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Framework for the Implementation of Smart Manufacturing Systems: A Case in Point

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Abstract: Smart manufacturing has become a vital technique for increasing productivity and efficiency. Firms are following a smart manufacturing implementation system to compete in the market. Therefore, it is mandatory to find the crucial factors that enable the implementation of intelligent manufacturing in enterprises. This study proposes the framework for a new model factory based on the three-dimensional model that extends the product lifecycle layer. It also analyzes the significant attributes and interdependence relationships of causes and effects through the fuzzy DEMATEL approach for the selected small and medium enterprises discussed as a case study. The results show that the factors in Region 1 are significant attributes that need to be focused on for the development and establishment of small and medium enterprises under consideration. These attributes include design documentation (A11), intelligently management of small and medium enterprises (A3), visualization and monitoring of logistics and production (A6), flow of information, energy, and materials (A12), management platform and data acquisition for equipment (A7), and visualization of quality and process (A5). The sensitivity analysis is also performed to check the results' validity, reliability, and robustness. This study aids any manufacturing firm in analyzing the critical attributes that contribute to implementing smart manufacturing.

Keywords: smart manufacturing; framework; fuzzy DEMATEL; significant attributes; sensitivity analysis

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1. Introduction

Smart manufacturing has been an interesting topic in recent years due to the continuous development of Industry 4.0. The fourth industrial revolution forced sectors to move from conventional manufacturing to fully automated and flexible ones [1]. A smart manufacturing system captures the network of the whole system and allows it to communicate fully. Smart manufacturing (SM) is the collaboration of physical and digital processes within industries. In smart manufacturing, emerging and advanced technologies are used to enhance the efficiency of conventional manufacturing processes. SM aims to find opportunities for automation and enhance manufacturing performance using data analytics [2,3]. As technology continues to advance, smart manufacturing systems are expected to become even more advanced and transformative, changing the way products are manufactured and delivered. A smart manufacturing system (SMS) is a highly advanced and interconnected system that uses technologies to automate and optimize manufacturing processes. The smart manufacturing system is efficient, event-driven, and information-driven, with technology-based solutions. It responds in real-time to fulfill customer needs and changing demands. It is designed to improve efficiency, productivity, and quality while reducing waste and costs [4]. Therefore, industries need to play an essential role in integrating all aspects, including lean manufacturing, using facilities efficiently, enhancing their relationships with stakeholders, and ensuring industrial progress to enable a smart manufacturing implementation system (SMIS). SMIS integrates and maintains the firm's activities to achieve a collaborative environment. SMS helps to enhance manufacturing productivity, sustainability, quality, and agility through advanced technologies. Therefore, assessing SMIS under SMS is essential for industries. Previous studies proposed different assessment frameworks to investigate SMIS performance. Some studies used SMIS factors to implement them in the automotive industry. However, performance attributes require evaluation and judgment for the system under consideration [5,6].

1.1. Research Gap

The researchers need to develop a generic framework for implementing smart manufacturing. Industries with SMIS contribute significantly to Industry 4.0. Xianyu Zhang et al. [7] proposed a three-dimensional conceptual framework for the smart manufacturing system. Three dimensions comprised the product life cycle, system chain, and smart characteristics. They extended the chain of fusion sharing to generate the smart manufacturing collaborative system. Their work still needs refinement in the product life cycle chain.

1.2. Related Work

Different studies have been performed to propose the frameworks for SMS, and many researchers have contributed to evaluating the critical factors using the fuzzy decision-making trial and evaluation laboratory (DEMATEL) technique. Muhammad Zeeshan et al. [8] reviewed the critical factors of radio frequency identification (RFID) and bar codes for smart manufacturing sectors. They proposed a framework with three different contexts, such as technology, organization, and environment. Both technologies are implemented in manufacturing domains like production planning, inventory management, and lean manufacturing. The limitation considered in this study was the high initial capital cost of implementing RFID. Felix Ocker et al. [9] developed a framework for smart factories with different terminological components of production ontologies. It helps the engineers support the system, ensure interdependencies, and enable better communication in smart manufacturing systems. Further improvement was required for this to minimize development times and facilitate the bonding of production resources across countries and vendors.

Soojeen Jang et al. [10] described the importance of smart manufacturing systems' maturity level for small and medium enterprises (SMEs) through contingency theory and a resource-based view. The research entailed a survey of 163 manufacturing SMEs in Korea. It was concluded that the maturity level of smart manufacturing systems directly relates to operational efficiency and financial performance when considering SMEs. The proposed scheme was limited to one country, Korea, but it could be extended to different countries. G. Citybabu et al. [11] reviewed the work related to lean six sigma for one decade and developed a smart manufacturing framework based on different aspects such as the type of author profile, year of publication, type of industry, and type of methodology for the work. It benefited the researchers working in the respective fields to capture valuable knowledge for better quality and productivity.

Ravindra Ojha [12] used the DEMATEL approach to identify the prominent factors for lean manufacturing in a technology-driven industry. A total of 18 factors were selected, and after analysis, it was concluded that two factors were crucial: significant data acquisition and analysis and technology-driven talent. This study was also helpful for assessing smart industries' threats to sustainability. Jamshid Afshani et al. [13] proposed an approach to combine the fuzzy DEMATEL and fuzzy analytical network process (ANP) to describe the interdependence and weight of each activity. This work had a few limitations, like activity charts being introduced in non-fuzzy formats, which is why a new model is needed that could prioritize the factors without redesigning the activity model.

Shikang Chen et al. [14] proposed an assessment framework to describe the applicability of one of the emerging technologies of smart manufacturing called blockchain while considering product lifecycle management. Essential features of blockchain were discussed, and they also addressed the technical and non-technical challenges of product lifecycle management in data management by implementing blockchain. A case study is needed to verify and demonstrate the prescribed mechanism.

Honey Yadav et al. [15] used the fuzzy DEMATEL technique to examine the barriers to adopting e-commerce technology for small and medium enterprises. In this research, the interdependence relationship among factors and the sensitivity analysis of the system were also discussed. The proposed work can be extended to other fields like electronics, the oil and gas sector, logistics, and supply chain management with more decision-makers and different hybrid decision-making models to get the required results.

Product development plays a crucial role in industrial progress. In conventional product development, physical validation is used to confirm the design scheme before manufacturing. However, physical validation is inefficient and costly, which hinders rapid product development. This issue was removed by Sihan Huang et al. [16] by proposing the framework for the digital twin in the context of smart manufacturing. A case study was also discussed to implement the prescribed framework and accelerate product development.

A.G. Hamzehkolaei et al. [17] used fuzzy DEMATEL to analyze the causal relationship between the sustainable smart city dimension. Results showed that policy factors affect all other factors and are influenced by all other factors, excluding environmental factors. The proposed approach can be applied to various smart city environments.

Paul Grefen et al. [18] developed the framework as a reference architecture model for industry 4.0 (RAMI 4.0) with three-dimensional layers having hierarchy levels, lifecycle chains, and value streams to elaborate smart manufacturing based on their research for two decades. It helped to connect processes from the shop floor to manufacturing equipment and enterprise-level businesses for smart factories. [19] used the fuzzy DEMATEL approach to identify the critical factors and cause-effect relationships for manufacturing strategy outputs. The decisive factors included the number of advanced features, cost per unit produced, and customer satisfaction. This study enabled the adoption of smart manufacturing to promote Industry 4.0.

Qing Chai et al. [20] determined the critical success factors that affect implementing a safety program to regenerate abandoned industrial building (RAIB) projects in China. The fuzzy DEMATEL approach is used to identify the interdependence and cause-and-effect relationships among factors. This study guided stakeholders and managers to improve industrial building projects' safety measures and sustainability goals. Other countries have further development levels and stages of RAIB projects, and this study is limited to China.

1.3. Research Contributions

The study's contributions are as follows: It proposes the framework of a new model factory under each layer of the product life cycle and for identifying the perspectives, aspects, and attributes that enhance the system's performance under consideration. It also identifies the significant attributes needed for the small and medium enterprises discussed as a case study to implement smart manufacturing. Integrating fuzzy DEMATEL with the frameworks can tackle the interdependent relationships between causes and effects under uncertainty. The sensitivity analysis is also performed to check the results' robustness, reliability, and validity.

1.4. Aim of the Paper

The aim of this article is to help those industries that are looking forward to implementing smart manufacturing according to the resources they have and want to know their strengths and weaknesses.

The structure of this article is as follows: Section 2 offers a framework for the product life cycle, the extension of each CP layer, the identification of perspectives, aspects, and attributes a case study of SME, and the fuzzy DEMATEL technique. Section 3 presents significant attributes for SMS: cause-and-effect interdependence relationships, practical significance, and sensitivity analysis. Lastly, Section 4 summarizes the findings.

2. Methodology

This section develops the framework and extends each CP's layer to identify the perspectives, aspects, and attributes of SMS and SMIS. The related attributes were initiated through a survey of SME discussed as a case study. Finally, the fuzzy DEMATEL technique is used to compute the required results.

2.1. Framework for Product Life Cycle with SMS and SMIS

Product Life Cycle (P), System Hierarchy (H), and Smart Characteristics (C) are the three dimensions that make up the framework of SMS, as shown in the upper part of Figure 1. The "Product Life Cycle" dimension refers to the collection of activities that cover the entire procedure from initial product design to ultimate product disposal. The "System Hierarchy" dimension refers to the division of production resources and activities from small to large, i.e., equipment to cooperation. The intelligence function divides the "Smart Characteristics" dimension from resource elements to an emerging industry. The combination of any two SMS dimensions for deployment generates the SMIS layer. There are three main layers of SMIS: C-P, H-C, and P-H. Integrating the 'C' and 'P' dimensions creates the C-P layer. The combination of the 'H' and 'C' dimensions generates the H-C layer; similarly, the 'P' and 'H' dimensions generate the P-H layer, as shown in the lower part of Figure 1. Every layer has its sublayers. For instance, the C-P layer has nine sublayers, from CP1 to CP9. CP1 is related to design; CP2 is related to the flow of information, energy, and material; CP3 is related to manufacturing systems; CP4 is related to production; CP5 is related to assembly systems; CP6 is related to packaging and dispatch; CP7 is related to the distributor; CP8 is related to the client; and CP9 is related to recycling. The elements included in these sublayers are described in Section 2.2. Similarly, the elements included in the H-C and P-H layers are given in Section 2.3.

2.2. Extension of Product Life Cycle Based on New Model Factory

This section includes a description of the CP layer and its sublayers. This layer entails the description of the Product Life Cycle. It includes the following terminologies: design, input, manufacturing systems, production, assembly systems, packaging and dispatch, distributors, clients, and recycling, as shown in Figure 2. The description of each term is described in the following layers.

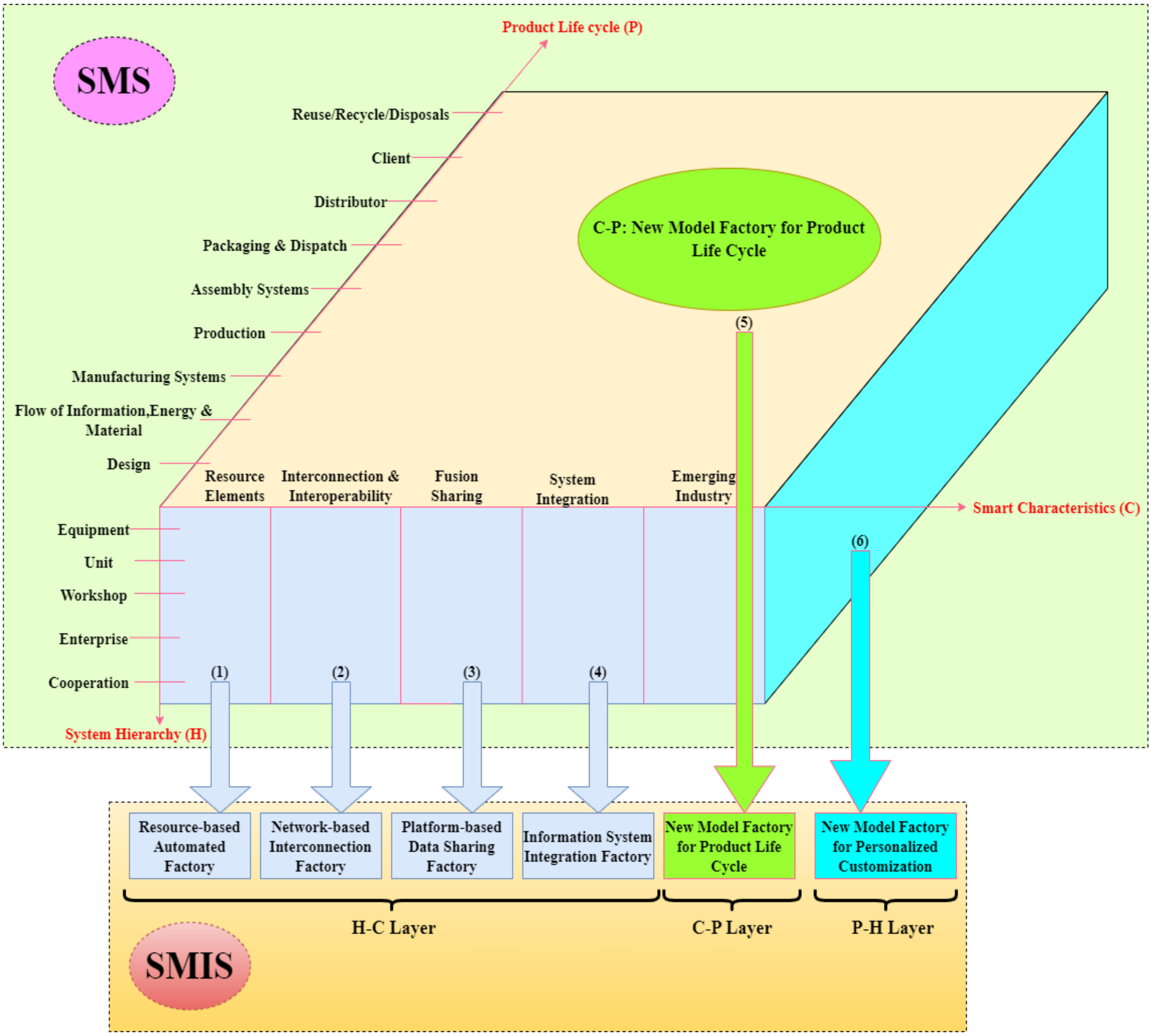


Figure 1. Three-dimensional framework of SMS and SMIS.

