Innovative Framework for Assessing the Impact of Agile Manufacturing in Small and Medium Enterprises (SMEs)

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Abstract: In the competitive manufacturing era, agile manufacturing has evolved as a revolutionary manufacturing strategy that manages quality, innovation, responsiveness, introduction time of product, and uncertainties to maximize profit and to satisfy fluctuating demands of customers. The decision of implementing agile manufacturing is always complicated for organizations because they fear failure during the implementation process. This paper presents an innovative framework that can help decision-makers well before the implementation of agile manufacturing practices by evaluating the potential impact on an organization. The framework is based on three components, including agility cost, agility fitness, and agility outcome. The framework has been developed after intensive literature investigation, field study of manufacturing SMEs, and interviews with experts. Based on the framework, a knowledge-based system (KBS) has been developed to aid SMEs in decision-making at the implementation stage. The system is validated by case studies and by industrial experts through detailed interviews.

Keywords: agile manufacturing; decision support system; small and medium enterprises; manufacturing; flexibility; sustainability

1. Introduction

Businesses are rearranging and adjusting themselves to cope with new challenges of the 21st century. The greatest challenges of today’s businesses include competing for customer’s fast-changing requirements of high-quality, low-cost products [1]. Manufacturing approaches that have been developed and evolved over the past two hundred years can be briefly described in key categories such as preindustrial revolution, industrial revolution, lean manufacturing, and flexible manufacturing [2]. Agile manufacturing has also appeared as an innovative manufacturing methodology and is considered to be a substitute for the present-day industrial paradigm.

In the past, the policies of mass production based on economies of scale and full application of plants succeeded in the manufacturing world. As the plants and production setups were by no means easy to reconfigure, all this was attained by surrendering flexibility in manufacturing. Several authors debated about dissimilarity among agile and flexible manufacturing. Flexible production is a reactive methodology, while agile manufacturing is a proactive approach [3]. Some authors also associate agile manufacturing with lean manufacturing. According to Goldman and Nagel [4], lean is a collection of operational methods devoted to the constructive use of resources, while agility has characteristic of withstanding through unsure circumstances. The corporations aspiring to take the lead in the market must accelerate their evolution to agile manufacturing [5]. Abdulnour et al. [6] described that the challenges faced by manufacturing SMEs to remain competitive and enhance productivity can be overcome by introducing modular product structures, digital shift, lean practices, and above all, an agile system.

Studies conclude that more than fifty percent of companies fail to employ agile methods during the implementation stage [7]. Reasons of failure vary from wrong assessment
of potential challenges, inability to assess capacity of the organization to take up agile manufacturing, and fragile cost and benefit analysis. Small and medium enterprises (SMEs) struggle with the ability to make informed decisions in the implementation stage of agile manufacturing. Researchers have developed various models, methodologies, and frameworks in the context of agile manufacturing [8–16]. Their focus is ranging from AM drivers, AM enablers, AM impediments, AM assessment, and AM implementation to AM performance outcomes. The limitations of these models, methodologies, and frameworks are as follows. They focus exclusively on individual AM issues, for example, on the theoretical side, the authors discuss the factors that drive companies to opt for AM, the factors that enable companies to become agile, and the barriers against AM. On the practical front, the authors discuss various frameworks that focus on the measurement of agility of a company, ways of AM implementation, and the relationship of AM with performance outcomes. Frameworks on these individual fronts do not provide sufficient guidance to the companies regarding whether they should go for AM implementation or not by providing them explicit direction. This results in wastage of resources when implementation fails in the middle of a venture. Therefore, it is desirable to develop an impact assessment framework that can help practitioners to decide the viability of the agile manufacturing implementation well before committing resources to the project.

This research aims to develop an innovative framework to assess the impact of agile manufacturing in small and medium enterprises (SMEs) by evaluating potential cost, impact/benefit, and capability of organization. Organizations are in dire need of a system that can give them decision support at the planning stage regarding whether they should apply AM practices or not by assessing the organization from three dimensions, which include agility cost, agility impact, and the organization’s agility fitness. In order to meet the objective, we constructed the following research questions for this study.

- What are contributing factors to the agile manufacturing impact assessment framework?
- How can the impact assessment framework reduce the chances of agile manufacturing implementation failure?

The remaining paper is structured as follows. Section 2 is dedicated to literature review, Section 3 outlines research methodology, Section 4 presents agile manufacturing impact assessment framework, validation of the system is described in Section 5, and Section 6 refers discussion and implications. Finally, conclusions, limitations, and future directions are discussed in Section 7.

2. Literature Review

The journey toward agile manufacturing has been a debatable subject, especially regarding the difference between lean and agile manufacturing, as the majority of researchers focused on the comparison of both methodologies. Although both concepts can coexist, they are exclusive when it comes to the output of both methodologies [17]. Agile manufacturing specifically deals with flexibility and responsiveness toward uncertain market requirements. Goldman and Nagel [4] described AM as a new production philosophy that has emerged from changes in the business environment. It links information, innovations, and communication technologies to deal with the fast pace of market requirements [18]. Kidd [19] refers to agility as the capability of an organization to respond and exploit change in its favor. After establishing the clarity about agile manufacturing, researchers focused on the development of a framework that addresses the major agile manufacturing areas. The existing frameworks deal with agile manufacturing drivers, agile manufacturing enablers, agile manufacturing barriers, agile manufacturing assessment, agile manufacturing implementation in SMEs, and agile manufacturing outcomes. Subsequent paragraphs will recap these existing frameworks to pave the way for the framework developed in this paper.

