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Enhancing the Competitiveness of manufacturers through Small-scale Intelligent Manufacturing System (SIMS): A Supply Chain Perspective

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***Abstract*—In order to survive in this competitive and ever changing market, manufacturers have to improve and enhance the competitiveness, flexibility, responsiveness and sustainability with the application of the cutting-edge technologies and innovative management methods. New concepts, i.e., Intelligent manufacturing, flexible manufacturing, agile manufacturing, network manufacturing, green manufacturing and Industry 4.0, etc., have been proposed and developed in recent years based upon the newest and most advanced manufacturing technologies and Information and Communication technologies (ICT). This paper presents a new concept: Small-scale Intelligent Manufacturing System (SIMS), and the comparison with previous concepts and the benefits of SIMS are discussed in this paper. Different from the previous research works which mainly emphasize the technological integration for improving the flexibility and intelligence of an individual manufacturing system, this paper, however, focuses on and discusses the supply chain problems arisen from a holistic perspective. The features of the supply chain for realizing small-scale intelligent production and responsive distribution are discussed, and the limitation and future works are also discussed and suggested latter in this paper.**

Keywords—Small-scale intelligent manufacturing system; flexible manufacturing; intelligent manufacturing; supply chain management; logistics; sustainable development

I. INTRODUCTION

Nowadays, with the rapid technological development, the product lifecycle is becoming increasingly shorter, and meanwhile, customers prefer to have more and more customized products than traditional standardized consumer products [1]. In order to respond with the customers' requirements for diverse and highly customized products, manufacturing companies have spent significant efforts on improving the flexibility, intelligence and responsiveness of their manufacturing systems, and due to this reason, the modern manufacturing systems are featured with highly agile [2, 3], flexible [4], intelligent [5, 6], interactive [7], networked [5, 8], environmentally sound [9, 10], as well as other characteristics. The comprehensive parameters including production cost, quality of product and service, delivery time, environmental influence, flexibility and responsiveness to the customer needs, and knowledge, etc., have become the most important determinants for the success of manufacturing companies in today's ever changing market [11].

Recently, the concept of Industry 4.0 has been introduced and widely used to depict the future manufacturing system with the help of the most advanced manufacturing technologies and Information and Communication Technologies (ICT). In Industry 4.0 era, different from today's standardized products or customized products with long production lead time and high cost, customers could order a highly customized product with acceptable price and fast delivery. In order to achieve this goal, a large number of literature has recently been published for developing conceptual models and application of highly intelligent, responsive, interactive, integrated and networked manufacturing system with the cutting-edge technologies, i.e., cyber-physical system (CPS) [12], internet of things (IoT) [13], big data [14], cloud computing [15], 3D printing and additive manufacturing [16-18], etc.

This paper presents a new concept: Small-scale Intelligent Manufacturing System (SIMS) which aims at improving the competitiveness and sustainability of the manufacturing companies in Industry 4.0 era. Different from the most previous research works which aims mainly at tackling the technological challenges [12-18], this paper, however, focuses on and discusses the supply chain problems arisen from a holistic perspective. The supply chain characteristics for realizing the small-scale intelligent production and responsive distribution are focused and summarized, and the limitation and future works are also discussed and suggested latter in this paper.

The reminder of this paper is organized as follows. Section 2 provides a brief introduction and relevant literature for the evolution and development of modern advanced manufacturing systems and the concept of Industry 4.0. Section 3 proposes the concept of Small-scale Intelligent Manufacturing System (SIMS), and the supply chain characteristics for implementing SIMS in order to improve the competitiveness and sustainability of the manufacturing companies are also discussed in this section. Section 4 gives the summary of this paper and also proposes the suggestions for future research.

II. DEVELOPMENT OF MODERN MANUFACTURING SYSTEM AND INDUSTRY 4.0

This section provides a brief overview of the development of modern advanced manufacturing system and the introduction of Industry 4.0. With the improvement of productivity since the Industrial Revolution from 1760s, the manufacturing industry has become increasingly important for improving people's lives and lifestyle by providing a large number and variety of manufactured products. Meanwhile, the manufacturing industry plays an extremely important role in determining the economic and social development of a country, and throughout the history since Industrial Revolution, the world's superpowers and biggest economies have risen with the boom of manufacturing industry, for instance, UK, Germany, USA and China. The evolution of manufacturing process has gone through different stages from the craft production at the early stage, and then mass production of standardized products for taking advantage of economy of scale, and towards the modern advanced manufacturing featured with mass customization and personalization [19]. Fig. 1 illustrates the development of modern advanced manufacturing system which significantly affects the advancement of relevant manufacturing technologies and management methods [20].

