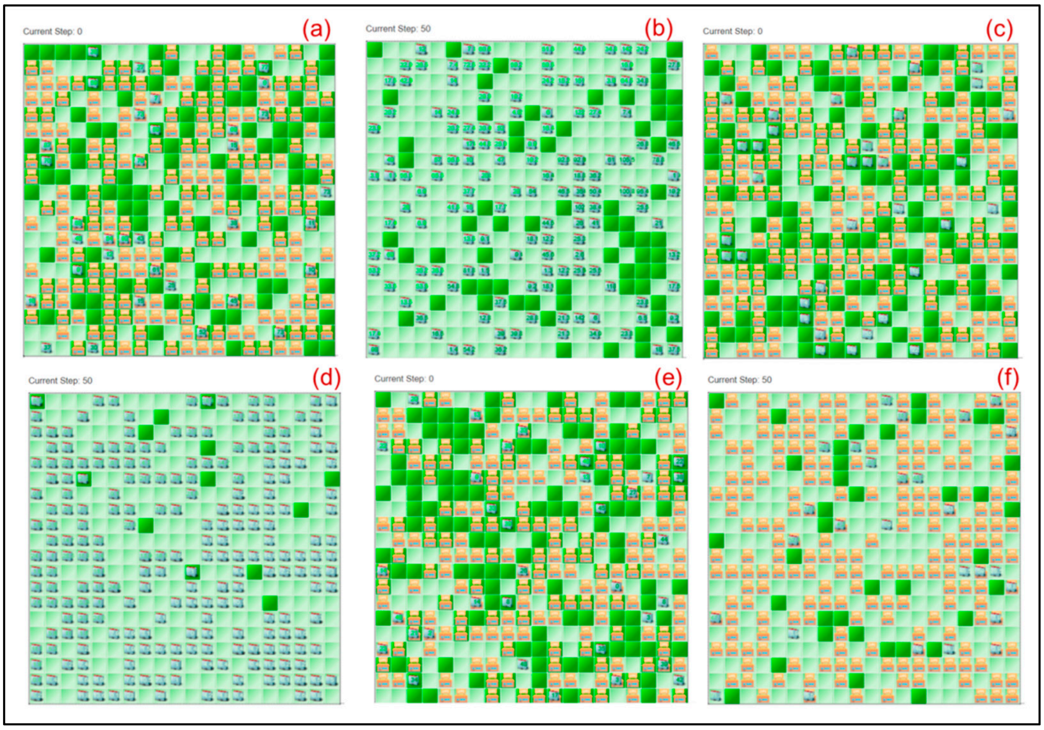

Figure 3. Simulation states: (**a**) 1st scenario initial, (**b**) 1st scenario termination, (**c**) 2nd scenario initial, (**d**) 2nd scenario termination, (**e**) 3rd scenario initial, and (**f**) 3rd scenario termination.

The dynamics of the business competition by the SMEs and the competitor agents were to obtain maximum profit and occasionally cover their operational costs. These conditions are represented by the agents' behavior that is plotted timely as the simulation started. Figure 4 presents each plot of each simulation scenario. Figure 4a represents the first scenario that indicates that the competitors are superior to the SMEs. The competitors fully absorb the profits on each simulation step. Meanwhile, the SMEs were eliminated from the competition early in the 6th year. This event strengthens the competitors as the competitors absorb the reinitiated profits at each simulation step. However, the competitors were self-competing, which decreased the competitor population after the 18th year.