Turbulence in the market environment forces industries to rearrange their production systems. Therefore, academicians and practitioners look for those specific elements which require industries to adopt agile manufacturing practices. These elements are named agile manufacturing drivers. The work in this area is focused only on identification and
prioritization of agile manufacturing drivers. Bottani [20] discussed five agility drivers that include market competition, market changes, changes in customer demands, social factors, and technology changes. Sindhwani and Malhotra [21] identified AM drivers such as automation and cost consideration, widening customer choice and expectation, competing priorities integration, proactivity, and achieving manufacturing requirements in synergy. There is no consensus on the importance of these drivers, which is why researchers have also focused on prioritizing these drivers so that very critical drivers can be focused on while developing a manufacturing strategy. Jafarnejad et al. [22] used Multicriteria Decision-Making to prioritize drivers of agility that concluded that suppliers, customer needs, competition, inner complexity, technology, market, and social factors are important drivers. The work in this area is aimed at the identification and prioritization of agile manufacturing drivers.

The identification of AM drivers triggered the next concern of researchers and industry practitioners, which is to look for those capabilities which can lead industries toward agility. These capabilities are termed agile manufacturing enablers. Various researchers worked on the identification and prioritization of these enablers. Gunasekaran [18] presented a conceptual framework that incorporates enablers including legal issues, business process, concurrent engineering, computer integrated manufacturing, total quality management, information technology, and cost management. Zhang, Sharifi et al. [23] described a methodology to assist companies to become agile. They concluded that cost effectiveness, technology, and strategic vision are key capabilities to achieve agility. Furthermore, [24–28] pointed out information technology as an enabler for agile manufacturing. Adoptability, flexibility, and customer satisfaction are important enablers in the context of supply chain agility, whereas customer satisfaction is ranked among the top-priority enablers [29–31]. Individual enablers provide insight to the organization about what it takes to become agile but do not provide complete guidance to become agile. A comprehensive set of agility enablers which addresses all segments of an organization was identified by Ramesh [32] and refined by Vinodh [33] and includes management responsibility agility, manufacturing management agility, workforce agility, technology agility, and manufacturing strategy agility. These five enablers were further expanded to criteria which can be used to measure agility to figure out agility fitness of an organization. Most of these studies are focused on the identification and prioritization of enablers by empirical means and does not consider other parameters such as agility cost, agility fitness, and agility impact simultaneously. In contrast to the agility drivers, the list of enablers is continuously updated according to the latest market requirements.

The hindrances against agility, agility measurement, and agility implementation are the next concerns of industries and academicians. Frameworks developed in this area are dedicated to the identification of agile manufacturing impediments, the measurement of agility, and methodologies to effectively implement agile manufacturing. Management responsibility plays a key role in the success of agile manufacturing. Lack of management commitment is identified as the most critical agile barrier by various researchers [34–40]. Improper forecast, resistance to change, lack of workforce flexibility, and poor integration of customers are other important barriers against agile manufacturing. A great portion of the literature is dedicated to the assessment of the manufacturing agility of organizations, sometimes also termed agility evaluation. Agility assessment provides a snapshot of responsive capabilities of an organization by highlighting strong and weak areas. By employing agility enablers and attributes, various authors have developed methods to measure the agility level of an organization. A scoring approach and agility index have been used to measure the agility of various organizations [41–46]. Due to the involvement of large quantity of variables, they relied on an analytical hierarchy process. Frameworks for agile manufacturing implementation have also been discussed in the literature. Sharifi [47] constructed a framework for developing agility in manufacturing which was used in eighteen manufacturing companies. They recognized the need for the integration of people and information systems for successful agile manufacturing implementation. Vinodh [25]
demonstrated application feasibility of IT to achieve agility, and the implementation was conducted in an electronics company. Sreenivasa [48] developed a model for enhancing total agility level and verified its compatibility with regenerative air dryer manufacturing. Various frameworks and indexes developed and their implementation in manufacturing companies were observed [13,14]. Frameworks and methodologies discussed in this segment are focused only on either the identification of agile manufacturing barriers, agility measurement, or implementation of developed methodologies. Finally, the outcomes of agile manufacturing practices have also been investigated to figure out the impact of agile manufacturing on the performance of an organization. Manufacturing industries are investing in adopting AM to obtain a better performance; therefore, various researchers focused on areas where agile manufacturing creates positive changes. Cost of implementation of AM and uncertainty of the outcomes are major concerns for the industry practitioners. Therefore, it is necessary to identify and inspect the outcomes as an impact of agile manufacturing. AM has a productive influence on financial and operational performance, which ultimately impacts the overall market performance [49–51]. Customer satisfaction is a major concern of any business, and agile manufacturing improves this indicator by responding quickly to the needs of customers. Shin [52] evaluated the relation of strategic agility with the operational and firm performance and concluded that it has a positive influence on customer retention. Researchers such as Zerenler [53] observed a positive correlation between agile manufacturing and logistic performance improvement, Tarigan [54] identified positive impact of supply chain agility on sustainability, Singh [55] explored the positive influence of agility on sustainability, and Khalfallah [56] observed AM’s impact on operational performance. Although the implementation of agile manufacturing is not straight forward, if managed properly, it can improve the sustainability of manufacturing systems [57]. Inventory in any manufacturing system is considered as an evil, and efforts have been made to eliminate it; agile manufacturing eliminates various sources of variability, particularly, the inventory [58,59]. Investigations of outcomes of AM in Indian manufacturing industries suggest that AM enhances responsiveness, customer retention, and employee morale [60].