2.2.1. Extension of the CP1 Layer

The design layer corresponding to CP1 is extended in Figure 3a. Three types of designs are included: original, adaptive, and variant. An original design covers 25% of all design tasks. The terminologies studied thoroughly are need, concept design, specification, and respective standards. Concept design is about shaping a new idea or approach to implement. An adaptive design covered 55% of all design tasks and focused on embodiment design. Embodiment design is an important stage of the design process and is also known as system-level design, which chooses the best design layout so that it can further become the starting point of detail design. The variant design covered 20% of the total design tasks and focused on embodiment and detail design. The detailed design is a precise and complete description of all the components in the product [21].

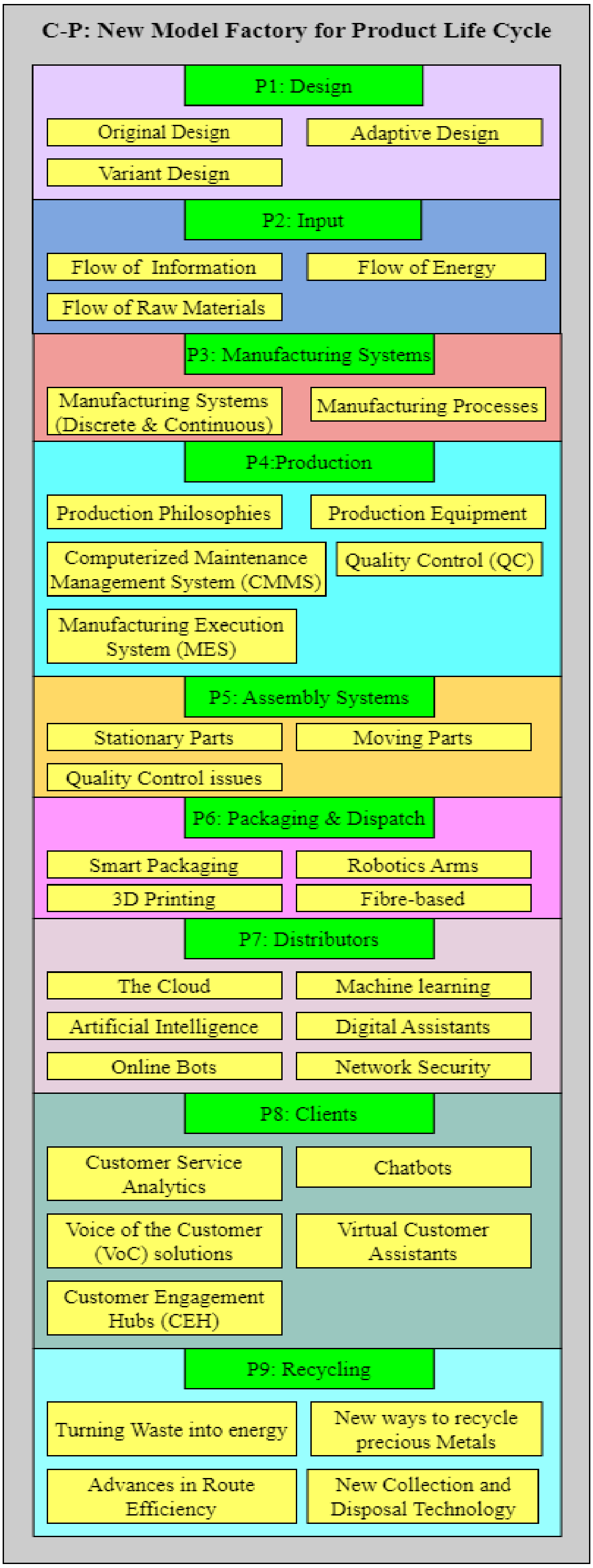
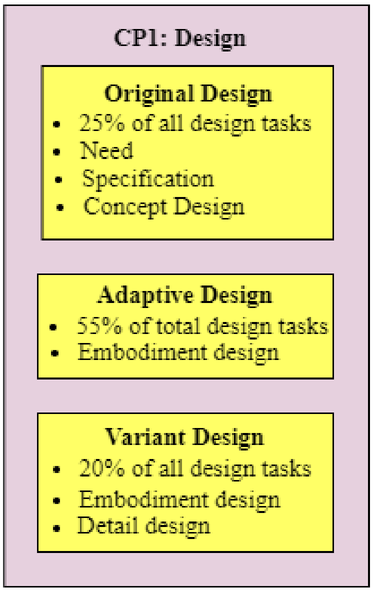


Figure 2. Extension of the CP layer.



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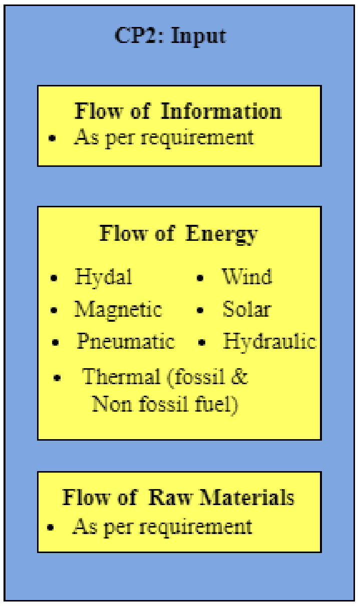

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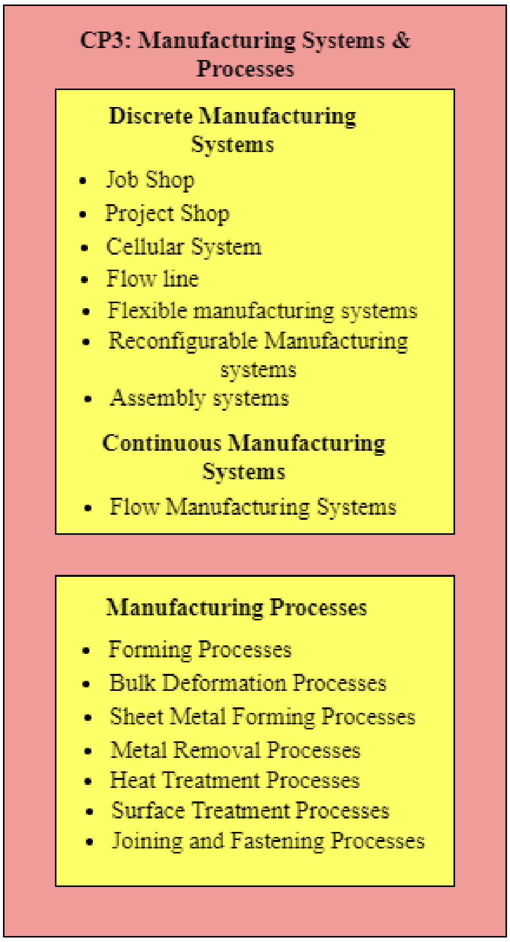

(**c**)

Figure 3. Extension of (**a**) the CP1 layer, (**b**) the CP2 layer, and (**c**) the CP3 layer.

2.2.2. Extension of the CP2 Layer

The next layer is CP2 regarding input, as shown in Figure 3b. It includes three parts: the flow of information, the flow of energy, and the flow of raw materials. The flow of information concerns the deep knowledge of the respective system. The flow of energy as input deals with the required form of energy; it may be hydroelectric, wind, magnetic, solar, pneumatic, hydraulic, or thermal. The flow of raw materials contains the required raw materials as they are going to be dealt with.

2.2.3. Extension of the CP3 Layer

The next layer is CP3 regarding manufacturing systems and processes, as depicted in Figure 3c. Manufacturing systems have two types: discrete manufacturing systems and continuous manufacturing systems. Discrete manufacturing systems include a job shop, a project shop, a cellular shop, a flow line, a flexible manufacturing system, a reconfigurable manufacturing system, and assembly systems. A continuous manufacturing system contains a flow manufacturing system. All machines have the same number in the job shop, and functions are grouped together. For example, if there is a lathe machine, it creates a turning workstation; similarly, milling will form a milling workstation. It is used for small quantities (1–100 parts at a time). In the project shop, the product does not move; the machines move towards the product according to the required work. It also produces small quantities (1–10 parts at a time). In a cellular manufacturing system, different machines are grouped according to the processes needed for the number of products. It is used for slightly larger quantities; the lot size is 800–1300. In the flow line, the proper sequence of machines is grouped according to one or very few parts. At a time, only one part can be manufactured. It is mostly used for larger quantities of 700 to 15,000 parts. A flexible manufacturing system (FMS) combines a cellular manufacturing system and a job shop. It has greater flexibility in process sequence and part types and a higher level of automation. Very little labor work is needed for such a system as it contains the characteristics of two manufacturing systems, which is why it can produce a large number of parts. A reconfigurable manufacturing system is a system that has the capacity for a sudden change in its structure, including the software and hardware components, in order to maintain production as a result of market changes. This is a very dynamic and order-intensive type of manufacturing system. Discrete manufacturing systems produce discrete products, and continuous manufacturing systems produce non-discrete products like sugar, grains, and powder. In a flow manufacturing system, parts are manufactured in stock and not according to specific orders but to follow the sales forecast while considering past orders and inventory. In this system, scheduling and routing can be standardized.

The second part of this layer includes manufacturing processes. In forming, plastic deformation occurs due to applied stresses such as tension, shear, and compression. Forming processes include rolling, forging, drawing, and extrusion. In the bulk deformation forming process, the cross-section area changes significantly through plastic deformation. The initial shape of the workpiece could be a billet, slab, or rod. In the sheet metal forming process, the initial shape of the workpiece is a sheet, and the sheet's geometry changes upon the application of force. In the metal removal process, the finished product is obtained by removing significant material from the workpiece. It may include traditional machining processes (turning, milling, and drilling), non-traditional (electric discharge machining and electro-chemical machining), and abrasive processes (grinding, lapping, and honing). Heat treatment processes use heat to modify the properties of materials at different levels. The most common processes in this category include annealing, normalizing, hardening, and tempering. Surface treatment processes are sometimes known as post-processing and play a prominent role in the product's aesthetic and functional aspects. Some common processes included in this category are case hardening, thermal spraying, vapor deposition, electroplating, and painting. Joining and fastening processes include the assembly of parts by some means. Two types are included in it: temporary joining and permanent joining. Temporary joining includes fastening, press-fit, seam joints, key joints, etc. Permanent joining includes welding, soldering, coupling, etc.

2.2.4. Extension of the CP4 Layer

The next layer is CP4 related to production, which is further extended to production philosophies, theories, and equipment, a computerized maintenance management system, a manufacturing execution system (MES), and quality control, as shown in Figure 4. In group technology (GT), parts with the same manufacturing processes, geometry, and functions are manufactured in a unique location using fewer machines. This technology can be applied to any industry, such as plastic molding, foundries, and welding. Just-in-time (JIT) is a management strategy in which goods are received upon request. It is really helpful to increase inventory and reduce holding costs. Material resource planning (MRP) enables manufacturers to schedule, plan, and manage their inventory during the process. It is a software-based system. MRPII is an accumulative information system used by enterprises. It is derived from MRP, with integrated financial needs and employee data. Enterprise resource planning (ERP) helps to manage the company's supply chain, financial, reporting, human resources, and manufacturing activities. Supply chain management manages the flow of services and goods, including all the operations that convert the raw materials into final products. The Theory of Constraints (TOC) is a methodology for analyzing the constraint referred to as a bottleneck that causes hindrance in achieving a goal and then improving that constraint so that it may no longer be the limiting factor. Lean manufacturing is a technique to minimize waste or resources to maximize profit and productivity. Waste may be anything that a customer does not want to pay for. Agile manufacturing applies to an organization that established the system to enable it to respond quickly according to market changes and customer needs while setting quality and cost. It is related to lean manufacturing. Six Sigma is the managerial approach, including the tools and techniques for process improvement. It has five principles: define, measure, analyze, improve, and control. Kaizen is a Japanese business philosophy, a mixture of Japanese words meaning continuous improvement. It helps to engage all the employees in the continuous improvement of different company sectors. Computer-integrated manufacturing (CIM) is a fully automated manufacturing system with all the processes operating under a computer with digital infrastructure.

The next part of this layer is production equipment. Three factors are paramount in production: input, process, and output. The input for production equipment may be type, shape, energy source, and other raw materials. The implementation of the process permits the transformation from raw materials to finished products by using different tools, including cutting tools, coolants, and lubricating oil. The output from the production equipment may contain the required product and scrap.

A computerized maintenance management system (CMMS) is software that assists the organization in storing and organizing complete information related to physical assets and maintenance tasks. Its purpose is to provide an overall improvement in maintenance tasks. Several features of CMMS enhance the efficiency of the plant floor, such as mobile-enabled features, project management, preventive maintenance planning, asset management, predictive maintenance capabilities, work order management, report generation, and vendor management, as shown in the figure.

MES is software that helps monitor, manage, and harmonize all the physical processes that convert raw materials into finished products. It mainly covers the following: product lifecycle management (PLM), production monitoring and analysis (PMA), production scheduling (PS), and maintenance management (MM). PLM helps enhance the finished quality and monitor the product lifecycle. PMA keeps focusing on the production facilities and alerting users of subsequent problems. PS aids in generating machines and tools' production schedules. It also assists in tracking inventory levels. MM helps to manage and schedule preventive maintenance.