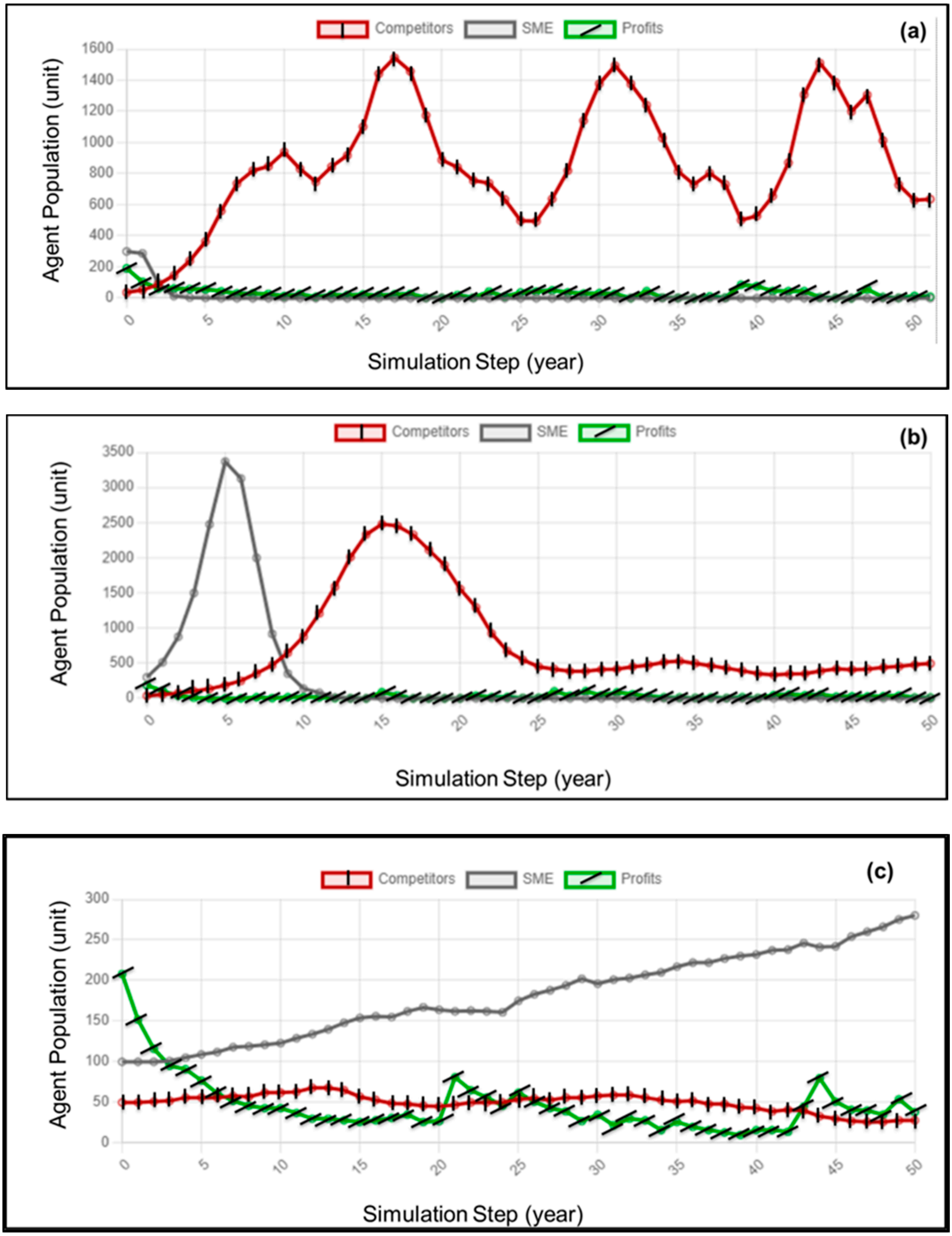

Figure 4. Competition simulation plot: (**a**) superior competitors, (**b**) SMEs growth rate doubling, and (**c**) balanced competition.

Third-party involvement changed the competitive dynamics. The SMEs with doubled growth rate shown in Figure 4b rapidly increased along with the exponentially rising government aid during the first five years. However, because of the model obeying the first assumption, competitors were able to overtake SMEs profits. This definition of assumption was due to the competitors being more technologically sophisticated and having better financial management. In year 9, the SMEs population fell, followed by the exponential growth of the competitors. As the SMEs vanished in year 14, the competitors began to self-competing. As a result, the competitors' population became narrower. The narrowed competitors competed in the balance competition from year 26 to the termination year. The dynamics of the balanced model shown in Figure 4c indicate small growth for SMEs and competitors. The SMEs were in favor of their higher initial population compared to the competitors. Additionally, the TS helped SMEs technology advancement to compete equally with the competitors.