From an in-depth literature review, it has been identified that existing frameworks discuss agile manufacturing drivers, agile manufacturing enablers, agile manufacturing barriers, agile manufacturing implementation procedure, and agile manufacturing performance outcomes. The following missing points have been identified after detailed study.

- Agility impact is mostly assessed in terms of performance outcome of an organization only; however, little or no work has been performed to identify the impact of agile manufacturing on an organization by considering the agility cost and agility fitness.
- A dedicated framework that possesses the capability to evaluate the impact of agile manufacturing in SMEs by employing agility cost, agility fitness, and outcome parameters.
- A knowledge-based system that can help practitioners to decide on agile manufacturing implementation at the concept-level stage.

3. Research Methodology

The research methodology adopted in this paper is comprised of three phases, as depicted by Figure 1. Phase 1 of the research deals with the problem of identification, followed by a detailed literature review. In this phase, an agile manufacturing implementation problem was identified, agile manufacturing enablers were explored, and agile manufacturing frameworks were investigated. The second phase of the research was related to research method identification, data collection, data analysis, and data validation. In this phase, data were collected through industrial surveys, expert interviews, meetings, and observation. For data collection, manufacturing SMEs which were already implementing agile manufacturing practices were targeted. The selected SMEs were performing business in the field of textile, automotive, electronics, furniture, and leather manufacturing. The CEO, production managers, and supply chain managers were accessed for relevant data collection. The data collected include type of business, years of experience in business,
agile manufacturing implementation experience, agile manufacturing capabilities of the organization, costs factors being employed for agility implementation, and output as an impact of agile manufacturing implementation. Annual reports related to performance output as a result of agile manufacturing implementation were also analyzed to validate the claims about postimplementation improvement. The final phase (phase 3) of the research was comprised of framework development, framework validation, KBS development, and KBS validation through case studies and expert opinions. In this phase, an impact assessment framework was developed based on literature investigation and industrial field study, whereas validation of the framework was performed through case studies and expert opinions. Furthermore, the KBS was developed based on the framework and validated through industrial implementation and expert opinions.

4. Agile Manufacturing Impact Assessment Framework

The agile manufacturing impact assessment framework is based on three components including agility cost, agility fitness, and agility outcome. Agility cost helps to identify financial requirements for agile manufacturing implementation. By adding an agility fitness function, the decision-maker evaluates the agile manufacturing capability of an organization. A preliminary need assessment component has also been added, which enables one to identify the company’s agility requirement. The detailed description of the framework has been provided in the section below.

4.1. Preliminary Need Assessment

Framework development initiates with agile manufacturing preliminary need assessment. Preliminary need assessment is carried out by company managers and decision-makers to identify whether there is a need for agile manufacturing implementation. This step not only saves the resources, but also saves time and cost of agile manufacturing implementation. After that, need identification, listing of needs, impact area identification, and corresponding resource requirements for the implementation of agile manufacturing practices are executed, as described in Figure 2. Table 1 shows needs which require agile manufacturing practices. The identification of impact area is conducted as a function of sustainability, lead time, responsiveness, inventory, and employee morale. The resources requirement is identified and includes manpower, consultancy, training, and system reconfiguration.

![Research Methodology Diagram](image-url)
identification, and corresponding resource requirements for the implementation of agile manufacturing practices are executed, as described in Figure 2. Table 1 shows needs which require agile manufacturing practices. The identification of impact area is conducted as a function of sustainability, lead time, responsiveness, inventory, and employee morale.

The resources requirement is identified and includes manpower, consultancy, training, and system reconfiguration.