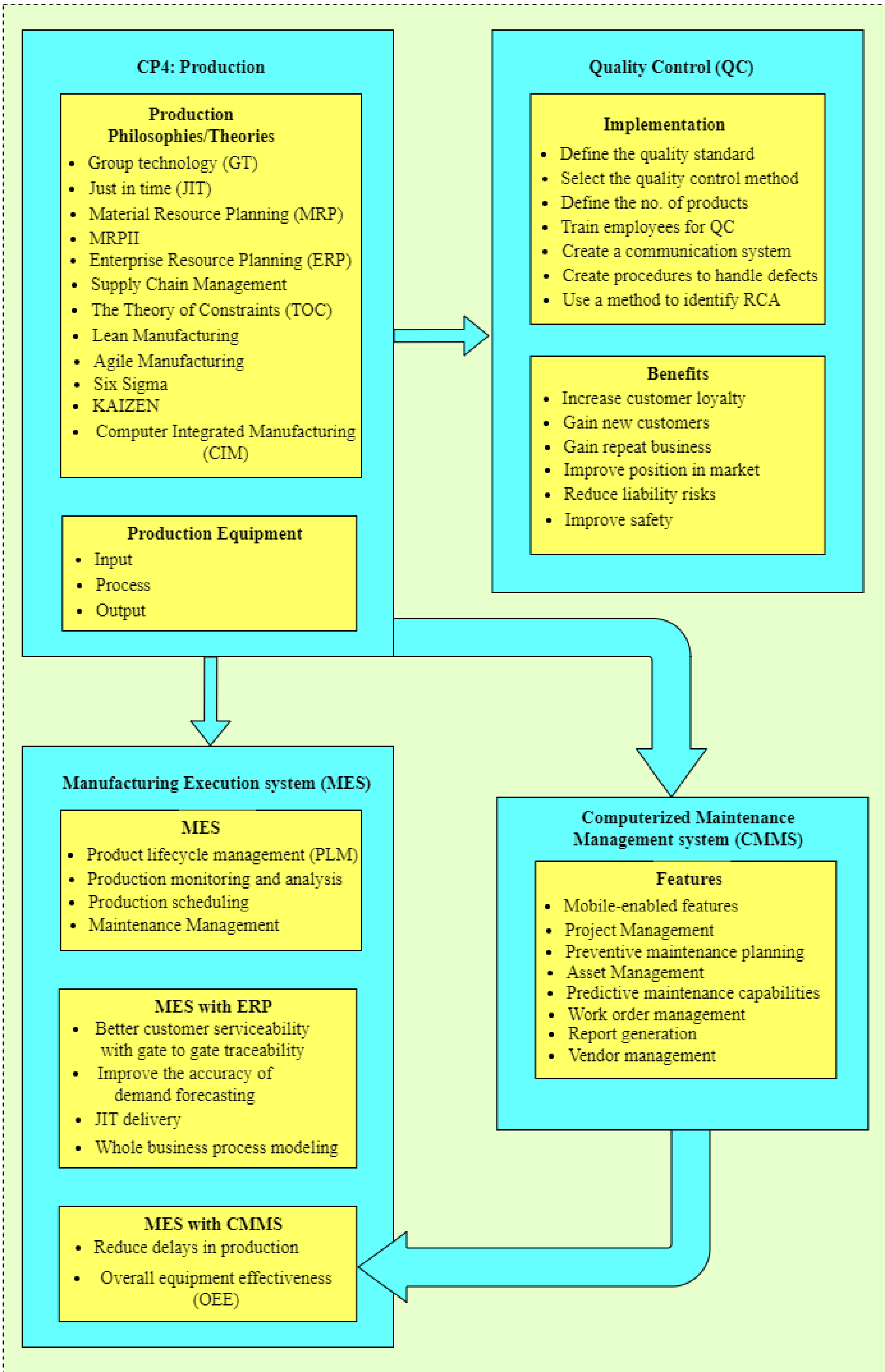

Figure 4. Extension of the CP4 layer.

There are various benefits to integrating MES with ERP, such as:

- Improve customer service with quick traceability:

When customer complaints provide information related to product issues, it becomes essential to trace each lot. After quick tracing from inventory receipt and throughput production, the management service can determine the issues and plan accordingly.

- Better accuracy of demand forecasting:

It becomes easy to tackle the abrupt changes in demand through the integrated MES/ERP system. The ERP software helps to proceed with the demand modifications to the production planning. By doing so, production units become more responsive and ultimately meet the requirements as forecast.

- Improve JIT delivery:

An integrated MES/ERP helps monitor work-in-progress inventory quickly. As a result, inbound and outbound inventory visibility can be enhanced to enable JIT delivery.

- Enhance business process modeling:

By integrating the MES/ERP system, managers ensure that each sector of the business works optimally. It reduces manual processes and allows new processes to be overcome. The continuous modeling of new processes results in the agility of the organization.

MES can be integrated with CMMS to provide a larger ERP solution. An integrated MES/CMMS system promotes early detection of the progressive flaws of specific equipment. It permits the team to plan accordingly. As a result, it causes less deterioration and delays during production. One of the vital key performance indicators for manufacturers, known as OEE, can be tracked easily through the MES/CMMS system. It is performed by using the information from CMMS and the production data from MES.

Quality control (QC) is the process of ensuring the products are flawless and meet customer demands. The first step to implementing QC effectively is to create and document the approach. It includes the following: defining the quality standards for all the products; selecting the appropriate quality control method; defining the number of products or batches that need to be tested; training employees for QC; and creating a proper communication system to report defects or major issues. The second step includes the creation of procedures for handling the concerning defects. The last step is to use an approach like 5-Whys to analyze the root cause analysis of the defects.

The benefits of QC are as follows: increase customer loyalty, gain new customers, gain repeat business, improve position in marketing, minimize liability risks, and improve safety.

2.2.5. Extension of the CP5 Layer

The next layer is CP5, which is related to assembly systems and quality control issues, as shown in Figure 5. Two types are included: stationary parts and moving parts. Stationary parts are further extended to stationary workplaces and moving workplaces. The assembly system for stationary parts with a stationary workplace has a high area and work capacity at the workstation with a reasonably low cost requirement. The assembly system for stationary parts in the moving workplace has a high area and medium work capacity at each workstation, with a medium cost. The assembly system for moving parts in a stationary workplace has a low area and work capacity at each workstation, with a significantly high system requirement. The assembly system for moving parts with a moving workplace has a medium area requirement and high work capacity at each workstation.

The next phase of this layer is related to quality control issues. There are several QC issues that may arise throughout the whole process of producing the final product. Common QC issues are as follows:

- Lack of standardized SOPs:

To fully meet the quality requirements, industries must clearly define standard operating procedures (SOPs) among the following sectors of operations: manufacturing, production, supply chain management, and various shop floor operations. Unclear SOPs create difficulty for workers to understand fully and ultimately cause inefficient results.

- Inefficient supplier quality management (SQM):

Manufacturers must focus on supplier quality; otherwise, the quality of the product will be affected. In this way, concerned leaders need to pay proper attention to the ongoing performance and quality metrics of the supplier. The only way to sort out that issue is to automate the process.

- Improper equipment management:

Industries must pay proper attention to keeping the return on invested capital (ROIC) high to maintain quality standards and meet customer requirements. Any disturbance in equipment management operations, such as maintenance or calibration, directly affects the output, ultimately raising the production cost. Equipment management can be simplified using Compliance Quest's equipment management software. This software also provides the user with a 360-degree view of the equipment and makes many processes, such as scheduling, tracking, and calibration, easy. It significantly contributes to the reduction of production costs.

- Siloed approach to quality assurance:

Siloed sections cause hurdles and cannot provide proper quality control data. This issue arises because of the legacy system that cannot unify people, processes, and systems. An enterprise quality management system is the solution to this problem. It integrates all the quality data in one location. It can also integrate with ERP, PLM, customer relationship management, and other systems. As a result, all the quality analytics are performed in real-time.

- High cost of quality (COQ):

When the cost of good quality (COGQ) is less than the cost of poor quality (COPQ), it affects the industry's total cost of quality. COGQ does not compromise product quality or output. COPQ arises due to non-conformance. This issue can be assessed by the CQ non-conformance management. It reduces the cost of quality and enhances quality management.

- Manual training:

Training permits the employees to perform the task in a feasible way. Industries using paper-based training need more visibility of trained workers and updated facilities. It causes a rise in production costs, waste of raw materials, and low product quality. This issue can be mitigated by using CQ training management. It integrates the training with enterprise quality management software that causes reliable, stable, and robust training management processes while adhering to regulatory needs and international standards like ISO 10012 and ISO 9001.

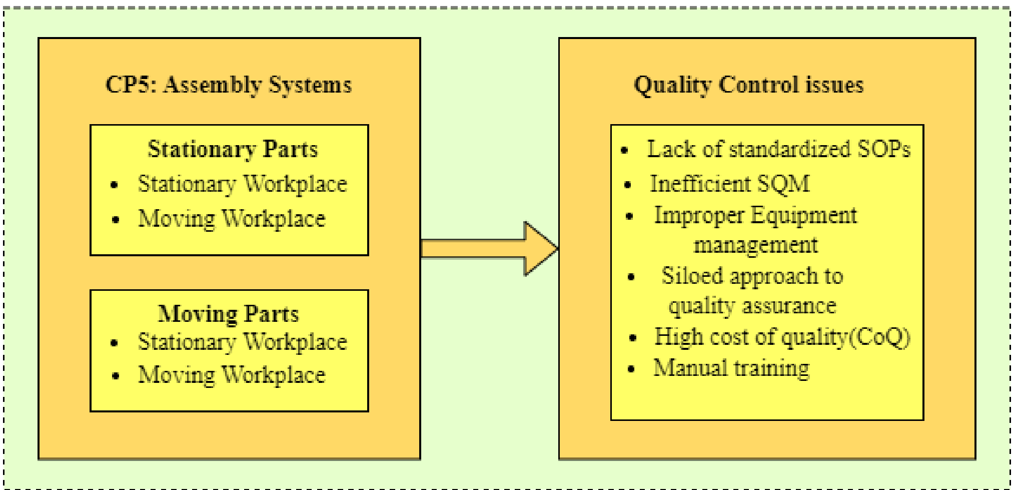

Figure 5. Extension of the CP5 layer.

2.2.6. Extension of the CP6 Layer

The next layer is CP6, which is related to packaging and dispatch, as shown in Figure 6a. New technologies in the smart manufacturing field have transformed the packaging trend. Smart packaging uses sensor technology with products to enhance shelf life, display information, and improve customer safety. It includes one developing technology, RFID (radio frequency identification), printed on the packaging. RFID sends signals through wireless communication, so retailers can easily track the goods across their entire inventory. Robotic arms also participate in smart packaging through mobile robotic platforms. They can sort items for quick delivery. Robotic arms are so flexible as they can be positioned for different jobs; meanwhile, the systems can be reconfigured. Autonomous mobile robots (AMRs) track their routes themselves to adapt the working station quickly. The 3D printing also plays a vital role in scaling packaging to the next level of creativity and customization. It helps to quickly test the products and perform packaging before going to the next stage. It is also known as additive manufacturing because it works layer by layer. Many packaging instruments have been made using this technology, compared to conventional techniques. For example, robotic arms used for packaging purposes can be produced in days using additive technology that was previously produced in months. Manufacturers are also using fiber-based materials for plastic packaging. For example, microfibrillated cellulose (MFC) is used to produce packaging materials that are much lighter and stronger than those made of carbon fibers or glass.

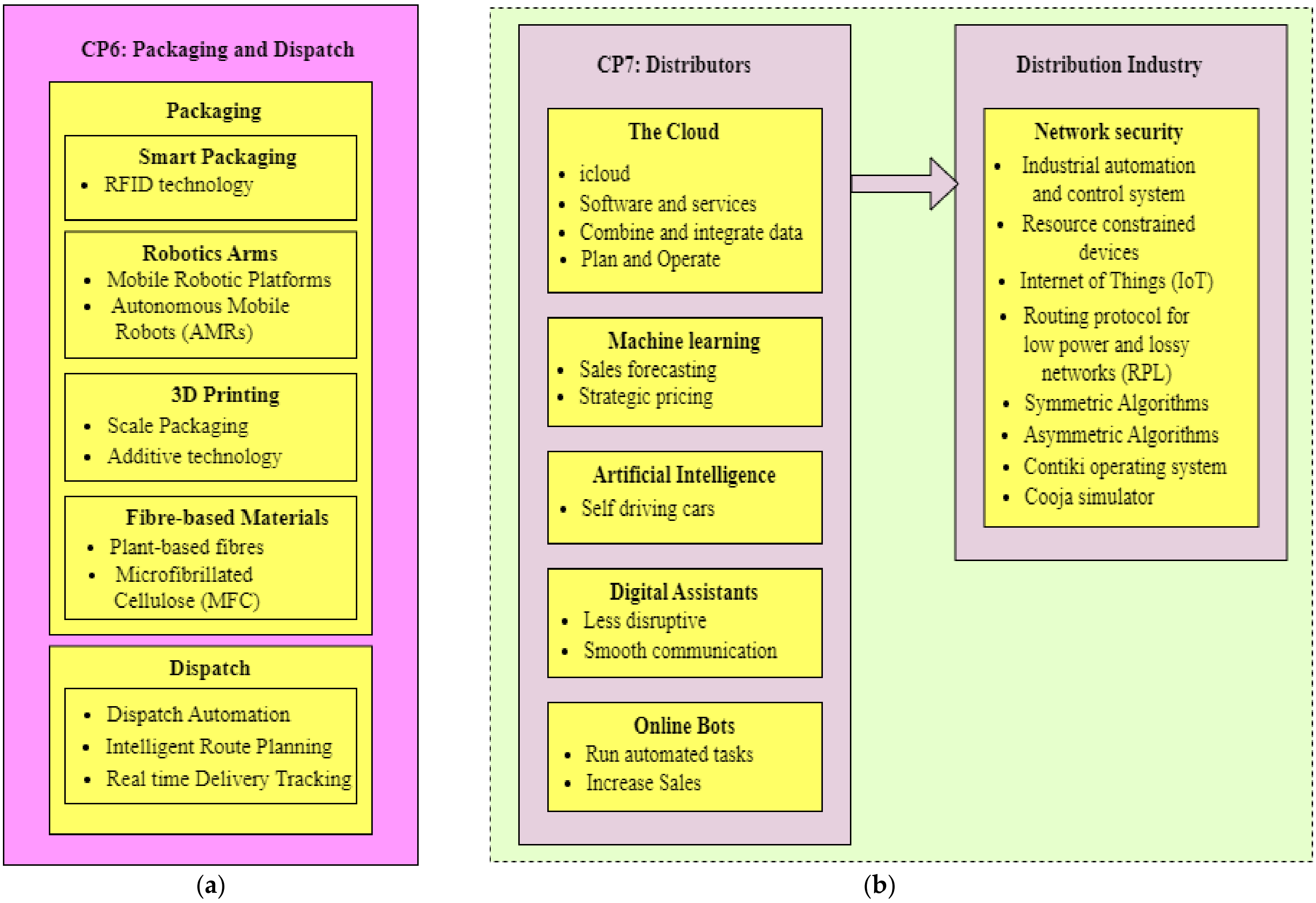

Figure 6. Extension of (**a**) the CP6 layer and (**b**) the CP7 layer.

The next phase of this layer related to dispatch and had technologies that transformed dispatch services. Dispatch automation helps deliver items with the same pin codes. By doing so, a lot of time and distance can be saved. In dispatch automation, delivery agents use mobile applications that share information about the tasks to be delivered within a given time. So, delivery executives do not wait at warehouses to get packages; they come with their known entire-day tasks. Intelligent route planning maximizes the number of deliveries on a single route, promoting efficient dispatching. It has many advantages over delivering items from one optimal path to another. It also brings up deficiencies like congestion, fuel consumption, tonnage, and no-entry windows. Real-time delivery tracking enables customers to track their items online rather than wait for their exact arrival. In the event of any delay, the customer must be notified via notification.