Before 1960s, the automation technologies and machineries were gradually introduced to the shop floors and manufacturing plants in order to replace the heavy manual works in manufacturing industry. With the transformation from labor-intensive craft manufacturing process to rigid automated production system, the production costs have been significantly reduced due to the economy of scale from mass production [19].

Between 1960s and 1980s, the manufacturers face more and more challenges from the customer requirements for not only standardized products but also customized products. In order to meet the customer needs, more and more advanced manufacturing technologies and management methods have been introduced in this period for improving the flexibility, responsiveness, effectiveness and efficiency of the manufacturing system. For example, computer-based technologies, i.e., computer-aided design and manufacturing (CAD/CAM) [21], virtual manufacturing (VM) [22], intelligent manufacturing (IM) [5], networked manufacturing [8], flexible manufacturing [4], etc., and advanced manufacturing planning and management methods, i.e., lean manufacturing [23], Just-in-Time (JIT) [24], total quality management (TQM) [23], material requirement planning (MRP) [25], etc. Those advanced manufacturing technologies and management methods helped to transform the manufacturing enterprises from mass production to mass customization in order to meet the customer needs through higher quality, flexibility and shorter lead time [20].

With the increased requirements for high customization and personalization from 1990s to 2010s, the modern advanced manufacturing system becomes more global, agile and integrated [26]. Three features are identified of the advanced manufacturing system in this period. First, the manufacturing system becomes much more intelligent enabling human-machine interaction and machine-machine interaction through the application of advanced ICT, i.e., cloud computing [15], IoT [13], CPS [12] and big data [14]. Second, the manufacturing process has been transformed from a pure product-oriented process to a product-service system, and the manufacturing enterprises provide services based on their products through the advanced system such as industrial production service system [27] and service-oriented manufacturing [28]. For example, when you buy an Iphone, you get not only a single smartphone, but also the access to App store and Itunes-U, from which you can download a great number of useful software, games and knowledge resources. Third, with the increased public concern for sustainable development, the environmental impact and sustainability issue of manufacturing process are focused in this period. Due to this reason, the reduction of environmental impacts through reverse logistics [29], green manufacturing process [9, 10], and green and holistic supply chain design and management [30, 31] have been extensively focused.

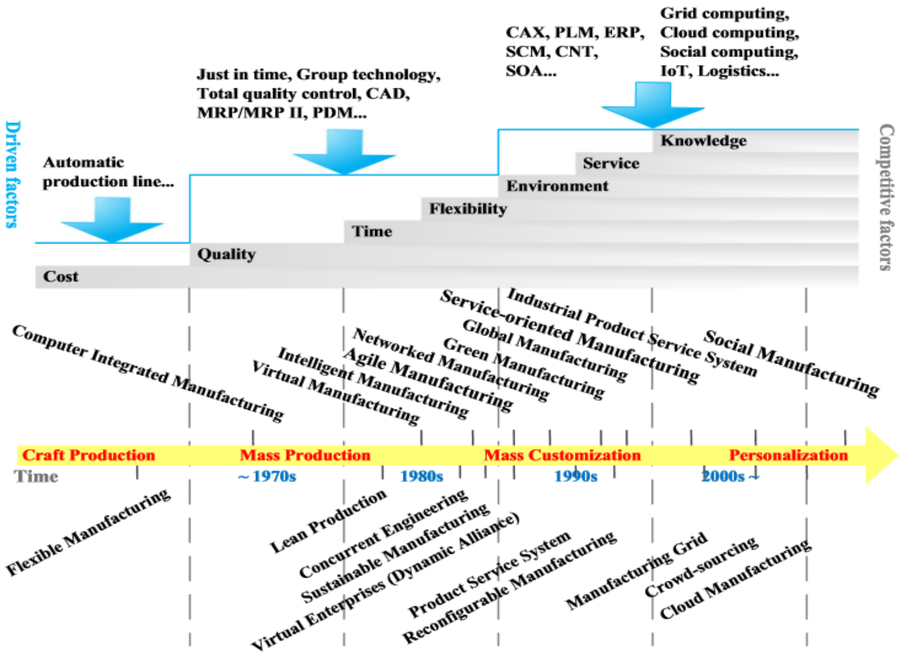

Fig. 1 Development of modern manufacturing systems [20].