**Figure 2.** Agile manufacturing preliminary need assessment process.

**Table 1.** SMEs needs that demand AM.

<table>
<thead>
<tr>
<th>Needs</th>
<th>Causes</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of responsiveness</td>
<td>Rigid processes</td>
<td>Unmet demands</td>
</tr>
<tr>
<td>Longer lead times</td>
<td>Bottlenecks</td>
<td>Late deliveries</td>
</tr>
<tr>
<td>Dissatisfied customers</td>
<td>Poor quality and underdeliver quantities</td>
<td>Loss of customers, revenue, and reputation</td>
</tr>
<tr>
<td>Poor workforce</td>
<td>Poor management, leadership, lack of training, and poor corporate culture</td>
<td>Low productivity, high defects, and turnover</td>
</tr>
<tr>
<td>Poor manufacturing strategy</td>
<td>Lack of cost and quality management</td>
<td>Poor quality and high costs</td>
</tr>
<tr>
<td>Lack of management responsibility</td>
<td>Rigid organizational structure</td>
<td>Poor coordination and decision-making</td>
</tr>
<tr>
<td>Obsolete technology</td>
<td>Lack of adoption of new technologies</td>
<td>Poor quality, defects, lower responsiveness, and longer lead time</td>
</tr>
<tr>
<td>Poor manufacturing management</td>
<td>Lack of customer response adoption, supplier involvement, and lack of exploitation of IT</td>
<td>Poor quality and customer dissatisfaction</td>
</tr>
</tbody>
</table>

**4.2. Agile Manufacturing Impact Assessment Framework**

To fulfill the objective of decision-making prior to the implementation of agile manufacturing, the assessment of its impact on the organization is very crucial, as depicted by Figure 3. The core purpose of the framework is to evaluate three components that
include cost of AM implementation, agility fitness of organization, and corresponding impact (benefit), so that a decision can be made at the stage of implementation. Details of these three components is given below.

Figure 3. Agile manufacturing impact assessment framework.
4.2.1. Agile Manufacturing Cost

The factors that contribute to the cost of AM are environment turbulence, impact area of agility, agility experience of organization, and size of the organization. The cost of AM can be categorized into direct cost and indirect cost [61]. The cost which results straightaway from implementation of AM is regarded as direct cost, which includes training expenditures, consultancy fees, replacement and rearrangements of equipment, and loss of revenues in implementation duration. Furthermore, as a result of implementation of AM, the costs that are not obvious cannot be ignored. Those cost include disruptions and delays, employee unease as a result of chaos (new setup may not cost their job), customer dissatisfaction as a result of delays, sabotage, and elevated level of work in progress during implementation.

Environment Turbulence

This refers to the environment in which a company operates. A more turbulent environment is one in which companies face more fluctuating customer demands. Changes in customers’ needs are very frequent, and product life cycle is also short most of the time. Product design changes are fast and very frequent. The higher the environment turbulence, the higher the cost of implementation of agile manufacturing practices would be.

Agility Impact Area

Cost is also dependent on the scope of implementation of agile practices. Agile manufacturing practices are implemented on one product, or an entire product line will determine final cost. If scope of implementation is large, the corresponding cost will also be large and vice versa.

Agility Experience of SME

The cost of implementation of agile manufacturing practices is also dependent on the familiarity of the company with agile manufacturing strategies. The company which is going for agile practices first will incur more cost due to the fact that it needs a lot of training for employees and resources for the reconfiguration of its manufacturing system. However, a company which is already familiar with agile practices and has partially implemented them will incur less cost comparatively because it is already trained in the required agile practices and fewer resources are needed to improve the implementation. The minimum cost will be incurred by those companies who are cautiously using agile practices.

Size of SME

Size of the company is also a determining factor for cost of implementing agile manufacturing practices. Because a greater number of employees are required to be trained in this process, the number of products and processes will also impact the cost volume. The higher the training and modification needs, the higher the cost will be, which implies that the bigger the size of the company, the larger the disruptions will be; hence, cost will rise and vice versa.

4.2.2. Agile Manufacturing Fitness

A company willing to implement agile practices needs to focus on certain attributes that support their journey toward agile implementation. The agility fitness of an organization has a key importance in the decision-making of agile manufacturing implementation, whether an organization is capable of pursuing agile manufacturing project or not. For this purpose, agility fitness is to be evaluated as well. The enablers of agility fitness include responsible management, manufacturing management, workforce, technology, and manufacturing strategy [33,41].
Management Responsibility

This includes organizational structure, devolution of authority, and nature of management. Organizational structure which is flattened, with personnel interchangeability, is supportive to the agile manufacturing philosophy. Clarity of responsibility, training, and participative management are key considerations while implementing agile manufacturing. The level of management responsibility will determine the fate of the agile manufacturing implementation project. A company with high management responsibility is more fit for agile manufacturing practices.

Manufacturing Management

This includes factors such as adoption of customer responses, outsourcing, and changes in business processes. Adoption of customer responses includes a culture of continuous improvement, feedback system, and personnel empowerment to resolve customers issues. Suppliers’ involvement and identification of small numbers of qualified suppliers are key factors in outsourcing. A flexible business system and the application of business re-engineering include major factors of change in business processes. A company with good manufacturing management is more fit for the implementation of agile manufacturing.

Workforce

A flexible, multiskilled, cross-trained, empowered, and involved workforce is necessary for agile manufacturing implementation. A company with high levels of these factors have bright chances of agile manufacturing implementation success.

Technology

This includes major factors such as manufacturing setups, product life cycle, product service, design improvement, production methodology, manufacturing planning, automation type, and IT integration. The companies who have a futuristic approach on all these factors are considered more fit for agile manufacturing implementation.