2.2.7. Extension of the CP7 Layer

The next layer is CP7, as shown in Figure 6b. It describes the technologies that are changing the distribution industry. It also covers network security for industrial automation and control systems. Cloud technology plays a prominent role for distributors. Many people have iCloud on their smartphones to get help throughout their lives. The term "cloud" also refers to services and software that run through the internet instead of a local server. Cloud technology permits software and apps to work anywhere and makes integrating and combining data easy. It also helps the distributors operate and plan the data. Machine learning helps the distribution industry with sales forecasting by giving information about the weather, discounts, traffic, and seasonality. With its help, companies know how many products they need in a given timeframe. Machine learning also has importance in strategic pricing, where businesses can determine prices based on price elasticity, promotions, historical sales, and lost sales. Artificial intelligence also contributes significantly to the distribution industry by introducing the idea of self-driving cars. Famous companies such as Tesla and Apple are working to create driverless cars. Digital assistants are also being used in the distribution industry to change client and company interactions. Clients can communicate through digital assistants to get information about the inventory. Companies can also get information about delivery trucks through digital assistants without interrupting the driver. It provides a less disruptive and smoother way of communicating. Online bots are software-based applications that are used to run automated tasks. They help to communicate online by making availability easier even if the office is closed. Bots also help find new clients and enhance overall sales by reducing workers' workload so they can focus on other important tasks.

Network security is a prime concern for Internet of Things (IoT)-enabled distribution industries. Industrial automation and control systems (IACS) are facing serious security challenges. IACS has IoT-enabled, resource-constrained devices. During communication through IACS, network layer attacks need to be tackled. Common attacks included in this category are blackholes, grayholes, wormholes, and sinkholes. All these attacks destroy the data coming from the source node. In order to mitigate the effects of these attacks, there are several routing protocols available. The routing protocol for low-power and lossy networks (RPL) is the most appropriate for the IoT-enabled manufacturing system, and 6LoWPAN is also used for this purpose. After properly selecting the routing protocol, a lightweight cryptographic technique should be considered. The cryptography technique encrypts and decrypts the data between sender and receiver. There are two types of cryptographic techniques: symmetric and asymmetric. Symmetric algorithms use only one key for encryption and decryption. Some renowned symmetric algorithms are Advance Encryption Standard (AES), Serpent, ChaCha20, Twofish, and Camellia. Asymmetric algorithms use two keys (public and private) for encryption and decryption. Some popular asymmetric algorithms are Rivest Shamir Adleman (RSA), elliptic curve cryptography (ECC), and Bluejay. Contiki is the operating system used for the network simulator Cooja.

2.2.8. Extension of the CP8 Layer

The next layer is CP8, which has technologies related to customer service, as shown in Figure 7a. Customer service analytics help enterprises improve individual agent performance. They disclose those insights that are helpful to increasing operational performance.

Chatbots vary from simple marketing tools to feature-rich platforms. They are dependent on artificial intelligence and machine learning. Voice of the customer (VoC) solutions combine different technologies to store, capture, and analyze indirect and direct customer feedback. After integrating data from different VoCs, firms can take actions more confidently at individual and process change (overarching strategic) levels. Virtual Customer Assistants (VCAs) permit organizations to prioritize the number of activities handled in the contact center. VCA has the ability to enable voice-enabled automated teller machines to decrease interventions for unconventional audiences. Customer engagement hubs (CEH) offer architectural frameworks combining multiple systems to engage customers optimally. CEH enables reactive and proactive communication using artificial agents, humans, and sensors across all channels. They can interconnect all the departments to synchronize sales, marketing, and customer service.

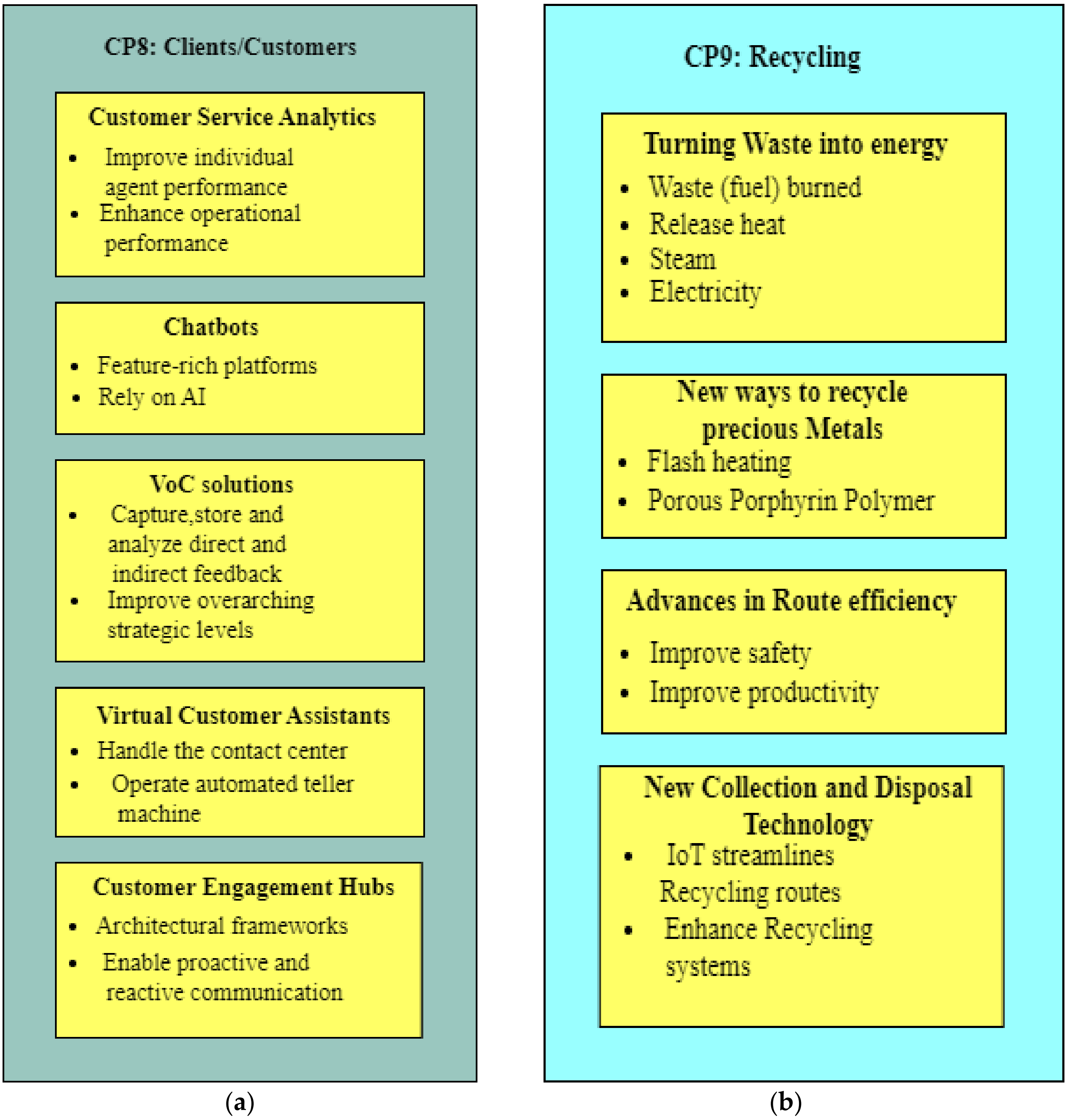

Figure 7. Extension of (**a**) the CP8 layer and (**b**) the CP9 layer.

2.2.9. Extension of the CP9 Layer

The last layer is CP9, related to recycling, as depicted in Figure 7b. Turning waste into energy involves burning waste called trash or garbage to generate steam in the boiler, which is later utilized to generate electricity. Flash heating is the process of recycling electronic waste (e-waste). It includes grinding e-waste into a powder and heating it to about 3000 degrees Celsius. This vaporizes the materials, accumulating the vapors in a cold trap that recondenses them into solid materials. After this, a conventional refining method can separate the metals. Precious metal recovery from e-waste can also be made with porous porphyrin polymers. Route optimization helps improve safety by reducing the time for vehicles on the road. Route planning software can help manage time properly, thus increasing productivity. New recycling technology has been growing so fast to enhance productivity and efficiency. IoT streamlines recycling routes using sensor hardware attached to garbage units to streamline collections of routes. They help the citizens manage their recycling in a better way. Radiofrequency identification (RFID) chips can also be attached to bins to improve recycling systems.

2.3. Framework for the Identification of Perspectives, Aspects, and Attributes

Figure 8 represents the framework for identifying the perspectives, aspects, and attributes of the SMS and SMIS layers. Before moving towards the fuzzy DEMATEL technique, it is pertinent to provide a clear demarcation of perspectives, aspects, and attributes. Three perspectives are chosen from SMS, six aspects from SMIS, and twenty-one attributes are derived from the corresponding aspects as depicted by color combination. These attributes are described in Table 1. The perspectives include System Hierarchy (H), Product Life Cycle (P), and Smart Characteristics (C). The attributes include machine tools and robots, simulation and digital design, and intelligently management of SME derived from the automated factory having resources as shown in orange. This factory was developed from the facilities of smart manufacturing systems for industries. The attributes include visualization of energy and equipment, visualization of quality and process, and visualization and monitoring of logistics and production derived from the Interconnection factory having a corresponding network, as shown in light blue. This factory is developed in the context of visualization and networking within industries. The attributes include the management platform and data acquisition for equipment, and the management platform for augmented reality (AR) data is derived from the data sharing factory platforms, as shown in gray. This factory was developed in the context of data-sharing platforms within industries. The attributes include information system integration for the process layer and information system integration for the enterprise layer derived from the information system-based integration factory, as shown in yellow. This factory is developed in the context of information integration within a smart manufacturing implementation system for industries. The attributes, including design documentation, flow of information, energy and materials, manufacturing systems, production policies, assembly systems, packaging and dispatch, logistics distribution, and client attraction, are derived from the new model factory for the product life cycle, as shown in green. The attributes, including personalized customization and flexible manufacturing, are derived from the aspect named new model factory for personalized customization. This factory is developed on the basis of different flow processes related to the product life cycle at the system layer of smart manufacturing. It prefers customer demands and converts conventional mass manufacturing to mass customization.

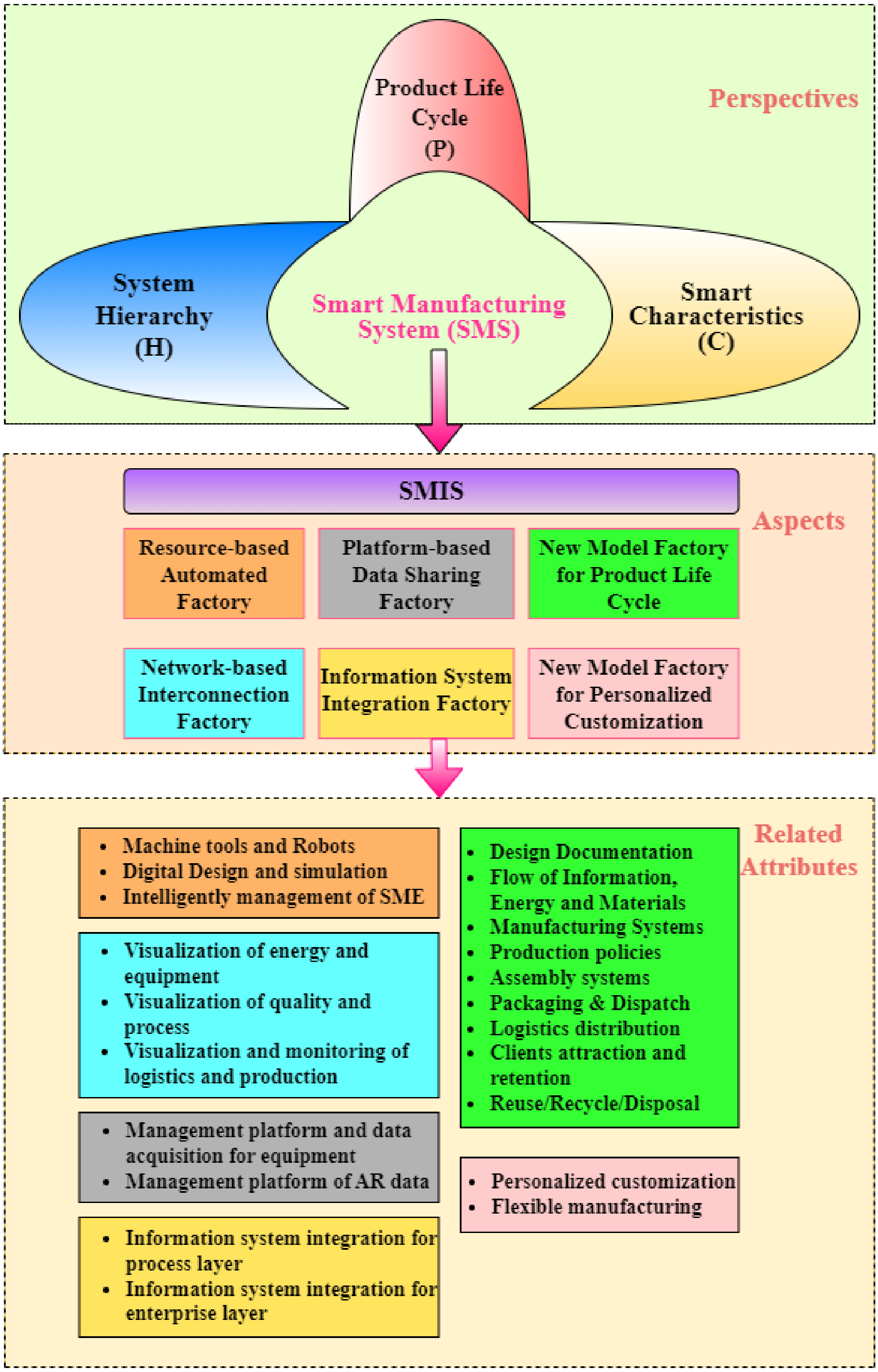

Figure 8. Identification of perspectives, aspects, and attributes.

Table 1. Related attributes and their descriptions.