3.2. High-Level Abstraction Analysis

The high-level abstraction of CLD simulates the ability of SMEs to adopt Industry 4.0. The simultaneous equations (see Table 2) of the initial SMEs model flow generated the model shown in Figure 5. Current Indonesian SMEs capital depends on government aid with IDR 1.6 million/SMEs valuation and external investment [34]. In this model, the external investments were not from loans or returnable favors. Therefore, both variables reinforced the SMEs capital. The SMEs have to adopt Industry 4.0 to increase their competitiveness. However, the lack of digital infrastructure and digital literacy restricts them from Industry 4.0 adoption.

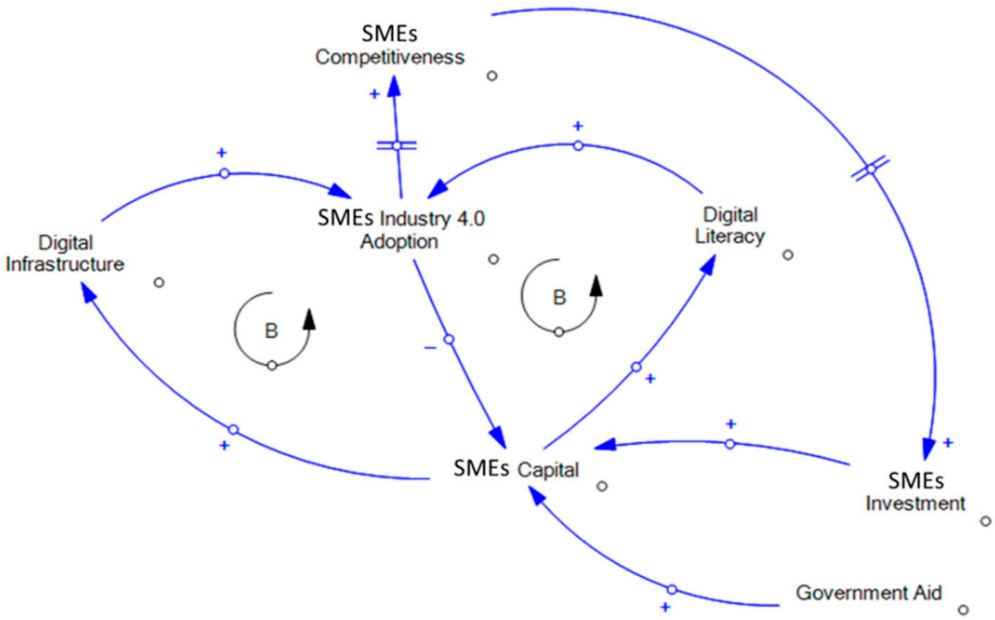

Figure 5. Causal loop of SMEs Industry 4.0 adoption without collaboration.

Industry 4.0 adoption requires cost and investments in digital infrastructure and digital literacy. Based on simultaneous Equations (10) and (11) in Table 2, Industry 4.0 adoption by the SMEs requires the SMEs to allocate the profit surplus. The required allocation was a 50% surplus. Both digital infrastructure and digital literacy create a balanced causal loop between SMEs capital and Industry 4.0 adoption capability. The delayed impact of Industry 4.0 adoption is the capital reinforcement as the future period investment increases due to reduced operational cost.

The TS collaboration covered all SMEs Industry 4.0 technological needs. Visually, Figure 6 depicts the TS collaboration causal relations. The TS is assumed to offer subscription-based digital infrastructures for the SMEs. This condition balances the SMEs capital as the SMEs only need to spend subscription costs. Additionally, venture capital and angel investors capitalize on TS. The capitalization enables them to own digital infrastructure and hire digitally literate employees. Hence, the collaboration with TS enabled the early adoption of Industry 4.0 by SMEs. Thus, this condition equates the SMEs with the larger companies.