Manufacturing Strategy

Factors included in manufacturing strategy are status of quality, status of productivity, cost management, and time management. Companies who are innovative in designs, remove nonvalue added cost, incorporate activity-based pricing, and use time management approaches effectively have more chances of success in agile manufacturing implementation.

4.2.3. Agile Manufacturing Outcomes

Major outcomes because of agile manufacturing implementation are sustainability [57,62,63], short lead time [16,64], responsiveness [60], reduced inventory level [58], and high employee morale [65]. Return on investment, multiskilled workforce, and flexibility in manufacturing are direct outcomes of the AM. However, on a long-term basis, a company’s market reputation, creativity-oriented and adaptable culture, high employee morale, and evolution of robust processes are key indirect benefits of AM.

Sustainability

Customers are shifting to products that are manufactured through substantiable processes without compromising future resources; adaptability to these customers’ requirements is a main objective of agile practices. Agile manufacturing practices create innovative manufacturing environments within organizations that lead to sustainable manufacturing solutions according to modern requirements. The manufacturing system is considered sustainable if it remains relevant to the customers and society at any point in time. In an agile manufacturing system, the sustainability is viewed as the survival of the system on a long-term basis due to its ability to generate a variety of interactions with the market environment and at the same time keep internal complexity at low [62].
Lead Time

Lead time is a key factor in assessing the impact of agile manufacturing. Companies focus on delivering products into the market well before their competitors and within agreed-upon timeframes with the customers. The target of agile manufacturing practices is to reduce the time a product takes from design to customer delivery.

Inventory Level

Higher levels of inventory not only tie up huge amounts of capital but also hide the inefficiencies of the manufacturing system, so reduction of inventory is a goal of all companies. Agile manufacturing focuses on producing goods only when needed. So, inventory levels of a company are determining factors of the impact of agile manufacturing practices.

Responsiveness

To stay competitive in the market, companies tend to follow responsive manufacturing models. Agile manufacturing facilitates this by eliminating redundant costs and adapting to fast-changing customer requirements. Therefore, responsiveness is a determining factor of impact assessment of agile manufacturing.

Employee Morale

Employees’ involvement and ownership toward an organization is key to innovation in an organization that reciprocates organizational performance and employee morale. Having a satisfied workforce is a major goal of agile manufacturing practices. Therefore, the impact of agile manufacturing is reflected by employee morale.

Analysis of these three components, which are agility cost, agility fitness, and agility outcome, will lead to the decision of AM implementation. If benefits outweigh the costs and an organization is reasonably fit for agile manufacturing, AM implementation can be initiated, and if agility fitness is very low and cost outweighs the benefits, the decision of implementation is abandoned. Continuous revision of the impact assessment is an ongoing process.

The data collected from the companies who already implemented agile practices were analyzed. Factors which contribute to agile impact were identified and analyzed. The activity includes identification of agile manufacturing implementation cost, company agility fitness, and potential return as a result of agile manufacturing implementation. Analysis of the resources against agile manufacturing needs is critical to assess agile manufacturing affordability. After resource analysis, the evaluation of the agile manufacturing impact area is complete. This investigation includes whether agile manufacturing would improve indicators such as responsiveness, inventory, sustainability, employee morale, and lead time.

4.3. KBS Description

A knowledge-based system is developed on the basis of a framework which is already constructed. The necessary inputs for a KBS were extracted from the impact assessment framework. Three components were identified, namely, cost of agile manufacturing implementation, agility fitness, and output/impact, as a result of agility implementation. These three components are defined as subsystem 1, subsystem 2, and subsystem 3. Cost parameters are further categorized as direct and indirect costs. Direct cost involves costs related to manpower, consultancy, system reconfiguration, and revenue loss. Indirect cost includes cost of disruptions, cost of dissatisfied customers, work in process, and employee morale. These cost factors generate major costs within a company and are incorporated in a KBS. Agility fitness is further categorized as technological and managerial aspects. Technological aspects include production methodology, manufacturing setups, automation, and information and technology, whereas managerial aspects include quality management, organizational structure, devolution of authority, and strong employee cooperation.

As a result of agile manufacturing implementation, the company expects certain outcomes/impacts. These outcomes can be both tangible and intangible. Return on investment, manufacturing flexibility, and flexible manpower come under the category of tangible
outcomes, whereas reputation, employee morale, and adoptable culture come under the category of intangible outcomes. Framework was presented to company experts to obtain an opinion regarding whether the cost, agile fitness, and agility outcome parameters are realistic for conducting an impact assessment on agile manufacturing. These exercises were conducted to formulate an impact assessment framework which is meaningful for users within SMEs. Satisfactory response from the practitioners led to the development of a system which has three subsystems.

Subsystem 1 is related to cost parameter, subsystem 2 refers to agility fitness, and the third subsystem refers to outcomes which are expected after agile manufacturing implementation. Subsystem 1, which is agility cost, includes parameters such as environment turbulence, agility impact area, agility experience of SME, and size of SME. Linguistic variables for environment turbulence are low, medium, and high. Agility impact area is described in the linguistic variables of introduction, piecemeal, and widespread. Agility experience of an SME is described in the linguistic variables of first-time user, repeat user, and continual user. Size of the SME is described as small, medium, or large. All these variables are assigned with corresponding numeric value of 1 to 3, from lower to higher levels, respectively.