Symbol	Attributes	Description	References
A1	Machine tools and robots	It contains high-grade CNC machine tools and industrial robots such as turning, milling, engraving, cobots, etc.	[22,23]
A2	Simulation and digital design	It covers simulation and product design based on a three-dimensional model and CAE analysis of the products.	[24,25]
A3	Intelligent management of SMEs	It entails sales management, material management, financial accounting, production management, and cost control, and also contains mobile applications.	[26,27]
A4	Visualization of energy and equipment	It includes network-based equipment interconnection, energy system monitoring, and real-time display of monitored energy data.	[28,29]
A5	Visualization of quality and process	It belongs to scrap rate, feed inspection results, SPC charts, X-R charts, etc.	[30,31]
A6	Visualization and monitoring of logistics and production	It comprises visualization of work order processes such as part name, part number, work order number, etc.; visualization of work-in-process inventory; and on-site visualization and monitoring such as production lines, factories, delivery working stations, etc.	[32,33]
A7	Management platform and data acquisition for equipment	It involves equipment data acquisition based on the enterprise intranet and remote online acquisition of device data based on the enterprise's external cloud platform.	[34–36]
A8	Management platform for AR data	It contains structured simulation data management, the association between product data and simulation data, the collaboration of simulation and design, and structured product simulation based on the analysis and design model.	[37–39]
A9	Information system integration for the process layer	It covers computer-aided process planning (CAPP) and product data management (PDM).	[40–42]
A10	Information system integration for the enterprise layer	It entails enterprise resource planning (ERP), supplier relationship management (SRM), customer relationship management (CRM), technical document management (TDM), and quality assurance (QA).	[43,44]
A11	Design documentation	It includes original, adaptive, and variant designs.	[21]
A12	Flow of information, energy, and materials	It belongs to the required information, energy, and materials, and energy may be in the form of hydroelectric, wind, magnetic, solar, pneumatic, etc.	[21,45]
A13	Manufacturing systems	It comprises the manufacturing systems and processes. Discrete manufacturing systems contain job shops, project shops, cellular systems, flow lines, flexible manufacturing systems, reconfigurable manufacturing systems, and assembly systems. A continuous manufacturing system contains a flow manufacturing system. Manufacturing processes include forming, bulk deformation, sheet metal forming, metal removal, heat treatment, surface treatment, and joining and fastening.	[21,46]

Table 1. *Cont.*

Symbol	Attributes	Description	References
A14	Production policies	It involves production philosophies and production equipment. Production philosophies include group technology, just-in-time, material resource planning (MRP), MRPII, enterprise resource planning, supply chain management, the theory of constraints, lean manufacturing, agile manufacturing, Six Sigma, Kaizen, and computer-integrated manufacturing. Production equipment contains input, process, and output.	[21,47]
A15	Assembly systems	It contains assembly systems with stationary parts and moving parts.	[21,48]
A16	Packaging and dispatch	Packaging comprises smart packaging, robotic arms, 3D printing, and fiber-based materials. Dispatch contains dispatch automation, intelligent route planning, and real-time delivery tracking.	[49,50]
A17	Logistics distribution	It covers the technologies that modify the distribution industry, such as the cloud, machine learning, artificial intelligence, digital assistants, and online bots.	[51,52]
A18	Client attraction and retention	It entails customer service analytics, chatbots, voice of the customer solutions, virtual customer assistants, and customer engagement hubs.	[53,54]
A19	Reuse/recycle/disposals	The following terminologies include turning waste into energy, new ways to recycle precious metals, advances in route efficiency, and new collection and disposal technology.	[55,56]
A20	Personalized customization	It belongs to the configuration of personalized orders, personalized products customized by customers, and precision marketing.	[57,58]
A21	Flexible manufacturing	It contains the flexible layout of production resources, order batch optimization, and scheduling for personalized orders.	[59,60]

2.4. Case Study

A new model factory representing small and medium enterprises (SME) is going to be established at XYZ Institute. It is mandatory to analyze the important factors for its development; that is why it is selected as a case study. All the machines available in SME are shown in Figure 9. These machines are used for additive and subtractive manufacturing. The 3D environment of the SME created on the Coppelia sim is shown in Figure 10.

Related Attributes

An attribute is a factor used as an evaluation criterion to implement smart manufacturing. It may be hardware, software, or a network. The attributes related to the case study that were collected from literature are given in Table 1 with their descriptions.

Figure 9. (**a**) CNC milling 1; (**b**) CNC milling 2; (**c**) CNC turning; (**d**) universal tensile testing machine; (**e**) FMC indigenous; (**f**) FMC retrofitted; (**g**) pneumatic jet printer; (**h**) automated guided vehicle (Cobot); (**i**) precision router; (**j**) selective laser sintering 3D printer; (**k**) binder jet; (**l**) 3D laser scanner; (**m**) five axis CNC milling machine; (**n**) electro-hydrodynamic jet printer; and (**o**) coordinate measuring machine.

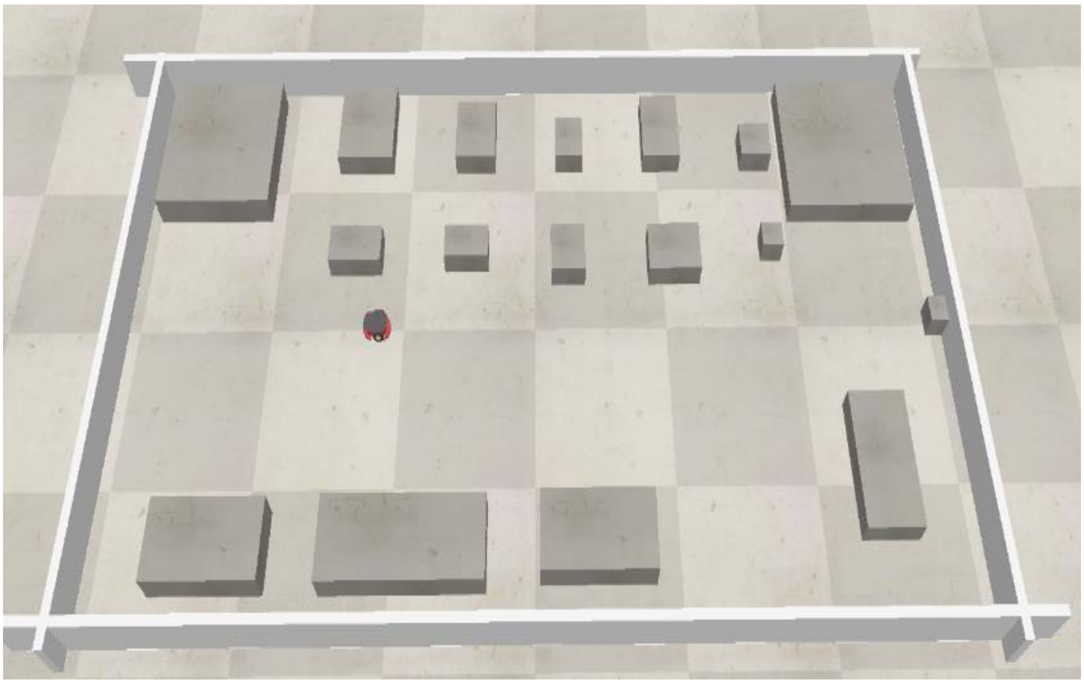

Figure 10. 3D environment of SME created on Copellia sim.

2.5. Fuzzy DEMATEL

Many methods can be used to detect the significant factors for the system under consideration, such as the technique for order preference by similarity to an ideal solution (TOPSIS) [61], the Analytic Hierarchy Process (AHP) [62] approach, and structural equation modeling (SEM) [63]. TOPSIS and AHP cannot be used for interrelationships among attributes. Under the given conditions and existing models, DEMATEL is better than SEM because data collection takes place from limited respondents. It also saves labor and time while collecting data. It covers all the possible interdependence relations between the attributes to improve decision-making [64]. After analyzing these limitations, it is concluded that fuzzy DEMATEL is the appropriate technique to explore the critical factors for the system under consideration. It uses matrix tools and graph theory to solve complex problems. It is also helpful to determine the causality and mutual relationships among factors. It can also be used for small sample sizes [65]. This paper uses the fuzzy DEMATEL approach to get the significant attributes and their interdependence relationships for small and medium enterprises. All the steps included in it are shown in Figure 11.

Step 1: A sample questionnaire with square matrices is prepared for elaborating on the relationship and significance among factors.

Step 2: Experts from the relevant fields are selected to fill out the questionnaire using the fuzzy linguistic scale as given in Table 2.

Table 2. Details about decision-making experts.

Teams	No. of Experts	Job Field	Experience (Years)	Education Level
Team 1	6	Professor	>8	Doctorate
Team 2	8	Assistant Professor	>3	Doctorate
Team 3	3	Owner	>10	Bachelor
Team 4	2	Lecturer	>4	Masters
Team 5	2	PhD Scholar	>2	Masters

Figure 11. Steps involved in the fuzzy DEMATEL technique.

Step 3: An initial direct matrix is obtained by transferring the linguistic variables into triangular fuzzy numbers (TFN). Suppose 'X' represents the universe of discourse. The equations can be developed as follows:

$$\widetilde{X}^k = \left[\widetilde{X}^k_{ij}\right]_{n \times n} k = 1, 2, \ldots, m \tag{1}$$

where 'k' denotes the number of experts, 'i' is the attribute taking the 'j' perception rating, and 'n' is the number of attributes. Each element in the matrix is given as

$$\widetilde{X}^k_{ij} = \left(l^k_{ij}, m^k_{ij}, u^k_{ij}\right) \tag{2}$$

where l, m, and u represents the left (lower), middle (medium) and right (upper) values of TFN, respectively.

Step 4: Normalize the triangular fuzzy numbers using the equation below:

$$xa^k_{1ij} = \frac{\left(a^k_{1ij} - mina^k_{1ij}\right)}{\Delta^{max}_{min}} \tag{3}$$

$$xa^k_{2ij} = \frac{\left(a^k_{2ij} - mina^k_{2ij}\right)}{\Delta^{max}_{min}} \tag{4}$$

$$xa_{3ij}^{k} = \frac{\left(a_{3ij}^{k} - mina_{3ij}^{k}\right)}{\Delta_{min}^{max}} \tag{5}$$

where $\Delta_{min}^{max} = maxr_{ij}^{n} - minl_{ij}^{n}$, $a_1, a_2,$ and a_3 are real numbers and $a_1 \leq a_2 \leq a_3$.

Step 5: Compute normalized (right and left) values using the equation below:

$$xls_{ij}^{k} = \frac{xa_{2ij}^{k}}{\left(1 + xa_{2ij}^{k} - xa_{1ij}^{k}\right)} \tag{6}$$

$$xrs_{ij}^{k} = \frac{xa_{3ij}^{k}}{\left(1 + xa_{3ij}^{n} - xal_{2ij}^{k}\right)} \tag{7}$$

where (rs) and (ls) are right and left normalized values, respectively.

Step 6: Acquire the crisp values using:

$$x_{ij}^{k} = \frac{\left[xls_{ij}^{k}\left(1 - xls_{ij}^{k}\right) + xrs_{ij}^{k} \times xrs_{ij}^{n}\right]}{\left(1 - xls_{ij}^{k} + xrs_{ij}^{k}\right)} \tag{8}$$

Step 7: Compute the total normalized crisp value using:

$$\widetilde{w}_{ij}^{k} = mina_{ij}^{n} + x_{ij}^{n}\Delta_{min}^{max} \tag{9}$$

where 'w' represents the weighted average fuzzy vector weights.

Step 8: Obtain the direct relation matrix by aggregating the normalized crisp values from all experts using:

$$\widetilde{w}_{ij}^{k} = 1/k\left(\widetilde{X}_{ij}^{1} + \widetilde{X}_{ij}^{2} + \ldots + \widetilde{X}_{ij}^{k}\right) \tag{10}$$

Step 9: Compute the normalized direct matrix (O) using:

$$O = P \times M \tag{11}$$

$$P = \frac{1}{\max\limits_{1 \leq i \leq n} \sum_{j=1}^{n} aij} \tag{12}$$

where M = respective normalized crisp value

Step 10: Establish an identity matrix (I) of the order 'n'.

Step 11: Employing the identity matrix (I) minus the normalized direct matrix (O)

$$E = I - O$$

Step 12: Inversing the matrix to get $(I - O)^{-1}$

Step 13: Total Relation Matrix (T):

Multiplying the $(I - O)^{-1}$ with the normalized direct matrix (O) to get the total relation matrix (T):

$$T = (I - O)^{-1} \times O \tag{13}$$

$$T = \left[t_{ij}\right]_{n \times n}, i, j = 1, 2, \ldots, n \tag{14}$$

where $\left[t_{ij}\right]$ denotes the degree to which 'i' affects 'j'.

Step 14: Calculation of 'D' and 'R' values:

Calculating 'D' and 'R' using the formulas given below:

$$\mathrm{D} = \left[\sum\nolimits_{i=1}^{n} \quad t_{ij}\right]_{1\times n} = [t_i]_{n\times 1} \tag{15}$$

$$\mathrm{R} = \left[\sum\nolimits_{j=1}^{n} \quad t_{ij}\right]_{1\times n} = [t_j]_{n\times 1} \tag{16}$$

where 'D' and 'R' denote the sum of rows and columns, respectively.

Step 15: Cause and effects diagram:

Computing the degree of importance (D + R) and the causal degree (D − R) to draw the causal coordinate diagram, representing cause and effects. The negative values of D − R represent effects, and the positive values represent causes.

Step 16: Conducting visual analysis:

Conducting visual analysis based on cause-and-effect diagrams to analyze significant factors. If the focus is on causal factors, then effects can be improved.

Step 17: Finding the threshold value from '*T*':

This step is related to finding the threshold value from the total relation matrix (*T*). It is basically the entire average value for the total relation matrix.

Step 18: Effective matrix:

With the help of the threshold value from the previous step, an effective matrix will be generated. If the corresponding value is greater than the threshold value, then the function keeps the original value; otherwise, it is replaced by a zero value.

Step 19: Identifying the effects:

This step is related to analyzing the relationship effects among all the factors. Those factors that have zero values have no relationship, and the factors with some values have a corresponding relationship.

Step 20: Identifying the degree of effects:

In this step, there will be categorization of effects by degree, with weak, medium, and strong effects, by setting the specific values for these zones.

Step 21: Mapping the arrows:

This step is related to mapping the arrows to generate the interdependence relationship among factors. The direction of the arrow should be considered here. The tail represents the effect of the corresponding factor, and the head represents the effect of the corresponding factor.