Recently, the concept of Industry 4.0 or the 4th Industry Revolution has been introduced and extensively focused and discussed by both academicians and practitioners. The idea of Industry 4.0 is based upon the technological evolution and development of the manufacturing system. The 1st Industrial revolution is marked with the introduction of large machineries, water power and steam power. The 2nd Industrial revolution is featured with mass production and assembly, and the use of electricity. The 3rd Industrial revolution enables the flexible, reconfigurable and automated manufacturing process based on the use of computer aided technologies. Today, German academicians and practitioners first proposed the new concept of Industry 4.0 which leads the transformation of modern advanced manufacturing system towards CPS-enabled production and service innovation [32].

In the Industry 4.0 era, the human-machine interaction will be replaced by machine-machine interaction through CPS and machine learning, and the manufacturing system should be able to handle a large amount of data within a short time for decision-making. With the help of analytic tools for big data, intelligent machine learning and CPS-enabled network, the manufacturing system becomes more responsive to customer needs through the interpretation of big data and is more flexible and agile through the machine-machine interaction and communication under CPS-enabled network. In order to achieve this goal, a great number of researches have been published in the past three years tackling the technological challenges [12, 32-34], however, the discussion from the whole supply chain perspective addressing the challenges in Industry 4.0 era is still difficult to find. Due this reason, this papers aims at filling the literature gap by providing a discussion on the supply chain issues based on a new concept: Small-scale Intelligent Manufacturing System (SIMS).

III. Small-Scale Intelligent Manufacturing System (SIMS) and The Supply Chain

Previously, the definition of different manufacturing systems is given based upon the technological integration and communication of the production systems themselves, and the introduction of Industry 4.0 from most published literature is also given from the technological perspectives. However, the most important characteristic of the next generation manufacturing systems is to realize the value creation and value proposition through fulfilling the highly personalized customer demands with high responsiveness and low cost. With this point of view, we define the Small-scale Intelligent Manufacturing System (SIMS) in such a way: SIMS is an intelligent manufacturing system that, with the help of modern advanced manufacturing technologies, ICT and management methods, i.e., CPS, big data analytic tools, additive manufacturing, industrial internet, lean manufacturing, etc., enables rapid and customer-involved product design, rapid and small-scale production and timely delivery of highly customized and personalized products with relatively low cost.

In order to achieve this goal, not only the manufacturing process, but also the other processes within the supply chain, i.e., outsourcing, transportation and warehousing, etc., are involved, and the coordination and alignment of different players within the supply chain will eventually determine the cost, responsiveness and environmental impact of the whole process, which has significant influence on the customers' satisfaction. Even if the manufacturing process itself may be the most advanced, flexible and responsive unit, the inefficient operations of the other players in the supply chain may become the bottleneck that lengthens the total lead time from customer order to final delivery and increases the overall supply chain cost. One

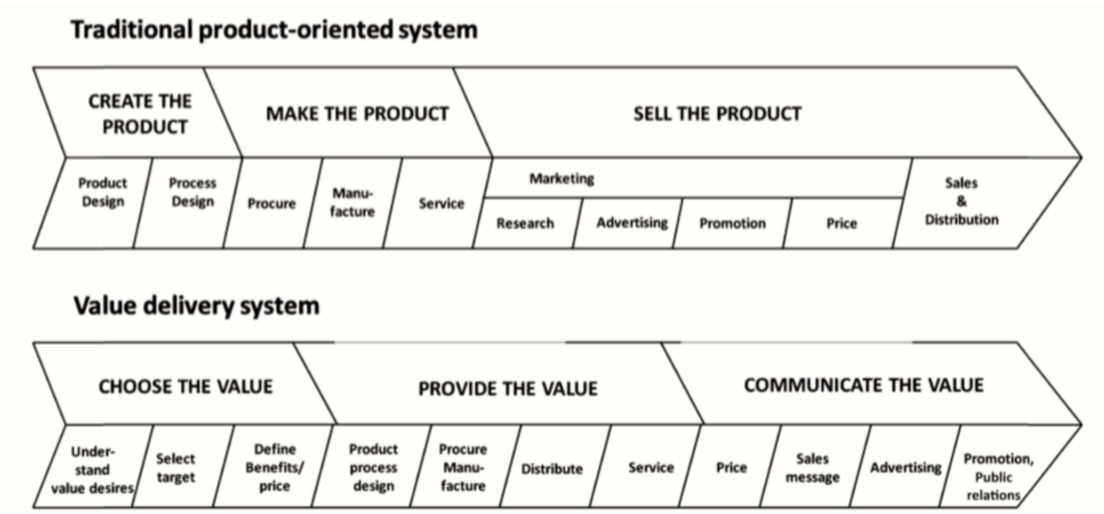

Fig. 2 The McKinsey framework of the value generation of traditional supply chains and demand-driven supply chains [36].

famous example is the Boeing Dreamliner project. Boeing is one of the most important airplane manufacturers in the world, and it provides a large variety of aircrafts for both commercial and military users. The latest Boeing 787 Dreamliner project was the most attractive one for the airline companies all over the world due to its higher fuel efficiency, and a lot of orders had been placed for purchasing the Dreamliner by several airline companies and new routes were planned using this new aircraft. The first delivery time was planned at 2007, however, with the project delay, the delivery was not made until 2011[35]. The delay has caused ripple effects on the planning and scheduling of the airline companies which had planned to operate the routine routes and open new routes using the Dreamliner, and this caused the loss of hundreds of million dollars of the airline companies.