Subsystem 2, which is agility fitness, includes parameters to evaluate agility fitness of SMEs that include management responsibility, manufacturing management, workforce, technology, and manufacturing strategy. Linguistic variables for management responsibility are described as poor, fair, and good. Manufacturing management is described as change rejecting, change accepting, or futuristic. Workforce is described in linguistic parameters as discouraged, involved, or empowered. Technology is described as not automated, semiautomated, or fully automated, whereas manufacturing strategy is described in the linguistic variables of equipment utilization-driven, value-driven, and responsiveness driven. These linguistic variables are given numeric values of 1 to 3, from lower to higher levels of each variable.

Subsystem 3 refers to agility impact that is expected after implementation of agile manufacturing practices. It includes parameters such as sustainability, lead time, responsiveness, inventory level, and employee morale. Linguistic variables for sustainability, responsiveness, inventory level, and employee morale are low, medium, and high, whereas linguistic variables for lead time are long, medium, and short. These linguistic variables are given numeric values of 1 to 3, from lower to higher level, of each variable.

Heuristic rules were developed for all these systems for all available combinations. Table 2 shows the samples of heuristic rules of these subsystems.

<table>
<thead>
<tr>
<th>Subsystem 1</th>
<th>IF Environment Turbulence is Low AND Agility Impact Area is Introduction AND Agility Experience of SME is First-Time User AND Size of SME is Small, THEN Agility Cost is Medium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agility Cost</td>
<td></td>
</tr>
<tr>
<td>Subsystem 2</td>
<td>IF Management Responsibility is Poor AND Manufacturing Management is Change-Rejecting AND Workforce is Discouraged AND Technology is Not Automated AND Manufacturing Strategy is Equipment Utilization-Driven THEN Agility Fitness is Not Fit for Agility</td>
</tr>
<tr>
<td>Agility Fitness</td>
<td></td>
</tr>
<tr>
<td>Subsystem 3</td>
<td>IF Sustainability is Medium AND Lead Time is Medium AND Responsiveness is Medium AND Inventory Level is High AND Employees’ Morale is Low THEN Agility Impact is Medium</td>
</tr>
<tr>
<td>Agility Impact</td>
<td></td>
</tr>
</tbody>
</table>

The results of these three subsystems contribute to the final decision made by this KBS. The system generates three decision statements based on the results of each subsystem; a sample is given in Table 3. These decision statements in the form of advice are “do not apply agile manufacturing”, “probably apply agile manufacturing”, and “apply agile manufacturing”.

Table 2. Sample of heuristic rules for subsystems.
Table 3. Sample of heuristic rules for final knowledge advice.

<table>
<thead>
<tr>
<th>Knowledge Advice 1</th>
<th>IF Agility Cost is Medium AND Agility Fitness is Not Fit For Agility AND Agility Impact is Medium THEN Knowledge Advice is Probably Apply Agile Manufacturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge Advice 2</td>
<td>IF Agility Cost is Medium AND Agility Fitness is Somewhat Fit for Agility and Agility Impact is High THEN Knowledge Advice is Apply Agile Manufacturing</td>
</tr>
<tr>
<td>Knowledge Advice 3</td>
<td>IF Agility Cost is High AND Agility Fitness is Not Fit for Agility AND Impact is Medium THEN Knowledge Advice is Do not Apply Agile Manufacturing</td>
</tr>
</tbody>
</table>

4.4. KBS Scenario

The developed KBS is very flexible and robust in its use, and detailed working of the KBS is shown by Figure 4. In first step, the platform requires the user to input identified needs in the form of a list and area of agility impact after detailed brainstorming with the management of organization. Then, the user is asked to input the impact of agility in that area in the second step corresponding to sustainability, lead time, responsiveness, inventory, and employee morale. In the third step, the user is then prompted to input the agility experience of SME in terms of first-time user, repeat user, and continual user. In step four, requirements for agility implementation in terms of manpower, consultancy, training, and system reconfiguration are input. In step five, the user is asked to input the number of agility cost parameters, their names, their linguistic variables, corresponding numeric values, and numeric ranges for the decision statement. The user utilizes the ‘perform calculations’ button to display agility cost results. In step six, the user is asked to input the number of parameters for agility fitness, their names, their linguistic variables, corresponding numeric value, and numeric ranges for the decision statement. The user then presses the ‘perform calculations’ button to display the agility fitness results. In step seven, the user is prompted with a window to input the number of parameters for agility impact, their names, their linguistic variables, corresponding numeric values, and numeric ranges for the decision statement. The ‘perform calculations’ button is pressed to see the results for the agility outcomes. In step eight, the user selects the results of agility cost, agility fitness, and agility impact to obtain a final decision about agile manufacturing implementation in the form of ‘do not apply agile manufacturing’, ‘probably apply agile manufacturing’, or ‘apply agile manufacturing’.