2.6. Application Procedure to Evaluate the Significant Attributes for Small and Medium Enterprises

The procedure to evaluate the significant attributes is shown in Figure 12. With the help of experts' opinions and a literature review, the following terminologies are selected: perspectives, aspects, and attributes for the smart manufacturing implementation system. After selecting the appropriate attributes, it is mandatory to implement those for small and medium enterprises discussed in the case study to analyze the significant attributes. Using the Delphi method, a group of 21 experts was selected for decision-making, as given in Table 2. Teams are made based on exception, experience, significance, and education. The next step is to make the questionnaire and hand it over to experts to evaluate the attributes using a fuzzy linguistic scale while considering the small and medium enterprises discussed in the case study. The fuzzy linguistic scale is tabulated in Table 3. After implementing the fuzzy DEMATEL technique, the total relation matrix (T) is computed using Equations (13) and (14), following step 13. It is tabulated in Table 4, which is the prerequisite to finding the effective matrix. The effective matrix (E) is computed using step 18, as given in Table 5; it gives the interdependence relationships among attributes. Centrality (D + R) and causality (D − R) can be calculated using Equations (15) and (16) and steps 14 and 15, respectively. Centrality and causality are given in Table 6. These are helpful in giving cause-and-effect factors.

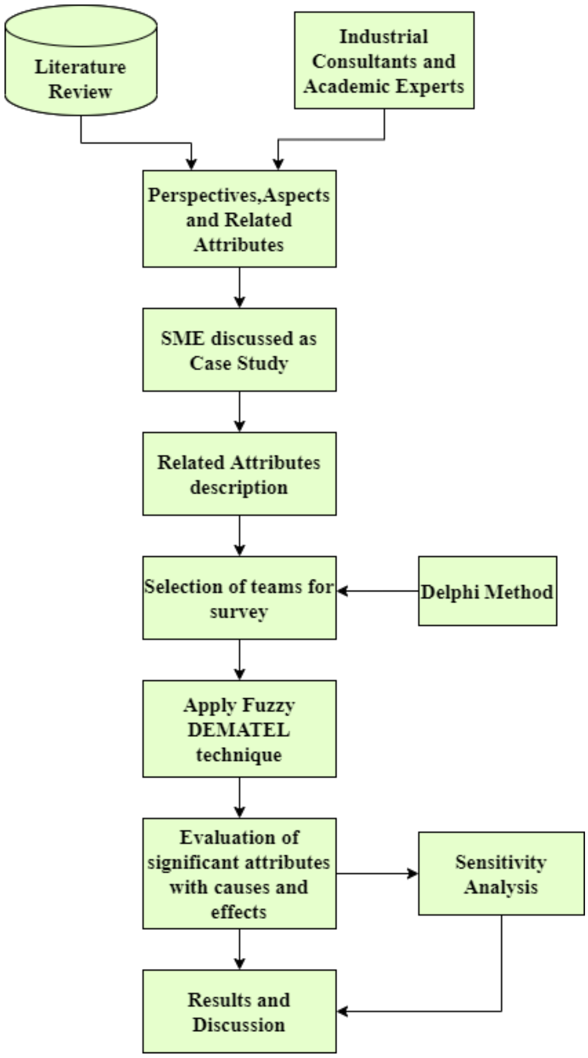

Figure 12. The framework of the proposed methodology to evaluate significant attributes.

Table 3. Fuzzy linguistic scale.

Linguistic Variable	Symbol	Corresponding Triangular Fuzzy Numbers
Almost no influence	NI	(0.0, 0.1, 0.3)
Very low influence	VLI	(0.1, 0.3, 0.5)
Influence	I	(0.3, 0.5, 0.7)
High influence	HI	(0.5, 0.7, 0.9)
Very high influence	VHI	(0.7, 0.9, 1.0)

Table 4. Total relation matrix (T).

	A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**	**A11**	**A12**	**A13**	**A14**	**A15**	**A16**	**A17**	**A18**	**A19**	**A20**	**A21**
A1	0.1218	0.0321	0.0667	0.1022	0.0982	0.0803	0.0464	0.0686	0.0908	0.0517	0.0419	0.0674	0.1077	0.1297	0.0707	0.0217	0.0248	0.0687	0.089	0.1233	0.1269
A2	0.0483	0.1038	0.0962	0.0379	0.0983	0.0642	0.0414	0.0371	0.0547	0.0375	0.1023	0.1060	0.0740	0.1123	0.0282	0.0269	0.0265	0.1294	0.009	0.1034	0.0920
A3	0.1458	0.0548	0.1602	0.1121	0.1488	0.1423	0.1442	0.1331	0.1533	0.1295	0.0706	0.1817	0.1686	0.1670	0.0950	0.1048	0.0796	0.1829	0.044	0.1764	0.1620
A4	0.1209	0.0367	0.0874	0.1165	0.1083	0.1184	0.1127	0.0452	0.1005	0.0612	0.0438	0.1206	0.1176	0.1111	0.0335	0.0269	0.0293	0.1089	0.007	0.1330	0.1089
A5	0.0954	0.0719	0.0952	0.0812	0.1385	0.1245	0.1030	0.0507	0.1388	0.0653	0.0537	0.1458	0.1258	0.1520	0.0357	0.0299	0.0328	0.1517	0.009	0.1288	0.1332
A6	0.0997	0.0433	0.1299	0.1002	0.1176	0.1365	0.0920	0.0537	0.1280	0.0852	0.0534	0.1523	0.1455	0.1400	0.0388	0.0349	0.0982	0.1426	0.011	0.1456	0.1360
A7	0.0856	0.0538	0.0599	0.0414	0.0878	0.0521	0.1230	0.1111	0.1325	0.0902	0.0536	0.1383	0.0994	0.1285	0.0782	0.0284	0.0292	0.1422	0.008	0.1349	0.1387
A8	0.0479	0.0347	0.0925	0.0347	0.0478	0.0426	0.1073	0.1129	0.1043	0.0413	0.0902	0.1247	0.1036	0.1108	0.0301	0.0266	0.0238	0.0658	0.008	0.1186	0.0626
A9	0.0638	0.0349	0.0493	0.0361	0.0645	0.0450	0.0917	0.0900	0.1294	0.0540	0.0916	0.1246	0.0748	0.1156	0.0300	0.0260	0.0254	0.1140	0.008	0.1211	0.1108
A10	0.0597	0.0282	0.1070	0.0326	0.0459	0.0411	0.0902	0.0429	0.1023	0.1077	0.0379	0.1090	0.0548	0.0931	0.0587	0.0579	0.0583	0.1143	0.008	0.1033	0.1076
A11	0.1456	0.1183	0.1375	0.1118	0.1358	0.1277	0.1269	0.1177	0.1495	0.1132	0.1426	0.1657	0.1528	0.1671	0.0945	0.0905	0.0955	0.1850	0.045	0.1758	0.1609
A12	0.1359	0.1217	0.1426	0.1152	0.1397	0.1313	0.1326	0.1366	0.1718	0.1323	0.1396	0.1968	0.1721	0.1875	0.0964	0.0923	0.0816	0.1767	0.092	0.1687	0.1813
A13	0.1204	0.1104	0.1218	0.1050	0.1247	0.1191	0.0639	0.0555	0.1308	0.0864	0.1068	0.1547	0.1575	0.1470	0.0413	0.0369	0.0386	0.1471	0.012	0.1522	0.1567
A14	0.1158	0.0611	0.1000	0.0845	0.1022	0.0968	0.0912	0.0847	0.1275	0.0837	0.1185	0.1340	0.1444	0.1645	0.0398	0.0346	0.0356	0.1546	0.011	0.1478	0.1366
A15	0.0337	0.0396	0.0667	0.0249	0.0360	0.0325	0.0636	0.0630	0.0564	0.0282	0.0619	0.0935	0.0430	0.0489	0.0901	0.0211	0.0518	0.0974	0.007	0.0881	0.0757
A16	0.0338	0.0409	0.0528	0.0248	0.0363	0.0324	0.0653	0.0638	0.0748	0.0453	0.0483	0.1131	0.0600	0.0512	0.0231	0.0923	0.0852	0.1010	0.007	0.0904	0.0624
A17	0.0258	0.0190	0.0439	0.0201	0.0280	0.0259	0.0399	0.0386	0.0480	0.0376	0.0249	0.0988	0.0656	0.0541	0.0179	0.0309	0.0856	0.1011	0.020	0.0464	0.0369
A18	0.0631	0.0312	0.0791	0.0530	0.0962	0.0943	0.0407	0.0351	0.0705	0.0356	0.0535	0.0623	0.1050	0.1255	0.0545	0.0380	0.0417	0.1369	0.007	0.1180	0.1081
A19	0.0347	0.0406	0.0662	0.0265	0.0347	0.0319	0.0453	0.0601	0.0401	0.0273	0.0629	0.0760	0.0893	0.0933	0.0186	0.0178	0.0169	0.0461	0.077	0.0699	0.0741
A20	0.1203	0.1109	0.1257	0.0730	0.1249	0.1180	0.0984	0.0907	0.1206	0.1044	0.1240	0.1188	0.1382	0.1654	0.0581	0.1005	0.0748	0.1706	0.012	0.1643	0.1600
A21	0.1376	0.0793	0.1245	0.1069	0.1263	0.1205	0.0852	0.1081	0.1524	0.0735	0.0949	0.1633	0.1420	0.1684	0.0570	0.0522	0.0706	0.1666	0.027	0.1463	0.1696

Table 5. Effective matrix (E).

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21
A1	0.122	0.000	0.000	0.102	0.098	0.000	0.000	0.000	0.091	0.000	0.000	0.000	0.108	0.130	0.000	0.000	0.000	0.000	0.089	0.123	0.127
A2	0.000	0.104	0.096	0.000	0.097	0.000	0.000	0.000	0.000	0.000	0.102	0.106	0.000	0.112	0.000	0.000	0.000	0.129	0.000	0.103	0.092
A3	0.146	0.000	0.160	0.112	0.149	0.142	0.144	0.133	0.153	0.130	0.000	0.182	0.169	0.167	0.095	0.105	0.000	0.183	0.000	0.176	0.162
A4	0.121	0.000	0.087	0.116	0.108	0.118	0.113	0.000	0.100	0.000	0.000	0.121	0.118	0.111	0.000	0.000	0.000	0.109	0.000	0.133	0.109
A5	0.095	0.000	0.095	0.000	0.138	0.125	0.103	0.000	0.139	0.000	0.000	0.146	0.126	0.152	0.000	0.000	0.000	0.152	0.000	0.129	0.133
A6	0.100	0.000	0.130	0.100	0.118	0.137	0.092	0.000	0.128	0.000	0.000	0.152	0.146	0.140	0.000	0.000	0.098	0.143	0.000	0.146	0.136
A7	0.000	0.000	0.000	0.000	0.088	0.000	0.123	0.111	0.132	0.090	0.000	0.138	0.099	0.129	0.000	0.000	0.000	0.142	0.000	0.135	0.139
A8	0.000	0.000	0.093	0.000	0.000	0.000	0.107	0.113	0.104	0.000	0.090	0.125	0.104	0.111	0.000	0.000	0.000	0.000	0.000	0.119	0.000
A9	0.000	0.000	0.000	0.000	0.000	0.000	0.092	0.090	0.129	0.000	0.092	0.126	0.000	0.116	0.000	0.000	0.000	0.114	0.000	0.121	0.111
A10	0.000	0.000	0.107	0.000	0.000	0.000	0.090	0.000	0.102	0.108	0.000	0.109	0.000	0.093	0.000	0.000	0.000	0.115	0.000	0.103	0.108
A11	0.146	0.118	0.137	0.112	0.136	0.128	0.127	0.118	0.150	0.113	0.143	0.166	0.153	0.167	0.094	0.091	0.096	0.185	0.000	0.176	0.161
A12	0.136	0.122	0.143	0.115	0.140	0.131	0.133	0.137	0.172	0.132	0.140	0.197	0.172	0.188	0.096	0.092	0.000	0.177	0.092	0.169	0.181
A13	0.120	0.110	0.122	0.105	0.125	0.119	0.000	0.000	0.131	0.000	0.107	0.155	0.157	0.147	0.000	0.000	0.000	0.147	0.000	0.152	0.157
A14	0.116	0.000	0.100	0.000	0.102	0.097	0.091	0.000	0.128	0.000	0.119	0.134	0.144	0.164	0.000	0.000	0.000	0.155	0.000	0.148	0.137
A15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.093	0.000	0.000	0.090	0.000	0.000	0.097	0.000	0.088	0.000
A16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.113	0.000	0.000	0.000	0.093	0.000	0.101	0.000	0.090	0.000
A17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.099	0.000	0.000	0.000	0.000	0.000	0.102	0.000	0.000	0.000
A18	0.000	0.000	0.000	0.000	0.096	0.094	0.000	0.000	0.000	0.000	0.000	0.000	0.105	0.126	0.000	0.000	0.000	0.137	0.000	0.118	0.108
A19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.089	0.093	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A20	0.120	0.111	0.126	0.000	0.125	0.118	0.098	0.091	0.121	0.104	0.124	0.119	0.138	0.165	0.000	0.100	0.000	0.171	0.000	0.164	0.160
A21	0.138	0.000	0.124	0.107	0.126	0.121	0.000	0.108	0.152	0.000	0.095	0.163	0.142	0.168	0.000	0.000	0.000	0.167	0.000	0.146	0.170

Table 6. Centrality and causality.

Attributes	D	R	D + R	D − R
A1	1.5482	1.8556	3.4037	−0.3074
A2	1.4298	1.2673	2.6971	0.1626
A3	2.7568	2.0051	4.7619	0.7517
A4	1.7490	1.4405	3.1895	0.3085
A5	1.9632	1.9405	3.9037	0.0228
A6	2.0849	1.7774	3.8622	0.3075
A7	1.8169	1.8049	3.6218	0.0119
A8	1.4316	1.5993	3.0309	−0.1677
A9	1.5010	2.2770	3.7780	−0.7761
A10	1.4610	1.4912	2.9521	−0.0302
A11	2.7598	1.6169	4.3768	1.1429
A12	2.8833	2.6475	5.5309	0.2358
A13	2.1890	2.3417	4.5307	−0.1527
A14	2.0691	2.6332	4.7023	−0.5642
A15	1.1233	1.0901	2.2134	0.0332
A16	1.2043	0.9913	2.1957	0.2130
A17	0.9095	1.1059	2.0155	−0.1964
A18	1.4495	2.7030	4.1526	−1.2535
A19	1.0497	0.3816	1.4312	0.6681
A20	2.3744	2.6560	5.0304	−0.2816
A21	2.3727	2.5008	4.8735	−0.1281

3. Results and Discussion

Figure 13 shows the causal coordinate diagram of different attributes resulting from the fuzzy DEMATEL technique. It has centrality (D + R) as abscissa and degree (D − R) as ordinate, capturing the data from Table 6. When we move from left to right in the abscissa, the greater values of attributes show a high significance for the whole system, and vice versa. The ordinate divides into two portions: one for the positive values related to impact intensity affecting other factors; the attributes in this portion are called causes; and the second portion denotes the negative values related to impact intensity influenced by other factors; the attributes in this portion are called effects. As we move upward in the positive direction, the corresponding attribute has a higher impact on other attributes. As we move downward in the negative direction, other attributes will have a greater influence on the corresponding attribute.