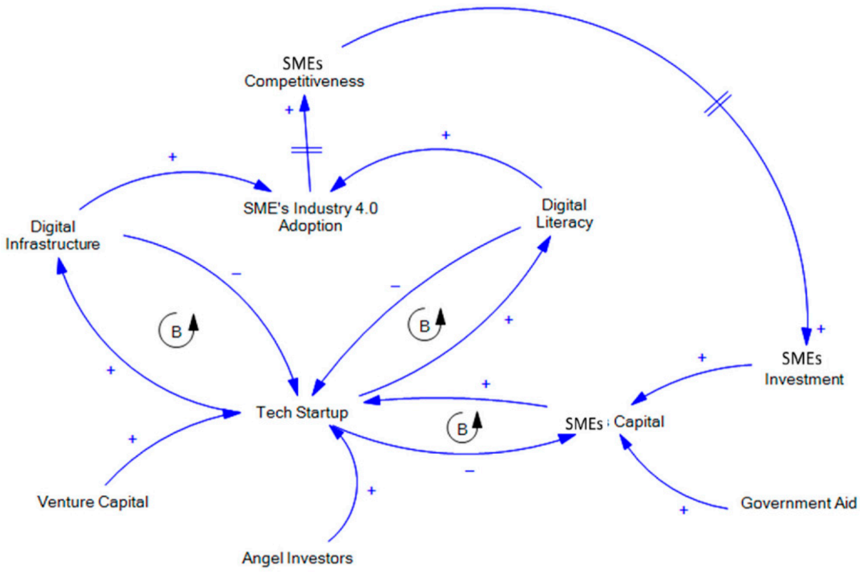

Figure 6. Causal loop of TS collaboration on SMEs Industry 4.0 adoption.

The quantitative results of the causal loop simulation indicate that TS collaboration is the best way to maintain SMEs competitiveness. The quantitative results shown in Figure 7 are the outputs of all simultaneous equations in Table 2 using ABM simulation parameters and outputs as the input of the equations. As a result, the link can be made from Figure 7a to Figure 4a, Figure 7b to Figure 4b, and Figure 7c to Figure 4c. The SMEs inability to adopt Industry 4.0 is visible in Figure 7a despite the linearly increasing capital each year. Figure 7b shows by growing the government aid exponentially each year, SMEs can adopt Industry 4.0 in the 18th year. The early Industry 4.0 adoption by SMEs and TS collaboration increases the SMEs investment rapidly by ten-fold compared to the previous scenario, as seen in Figure 7c. Thus, TS collaboration is critical to enabling the early adoption of Industry 4.0 for SMEs.

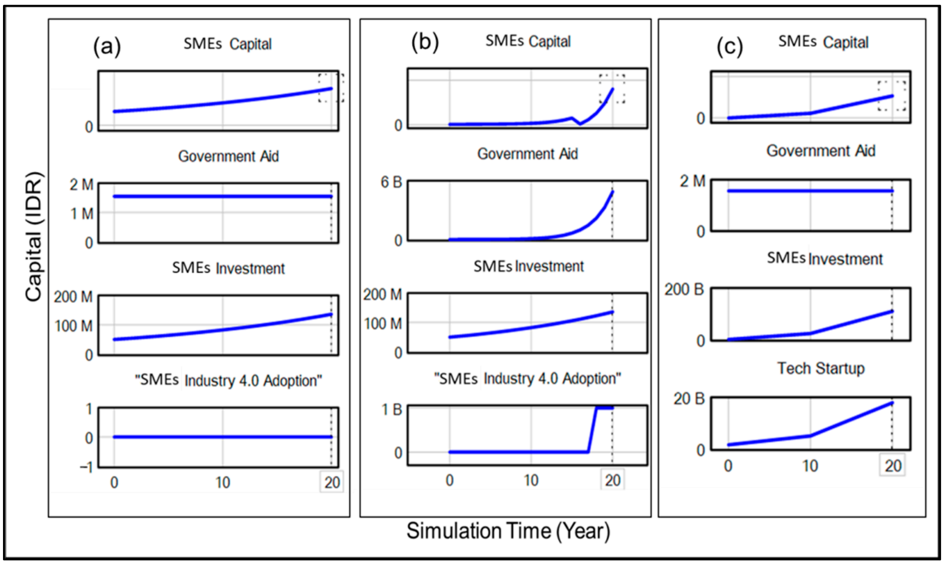

Figure 7. Causal loop simulation of SMEs Industry 4.0 adoption results: (**a**) steady system, (**b**) government aid exponential growth, and (**c**) TS collaboration.