Implementation in a Case Company

The framework has been validated through an industrial case study. The core business of the selected industry was electronics products manufacturing. The company exports its products to Europe and the USA. The collaborative research with the industry demonstrated that they currently had an informal decision-making system and relied heavily on intuitive decision making. Therefore, it was the company’s desire to incorporate a multifaceted tool to improve their decision-making. The company was researching those factors which need to be evaluated to decide about agile manufacturing implementation. The company was also confronting challenges of having a wrong assessment of its current situation. The wrong assessment had caused the failure of an agile manufacturing implementation project. Therefore, the company was keen to apply the KBS based on impact assessment framework for decision accuracy at an early stage. A refrigeration equipment manufacturing plant was selected for this purpose.
First of all, the company’s preliminary needs were assessed. Table 4 shows agility needs, area of agility impact, impact in that area, agility experience, and requirements for agility implementation. The number of factors for agility cost, agility fitness, and agility impact are put in the system according to the framework, as shown in Figure 5. The agility cost parameters’ values are input, and they include environment turbulence as medium, agility impact area as piecemeal, agility experience as first-time user, and size of SME as small. The result of the cost for this company is estimated to be medium, as shown in Figure 6. After that, agility fitness parameters are input, and they include management responsibility as poor, manufacturing management as change accepting, workforce as involved, technology as semiautomated, and manufacturing strategy as equipment utilization-oriented. The agility fitness result for the given company turned out to be somewhat fit for agility, as shown in Figure 7. After the agility fitness results, agility impact parameters are input, and they include sustainability as low, lead time as medium, responsiveness as medium, inventory level as medium, and employee morale as medium. The results for agility impact turned out to be agility impact is medium, as shown in Figure 8. The results of agility cost, agility fitness, and agility impact are selected for the given company to obtain final advice. Figure 9 shows that the decision for this studied company turned out to be probably apply agility.

Table 4. Case company profile.

<table>
<thead>
<tr>
<th>Company Type</th>
<th>Agility Needs</th>
<th>Area of Agility Impact</th>
<th>Impact in that Area</th>
<th>Agility Experience</th>
<th>Requirements for Agility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronics</td>
<td>Lack of Responsiveness, longer lead times, dissatisfied customers, poor manufacturing strategy, obsolete technology, poor manufacturing management</td>
<td>Refrigeration equipment manufacturing line</td>
<td>Sustainability, short lead time, responsiveness, reduced inventory, high employee morale</td>
<td>First-time user</td>
<td>Manpower, training, consultancy, system reconfiguration</td>
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</table>

Figure 5. Impact assessment factors and subfactors.

Figure 6. Agility cost parameters of case company.
Figure 6. Agility cost parameters of case company.

Figure 7. Agility fitness parameters of case company.

Figure 8. Agility impact parameters of case company.
5. Validation

The usability of the developed framework and the KBS was validated through expert opinion and case studies. The framework and the KBS were presented to experts to assess their functionality and accuracy. The experts were serving at management positions as either CEOs, production managers, or supply chain managers, as shown in Table 5. These experts were working in textile, electronics, automotive, furniture, and leather manufacturing industries. Only those experts were made part of validation process who had sound knowledge and expertise in agile manufacturing. For this purpose, a prevalidation screening of experts was conducted on the basis of their knowledge and expertise about agile manufacturing practices. Components of the framework were elaborated on and the factors agility cost, agility fitness, and agility impact were discussed with the experts. Meanings of linguistic variables and their numeric ranges were explained. The experts were given the opportunity to use the KBS for in-depth understanding about the working of a system. This was followed by the testing of heuristic rules by experts; in this step, the experts discussed the relevance of rules before accepting. After this activity, a questionnaire was used to collect their observations. Analysis of questionnaire results showed the confidence of the experts on the framework and the KBS.

Table 5. Validation exercise results.

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Company Type</th>
<th>Years in Business</th>
<th>Expert Role</th>
<th>Experts Experience</th>
<th>Experts’ Decision</th>
<th>KBS Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Textile</td>
<td>25</td>
<td>Production manager</td>
<td>15</td>
<td>Do not apply AM</td>
<td>Do not Apply AM</td>
</tr>
<tr>
<td>2</td>
<td>Electronics</td>
<td>20</td>
<td>Supply chain manager</td>
<td>10</td>
<td>Do not apply AM</td>
<td>Probably Apply AM</td>
</tr>
<tr>
<td>3</td>
<td>Automotive</td>
<td>20</td>
<td>CEO</td>
<td>12</td>
<td>Apply AM</td>
<td>Apply AM</td>
</tr>
<tr>
<td>4</td>
<td>Furniture</td>
<td>15</td>
<td>Production manager</td>
<td>10</td>
<td>Do not Apply AM</td>
<td>Do not Apply AM</td>
</tr>
<tr>
<td>5</td>
<td>Leather</td>
<td>12</td>
<td>CEO</td>
<td>13</td>
<td>Do not Apply AM</td>
<td>Do not apply AM</td>
</tr>
<tr>
<td>6</td>
<td>Automotive</td>
<td>17</td>
<td>Production manager</td>
<td>14</td>
<td>Probably Apply AM</td>
<td>Probably Apply AM</td>
</tr>
<tr>
<td>7</td>
<td>Automotive</td>
<td>16</td>
<td>Supply chain manager</td>
<td>12</td>
<td>Do not apply AM</td>
<td>Do not apply AM</td>
</tr>
<tr>
<td>8</td>
<td>Textile</td>
<td>11</td>
<td>Production manager</td>
<td>15</td>
<td>Apply AM</td>
<td>Apply AM</td>
</tr>
<tr>
<td>9</td>
<td>Textile</td>
<td>14</td>
<td>Supply chain manager</td>
<td>10</td>
<td>Probably Apply AM</td>
<td>Apply AM</td>
</tr>
</tbody>
</table>