Twenty-one attributes are divided into four regions by three horizontal and vertical lines, each based on the minimum, average, and maximum values of centrality and cause degree, as shown in Figure 13. The description and corresponding attributes of each region are listed in Table 7. Region 1 has a high significance for the whole system, a high intensity of affecting other attributes, and a low degree of influence by other attributes. The attributes in this region are A11, A3, A6, A12, A7, and A5. Region 2 has a low significance for the whole system, a high intensity of affecting other attributes, and a low degree of influence by other attributes. The attributes in this region are A19, A16, A2, A4, and A15. Region 3 has a high significance for the whole system, a low intensity of affecting other attributes, and a high degree of influence by other attributes. The attributes in this region are A13, A21, A20, A14, A9, and A18. Region 4 has a low significance for the whole system, a low intensity of affecting other attributes, and a high degree of influence by other attributes. The attributes in this region are A10, A17, A8, and A1.

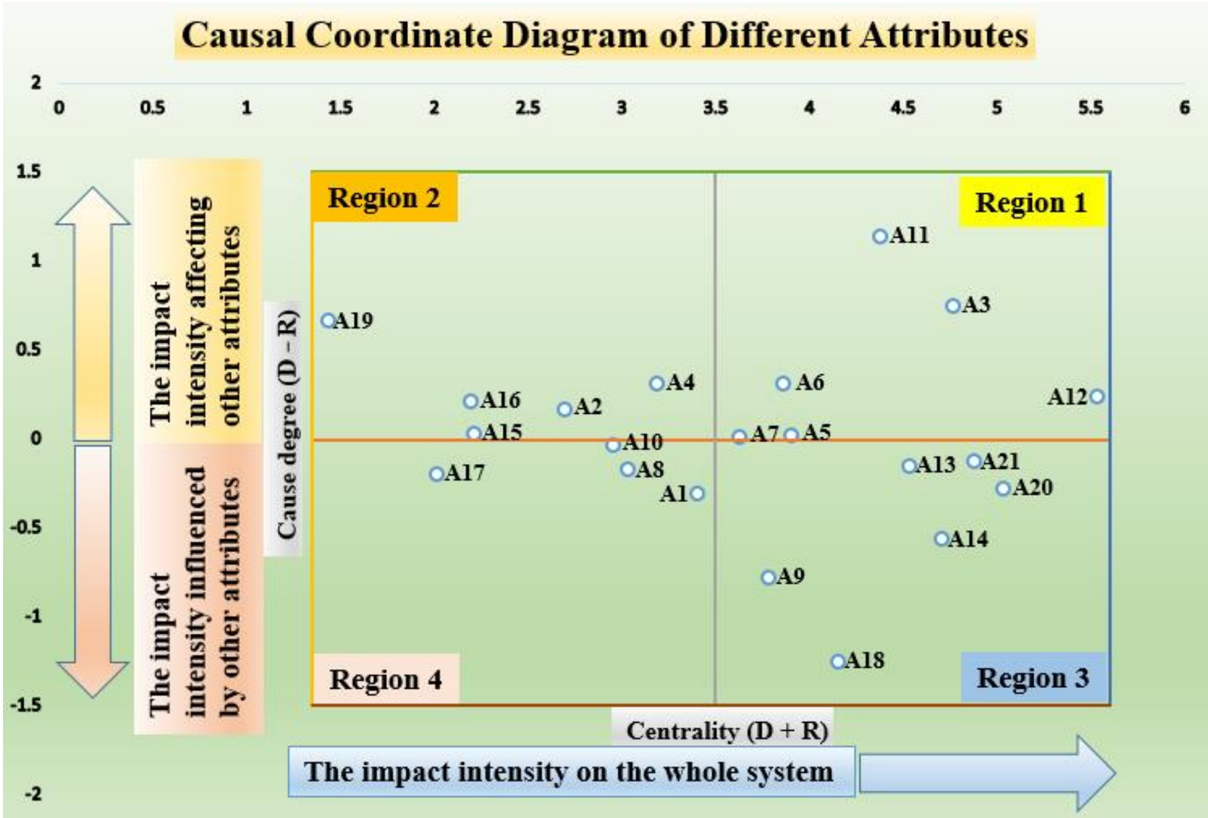

Figure 13. Causal coordinate diagram. The corresponding attributes "A1–A21" are defined in Table 1.

Table 7. Attributes divided into four regions with their significance.

Region No	Description	Attributes
Region 1	• The impact intensity on the whole system: High • The impact intensity affecting other attributes: High • The impact intensity influenced by other attributes: Low	**A11:** Design documentation **A3:** Intelligent management of SMEs **A6:** Visualization and monitoring of logistics and production **A12:** Flow of information, energy, and materials **A7:** Management platform and data acquisition for equipment **A5:** Visualization of quality and process
Region 2	• The impact intensity on the whole system: Low • The impact intensity affecting other attributes: High • The impact intensity influenced by other attributes: Low	**A19:** Reuse/recycle/disposals **A16:** Packaging and dispatch **A2:** Simulation and digital design **A4:** Visualization of energy and equipment **A15:** Assembly systems

Table 7. *Cont.*

Region No	Description	Attributes
Region 3	• The impact intensity on the whole system: High • The impact intensity affecting other attributes: Low • The impact intensity influenced by other attributes: High	**A13:** Manufacturing systems **A21:** Flexible manufacturing **A20:** Personalized customization **A14:** Production policies **A9:** Information system integration for process layer **A18:** Client attraction and retention
Region 4	• The impact intensity on the whole system: Low • The impact intensity affecting other attributes: Low • The impact intensity influenced by other attributes: High	**A10:** Information system integration for enterprise layer **A17:** Logistic distribution **A8:** Management platform for AR data **A1:** Machine tools and robots

Among all the regions, the most significant attributes lie in Region 1, as it has the best impact compared to other regions. Hence, the attributes in Region 1 show the highest impact in the SME establishment and development process, so these attributes need to be focused on. All the attributes in Region 1 have the following reasons to be selected: Intelligent management of enterprises (A3) entails all the managerial aspects, including sales, material, production, and financial; these aspects need to be considered in the development of small and medium enterprises, which is why A3 lies in Region 1. Design documentation (A11) covers the establishment of need with costing and specification aspects, concept, detail, and embodiment design. These aspects play a prominent role in the establishment of any firm. These are needed as input for all the required output included in the literature. Therefore, A11 lies in region 1. The flow of information, energy, and materials (A12) contains all the essential things that are needed as input for all the required outputs included in the literature. Hence, A12 lies in Region 1 and has the highest impact on the whole system compared to all other attributes. Visualization of quality and process (A5) comprises the factors like scrap rate, feed inspection visualization, SPC charts and X-R charts. These factors play a prominent role in improving quality control and quality assurance. Due to these reasons, A5 lies in Region 1. Visualization and monitoring of the production(A6) and logistics involve visualization of the work order process, work in process inventory and monitoring, such as production line, delivery working, etc. Any changes can be diagnosed accordingly to prevent the bigger loss at a later stage. Hence, A6 lies in Region 1. Management platform and data acquisition for equipment cover the enterprise intranet and online acquisition of device data based on the cloud platform. It helps to remotely access the devices, thus enabling the internet of things and smart manufacturing. Using data as input, cyber security measures can be further implemented to promote secure smart manufacturing. Based on these reasons, A7 lies in Region 1.

Figure 14 and Table 5 help to describe the interdependence relationship among attributes in terms of weak, medium, and strong relationships. To develop the interdependence relationships among the attributes, the threshold value is 0.0865, calculated from the total relation matrix (T) given in Table 4, using step 17 of the fuzzy DEMATEL technique. Based on this, the effective matrix can be generated by considering those values from the 'T' matrix higher than the threshold value; lower values become zero, as given in Table 5. From the effective matrix, the range of weak, medium, and strong relationship zones can be derived: the range of the weak relationship zone is 0.087 to 0.125, the range of the medium relationship zone lies between 0.126 and 0.161, and for the strong relationship zone, the range is 0.162 to 0.197. The zero value means there is no relationship. In Figure 14, the black line arrow shows the weak relation, the red line arrow shows the medium relation, and the blue line arrow shows the strong relation. A11 is selected as an example to understand the concept and describe its relationships with three different attributes having values in weak, medium, and strong zones. The value of A11 corresponding to A2 is 0.118, as given in Table 5; it lies in the weak relation zone; hence, A11 shows the black line arrow pointing towards A2 to represent the weak relation. The value of A11 corresponding to A9 is 0.150 as given in Table 5; it lies in the medium relation zone; hence, A11 shows the red line arrow directing towards A9 to represent the medium relationship. The value of A11 corresponding to A14 is 0.167 as given in the table; it lies in the strong relation zone; hence, A11 points the blue line arrow towards A14 to represent the strong relation. Similarly, A11 has a weak relationship with A4, A8, A10, A15, A16, and A17; a medium relationship with A1, A3, A5, A6, A7, A13, and A21; a strong relationship with A12, A18, and A20; and no relationship with A19. Likewise, the relationships among other attributes can be analyzed. Those attributes that have more relationships and associations with other attributes significantly impact the whole system.

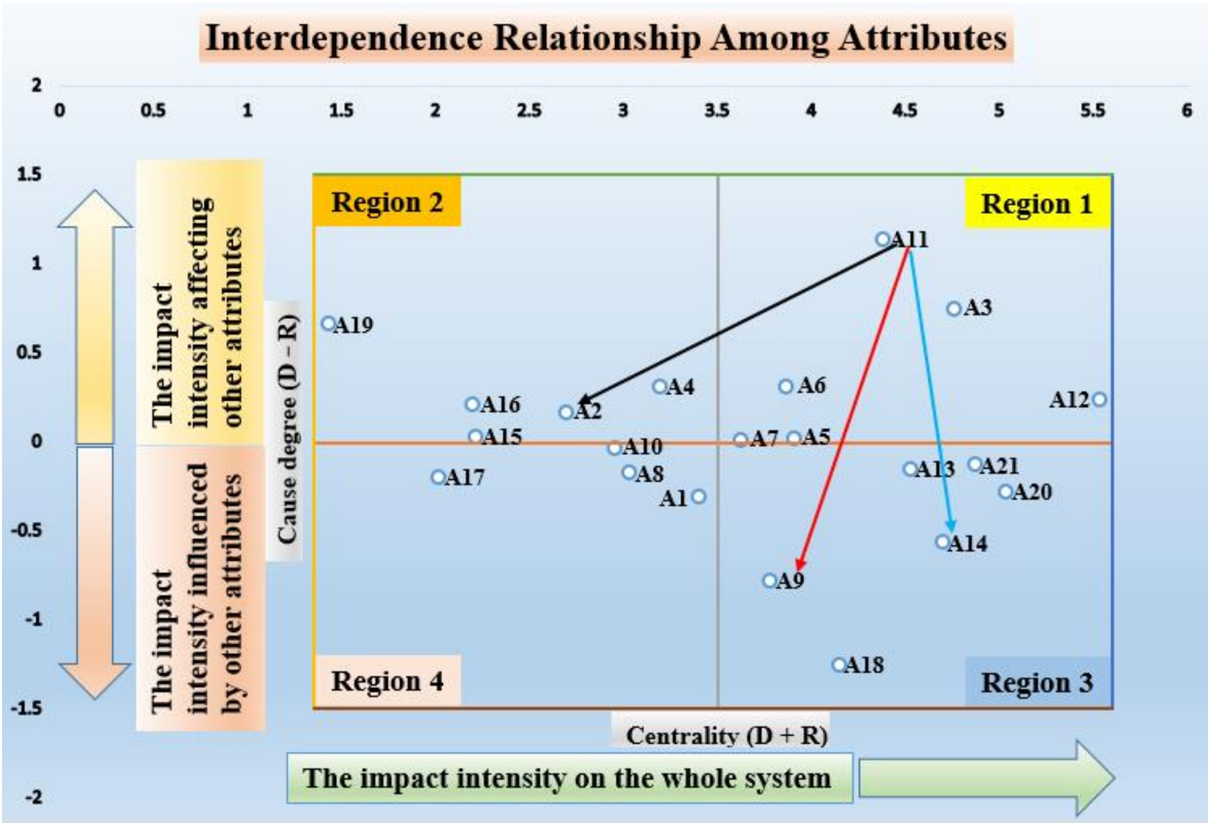

Figure 14. Interdependence relationship between attributes.

Since the number of interdependence relationships among the attributes is very large, it is complicated to represent all the interdependence relationships in one diagram. Therefore, it is divided into three groups: one shows the interdependence relationships among effects as depicted in Figure 15, the second describes the interdependence relationships among causes as shown in Figure 16, and the third gives the interdependence relationships between causes and effects as shown in Figure 17, by pointing the arrows in black, red, and blue colors to describe their interdependence relationship nature correspondingly. Figure 15 shows that the attributes with a high impact on the system have more connections. It can be seen from the figure that the attributes A20, A21, A13, and A14 have more connections as compared to other ones because of the high impact intensity on the whole system. Figure 16 also shows the same trend as the effects group: the attributes with high impact intensity on the system have more connections, such as A12, A3, and A11, than other attributes in this group. Figure 17 shows the interdependence relationships between causes and effects; it also follows the same logic: the attributes A12, A3, A11, A20, A21, A13, and A14 have more connections than other attributes.