4. Discussion

The combination of side-by-side medium- and high-level abstraction model simulation of SME's Industry 4.0 adoption provides some insights to view the future of the chosen strategies. The initial step of the simulation initiates the model dynamics as reflected by each simulation step and initiates future simulation steps. The ABM and the highly abstract CLD model utilization in this simulation employ encapsulated mannered simultaneous relation. Encapsulated simultaneous relation assumes the external factors are neglected once the system state has evolved [35]. Hence, the initial parameter settings are the only cause of the whole model dynamics.

The simultaneous model enables detailed focus observation on a few parameters of SMEs Industry 4.0 adoption. Therefore, the integrated model can provide correct behavior in each step. The physical system behavior validates the correctness of the model behavior. The behavior of Indonesian SMEs' business competition with the large competitors' validation is seen by comparing the SMEs' capability with that of large companies. The SMEs' lack of infrastructure, capital, and strategies in business enforce SMEs to gain smaller profits from the large competitors [36]. The behavior setting is a part of the first assumption of the ABM simulation. Therefore, the competitors are always capable of overtaking the SMEs market leads to SMEs bankruptcy. Hence, the ABM simulation model with provided assumptions correctly reflects the current business competition environment.

The real-time concurrent ABM integration with CLD reveals the relationship dynamics of high-level and medium-level abstraction variables. The model behavior is a direct response of ABM, CLD, or both model parametrical changes. The usual integration scheme of ABM and CLD is to specify one model as the receiver and the other model as the data transmitter [20]. Therefore, the behavior of the receiver model is steered by the transmitter model. The developed integrated model specifies both ABM and CLD to act as transmitter and receiver. Hence, both models affect each other as the simulation runs.

The ABM integration with the CLD helps the SME Industry 4.0 adoption possibility assessment. The simulation scenarios in the medium-level abstraction ABM simulation define the causal-loop simultaneous relationship. In the first scenario, the linear increment capital was not enough to help SMEs to adopt Industry 4.0 within 20 years. The exponentially incremented government aid is also not enough to support the Industry 4.0 adoption at the right time. The results fit with the current Indonesian SMEs' competition environment. The previous study shows that government support and competitor pressure do not affect SME business operations [37]. These reflect the successful model integration as the ABM parameter tuning leads to a change in CLD simultaneous behavior. Therefore, this integrated model is useful as a decision support tool for policy makers.

The long- and short-term robust system design is possible upon a strong initial parameter definition. The well-planned initial move in a competitive business environment affects the overall future decision [38]. Therefore, the current combined simulation model is fit for robust system planning. A robust system is a system that is unaffected or insignificantly affected by noise due to parametrical changes [39]. Although all models obey the Occam razor principle, this integrated model also possesses incorrectness due to assumptions [40]. However, the future state of SME Industry 4.0 adoptions planning is achievable by utilizing this integrated model. Therefore, the decision support role of the model is through current state-action planning.

The state-action planning of the integrated ABM and causal loop model offers dual-side future state prediction. State-action planning uses system modeling to predict the state of a system through parameter tuning [41]. As shown in Figure 8, the policy maker decides the initial parameter of the model based on the current situation. The policy maker can tune the parameters in the SMEs, ABM, and CLD simultaneously to assess both Industry 4.0 adoption and competition survival of the SME. The strategy should be chosen if the Industry 4.0 adoption and surviving competition were possible.

The implementation of state-action planning has been shown to be stable and a logically true prediction. A simulation model is defined as logically true if it can respond to parameter tuning as the real system respond to it [42]. The results shows the SMEs are unable to compete with larger competitors due to capital limitation. That limitation restricts their technological progression, which results in late adoption of the latest technology. Consequently, the larger competitors were superior to the SMEs. Hence, the result of the simulation is a valid representation of the physical system.

The collaborative strategy with TS removes SMEs' current limitations. Indonesian SMEs problems are marketing, technology, capital access, and human resources quality [43]. The first assumption of the competition simulation is based on these problems. The Industry 4.0 adoption removes the competition barriers due to the technology and human resource support by the TS. This barrier removal is due to today's marketing and is packed with technology components [44]. Consequently, the advances in technology improve the marketing capability of an SME. As most business processes are automated and assisted by technology, the quantity of human resources needed by SME decrease. As a result, the adoption of Industry 4.0 resolves the entire SME problem. Early adoption of Industry 4.0 is possible through TS collaboration. Thus, the interplay between government policy, TS solutions for SMEs, and SME efforts to collaborate with TS is an important factor in realizing the results of this simulation study.