To further validate the KBS decisions’ accuracy, the experts were requested to evaluate nine companies and asked to make an assessment about whether those companies should go for agile manufacturing implementation. Companies were evaluated by considering their capability to become agile, the potential cost they can incur, and outcomes they can obtain after implementation. The experts’ decisions about those companies were compared with the decisions made by the system; it was inferred that about ninety percent of the decision statements made by the experts would match with the decision made by the KBS, as detailed in Table 5 below. Furthermore, the experts validated the usability of the
framework and the KBS for consultants, industry practitioners, and academics. The four out of five companies who reached a decision statement of ‘apply AM’ and ‘probably apply AM’ based on the evaluation made by the KBS started an agile manufacturing implementation project and successfully completed it without failure in the middle the venture. That indicates the evaluation and decision accuracy of the KBS of up to 80%.

6. Discussion

In this paper, we have developed a framework to assess the impact of agile manufacturing in SMEs to help organizations to overcome failure of agile manufacturing implementation. For complete depiction of the organization, the framework is developed by incorporating agility cost, agility fitness, and agility outcome. It is observed that organizations willing to pursue agile manufacturing must excel in at least two segments to become successful in agile manufacturing implementation. The findings demonstrate that organizations who are very weak in any two or more segments fail in agile manufacturing implementation projects. That results in loss of resources in the form of time and money. This happens due to the unavailability of a comprehensive framework; therefore, the decision of agile manufacturing implementation is usually made haphazardly, without considering the overall situation of the organization. Furthermore, it is found that the decision of implementation of agile manufacturing made on the basis of evaluation performed by using the developed framework enhances the success rate to eighty percent. That is better than the existing rate of success, which is less than fifty percent [7]. The reason behind the improved success rate is the detailed evaluation of a company in the context of agile manufacturing. Consequently, only those companies are recommended to apply agile manufacturing who show promising results on all components of the impact assessment framework. As a result, these companies have a much lower probability of failure and succeed through the implementation process. The companies showing poor results in two or more components of the framework are advised to refrain from agile manufacturing implementation to avoid cost of failure.

Theoretical and Practical Implications

The existing frameworks developed by researchers address individual agile manufacturing knowledge areas and are mostly theoretical in nature. They do not provide sufficient guidance when it comes to addressing the issue of decision-making about the implementation feasibility of the agile manufacturing practices. The developed framework addresses this issue by evaluating agility cost, agility fitness, and agility outcome/impact. This work is a step toward a specific framework targeted at facilitating the industries in decision-making well before committing resources to agile manufacturing implementation. On the theoretical front, it opens a new research direction of impact assessment of agile manufacturing in SMEs, and on the practical front, it provides help to SMEs in making informed decisions about agile manufacturing implementation initiatives so that they can avoid failure. By using the framework, companies can evaluate agile manufacturing impact, and they can increase the chances of implementation success significantly.

7. Conclusions

Companies struggle with the decision of implementation of agile manufacturing practices due to fear of failure. So, there is market need for a solution that can assess the impact of agile manufacturing by evaluating agility cost, agility fitness, and agility outcome. To serve this purpose, an assessment framework was developed to see the impact of agile manufacturing well before reaching the implementation stage. The framework utilizes agile manufacturing cost as a result of implementation of the project, agile manufacturing fitness of the company, and outcome/impact of agile manufacturing. The parameters used to develop the framework are extracted from the literature and industrial experts. A knowledge-based system is developed based on the framework to facilitate users’ decision making. Companies using the framework and the KBS receive knowledge advice about
whether they should go for agile manufacturing implementation or should not go for implementation, based on risk-to-reward assessment. It is observed that the 80% of the companies who started a project of implementation of agile manufacturing on recommendation of the KBS were able complete the project successfully without failure in the middle of the venture. This work helps SMEs to understand what they require to evaluate while going for the decision of agile manufacturing implementation. This study has the following limitations and future directions.

- The study covers only manufacturing SMEs; the scope of study can be expanded to other SMEs as well.
- The accuracy of the developed system can be further increased by adding more factors to the framework.
- The framework functionality can be extended to the impact assessment of industry 4.0 by investigating relevant components.

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**Conflicts of Interest:** The authors declare no conflict of interest.

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