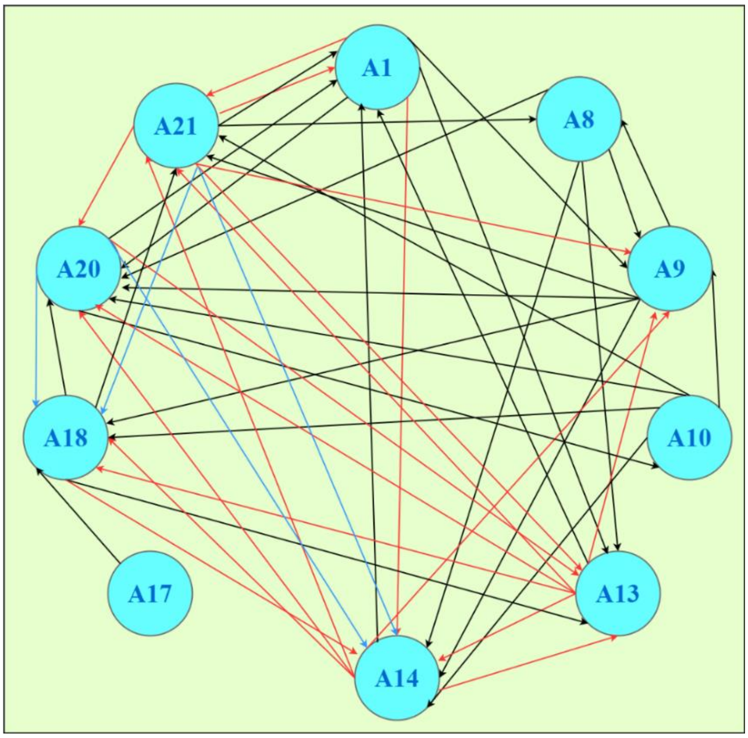

Figure 15. Interdependence relationship between effects.

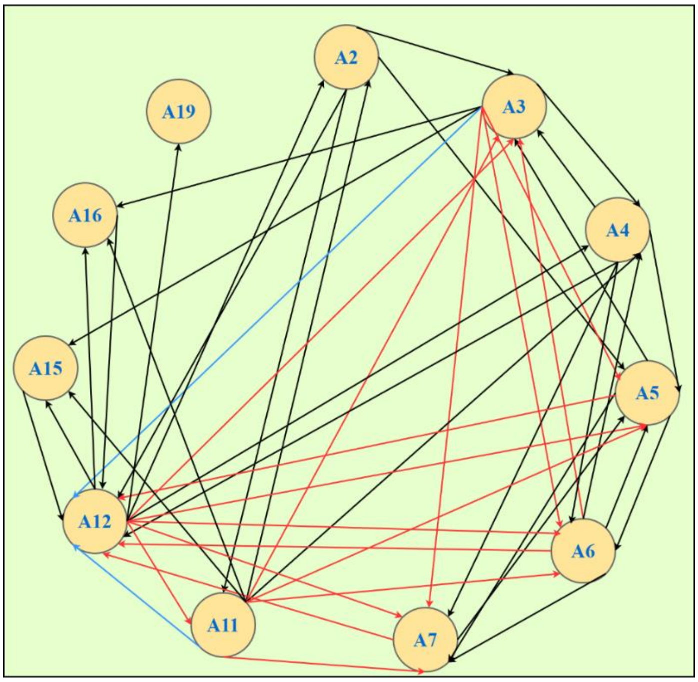

Figure 16. Interdependence relationship between causes.

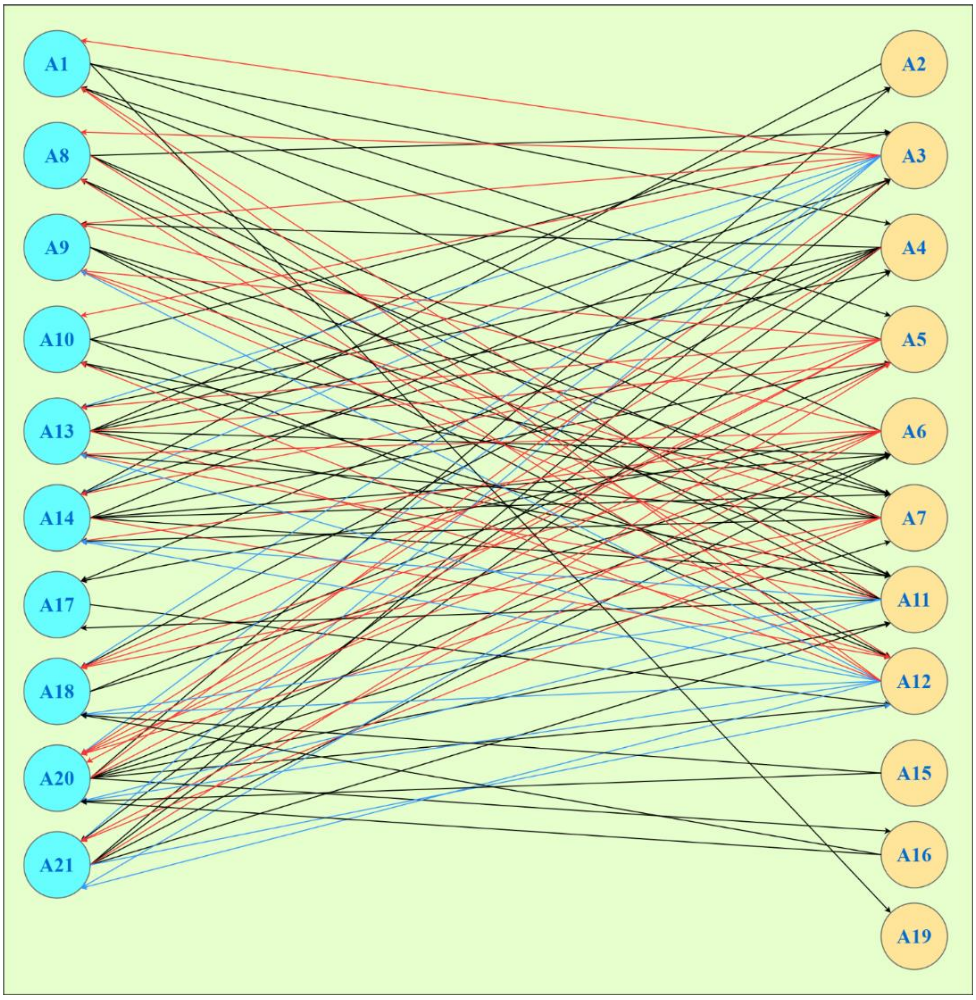

Figure 17. Interdependence relationship between causes and effects.

Sensitivity Analysis

Sensitivity analysis is performed to check the validity, reliability, and robustness of the results deduced by the experts. It is conducted by assigning different weights to the teams. Table 8 shows that equal weights are assigned to each team in Evaluation 1 to get the actual results. The weight of each team varies according to experience, education, significance, and job responsibilities. Teams 1, 2, and 3 are assigned higher weights than other teams as they have more experience, education, and significance. As tabulated in Table 9, five cases are evaluated by assigning different weights to the teams. The D + R and D − R values obtained in each evaluation is given accordingly. These values are plotted in Figure 18 for five evaluations. It can be seen that the results are close to the original value and do not show a significant variation; hence, the significant attributes, causes, and effects remain the same under the variation of weights. Thus, sensitivity analysis has shown robust, reliable, and valid results that prove the fidelity of the decision made by the experts. It is concluded that there is no major bias in the teams' opinions, and the experts' understanding of the attributes is adequate for the study.

Table 8. Different weights assigned to teams in the sensitivity analysis.

Teams	Evaluation 1	Evaluation 2	Evaluation 3	Evaluation 4	Evaluation 5
Team 1	0.3	0.5	0.5	0.5	0.45
Team 2	0.3	0.4	0.45	0.4	0.4
Team 3	0.3	0.17	0.17	0.3	0.35
Team 4	0.3	0.06	0.06	0.06	0.06
Team 5	0.3	0.2	0.06	0.06	0.06

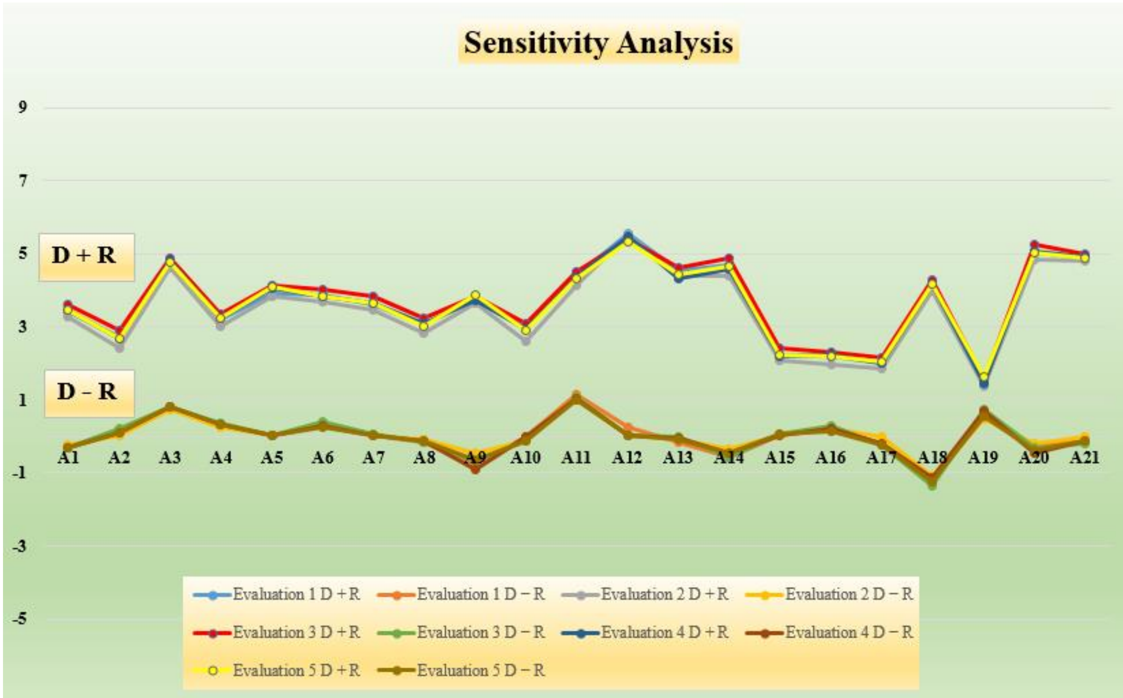

Figure 18. Centrality and causality of different evaluations.

Table 9. Centrality and causality obtained from sensitivity analysis.

Attributes	Evaluation 1		Evaluation 2		Evaluation 3		Evaluation 4		Evaluation 5	
	D + R	D − R	D + R	D − R	D + R	D − R	D + R	D − R	D + R	D − R
A1	3.4037	−0.3074	3.2626	−0.2364	3.6039	−0.3271	3.4409	−0.3012	3.4399	−0.3214
A2	2.6971	0.1626	2.4214	0.0222	2.9065	0.2203	2.6872	0.1113	2.6765	0.0893
A3	4.7619	0.7517	4.6009	0.7311	4.8641	0.8013	4.7865	0.7912	4.7811	0.7919
A4	3.1895	0.3085	3.006	0.2481	3.3593	0.3481	3.2199	0.3082	3.2191	0.3165
A5	3.9037	0.0228	3.8492	0.0191	4.1332	0.0112	4.0631	0.0191	4.1055	0.0111
A6	3.8622	0.3075	3.6641	0.2965	4.0219	0.4072	3.8421	0.2983	3.8265	0.2455
A7	3.6218	0.0119	3.4519	0.0117	3.824	0.0441	3.6419	0.0323	3.6409	0.0323
A8	3.0309	−0.1677	2.8365	−0.0919	3.2355	−0.1671	3.0855	−0.1365	3.0245	−0.1213
A9	3.778	−0.7761	3.636	−0.4609	3.822	−0.676	3.716	−0.9081	3.8511	−0.6411

Table 9. *Cont.*

Attributes	Evaluation 1		Evaluation 2		Evaluation 3		Evaluation 4		Evaluation 5	
	D + R	**D − R**	**D + R**	**D − R**	**D + R**	**D − R**	**D + R**	**D − R**	**D + R**	**D − R**
A10	2.9521	−0.0302	2.5981	−0.1311	3.0992	−0.1319	2.9213	−0.0217	2.8861	−0.1109
A11	4.3768	1.1429	4.1328	1.0862	4.5067	1.0621	4.3465	1.0121	4.2983	1.0033
A12	5.5309	0.2358	5.5155	0.0123	5.4109	0.0119	5.4611	0.0355	5.3113	0.0332
A13	4.5307	−0.1527	4.3939	−0.08221	4.6055	−0.0121	4.3021	−0.0613	4.4218	−0.0971
A14	4.7023	−0.5642	4.3986	−0.3406	4.8765	−0.5841	4.5902	−0.4613	4.6506	−0.4459
A15	2.2134	0.0332	2.0755	0.0111	2.4177	0.0541	2.2012	0.0185	2.2412	0.0513
A16	2.1957	0.213	1.9467	0.192	2.3119	0.276	2.2123	0.217	2.1759	0.1331
A17	2.0155	−0.1964	1.8514	−0.01463	2.1513	−0.2467	2.0029	−0.1992	2.0391	−0.2339
A18	4.1526	−1.2535	3.9719	−1.1113	4.291	−1.3455	4.1783	−1.1513	4.1828	−1.2653
A19	1.4312	0.6681	1.3711	0.4592	1.5509	0.719	1.4565	0.6888	1.631	0.5538
A20	5.0304	−0.2816	4.8309	−0.1914	5.2337	−0.3213	5.0814	−0.4803	5.0173	−0.3937
A21	4.8735	−0.1281	4.8031	−0.0219	4.9711	−0.1911	4.9097	−0.1419	4.8905	−0.1414

4. Conclusions

Smart manufacturing has been the grooming field these days, as it is the vision of Industry 4.0. This study aims to provide the product life cycle chain extension for the new model factory, which covers all aspects from initial product design to recycling. It classifies new concepts and advanced technologies for smart manufacturing. Furthermore, a case study is discussed in which an SME is selected that is going to be established in the developing institute. It is necessary to analyze the significant attributes that must be focused on for its development and establishment. Twenty-one attributes are selected from the literature, and a survey is conducted to find the qualitative analysis. In order to quantify them, the fuzzy DEMATEL technique is used to find the significant attributes from the experts' opinions with cause-and-effect interdependence relationships. These attributes play a prominent role in the implementation of smart manufacturing for the concerned SME. The DEMATEL technique is used to describe a better knowledge of the impact of finding the cause-and-effect criteria and enhance the system's applicability. This technique is a vital tool and is widely used in all industrial sectors to tackle problems that require survey-type decision-making in a fuzzy environment. Under the given models and circumstances, this technique is better than AHP and SEM. The sensitivity analysis is also performed to check the fidelity of the decisions made by the experts. This study is also helpful for organizations establishing SMEs in the manufacturing sector to analyze their important attributes regarding SMIS. The proposed framework can be extended further to describe aspects of a new model factory for personalized customization. In addition, more attributes and experts can be discussed and evaluated.

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