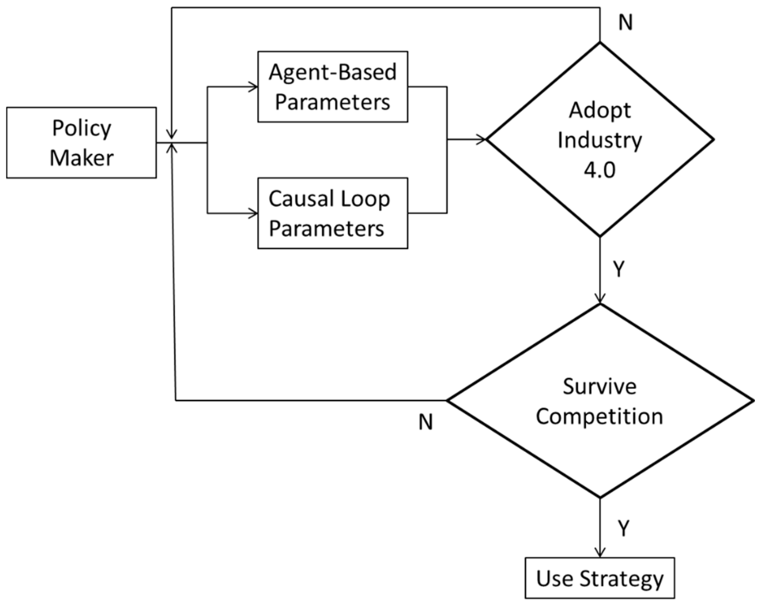

Figure 8. State-action decision support of the integrated model.

This study contributes to the development of real-time concurrent DS integration with ABM. The contribution is as shown in Table 3. This study reports the first concurrent DS and ABM simulation that includes understanding each other state. The DS model processes the ABM output while the ABM processes the DS output. Therefore, the integrated model developed is the combination of the top-down integration by [18] and bottom-up integration by [45]. Additionally, the concurrency of the model is maintained in real-time. Furthermore, the developed concurrent integrated model also removes the behavior steering by one model since both models steer each other.

Table 3. DS and ABM integration technique comparison.

Study	Case	Integration	Behavior Steering
This study	Industry 4.0 Adoption	DS concurrent ABM	
[18]	Waste Management	DS on top ABM	✓
[45]	Industrial Process	ABM on top DS	✓

✓causing behavior steering.

Along with the benefits of the constructed integrated model, it also imposes some limitations. The current integrated model relied on the initial parameters of the ABM and CLD. Some detailed parameters of SMEs' business competition were random and uncontrollable. Therefore, the effectiveness of the model still relies on simulation replication. The reliance on random variables can be improved in the future by understanding the fundamental mechanism of SMEs' business operations. The integrated model application in different research areas is also considered. A future test of the model in a different system other than Industry 4.0 transformation is required to assess the flexibility of the constructed integrated model.

5. Conclusions

This study confirms that Indonesian TS has a significant role as SMEs' Industry 4.0 transformation helper. This study provides an interabstraction provisional model by integrating ABM and CLD. The model utilization is to explore the future solution for Indonesian SMEs adoption of Industry 4.0 by including the external variables of TS growth and government aid. The ABM models the SMEs' business competition and the CLD models' relationship to the external variables. The simulation model reveals the collaboration and competitive dynamics of Indonesian SMEs. The simulation results suggest TS collaboration provides capital immune for the SME. Rising government aid may accelerate Industry 4.0 adoption but does not alter SME competitiveness due to late adoption. The SME collaboration with TS is the best strategy to sustain Indonesia SMEs in the business competition. TS cover the SME limitations by providing digital technology access through a subscription at a lower cost and without initial investment. However, the current developed integrative model relies heavily on random parameters generated by ABM. Hence, understanding fundamental SMEs operation is important to build a more effective model. The generalization of the proposed concurrent real-time model to solve another problem is also considered.

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