Due to this reason, when we define SIMS, different from the previous literature which only focuses on the technological issues of an individual manufacturing process, a broader dissuasion from the supply chain management point of view is given in this paper. In order to make the manufacturing companies becoming more competitive and sustainable in Industry 4.0 era, the supply chain for implementing SIMS should have four characteristics: Demand-driven, servitization-based, highly intelligent, flexible and resource sharing, and sustainable, respectively.

A. SIMS-based demand-driven supply chain

In the past three decades, supply chain management has become the most popular topic among managers, business consultants and academicians in order to improve the profitability through fulfilling customer demands with lower cost and higher responsiveness. Traditionally, the emphasis of supply chain management is from the supply-focused point of view where the dominant logical flow is based upon a manufacturing push system rather than a customer pull process [36]. However, with the booming of ICT and additive manufacturing, not only the customers require traditional standard products or mass customized products, but also they wish to be involved in the product design and fabrication process and to have highly personalized products with low cost and fast delivery. The traditional supply chain design and optimization models are not planned to archive this function [37, 38].

Today, we are in a totally different business environment than 30 years ago. The biggest problem is no longer the shortage of resources but is the way we consume the resources, and the overuse and overconsumption lead to the waste of resources and increased generation of solid waste. For example, a recent investigation shows that approximately 50% of food produced all over the world eventually become organic waste [36]. Due to this reason, the supply chain should be reconsidered, redesigned, remodeled and re-optimized in order to respond to the customer demands in a more effective and sustainable way.

A comparison of the value creation and proposition between a traditional supply chain and a demand-driven supply chain is illustrated in Fig. 2. In a traditional production-driven supply chain, the value creation is obtained through product design, manufacturing, and marketing and sales, which focuses primarily on the efficiency of the production system and the supply chain. However, SIMS aims at operating in a demand-driven supply chain within an ever-changing business environment, so the value creation process is opposite to the traditional supply chain. With the help of the big data analytic tools, CPS-based flexible manufacturing system, and additive manufacturing technology, the value creation of the SIMS-based supply chain starting from the choosing of value (e.g., identify what is the customer needs through big data analysis), providing the value (e.g., customer-involved design and production as shown in Fig. 3, and rapid distribution) and communicating with the value (e.g., pricing, advertising, marketing and sales). In order to realize the value creation and proposition of SIMS-based demand-driven supply chain, the decision-making tools need to be developed for replacing the traditional supply chain design and planning models, and the new decision-support systems should simultaneously be lean, flexible and agile for improving responsiveness while reducing the inventory level and overall cost [39-41].

B. SIMS-based servitization

In today's business world, servitization becomes an

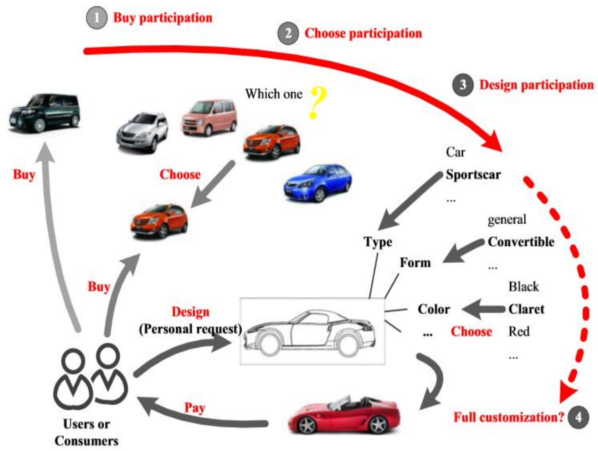

Fig. 3 The schematic of customer-involved product design [20].

extremely popular concept for shaping the landscape of the future manufacturing system and supply chain. Servitization or product-service system indicates the manufacturers and supply chains provide not only the manufactured products but also add-on services to their customers in order to become more customer-oriented and competitive. SIMS-based supply chain should be able to provide the companies with the possibilities for achieving improved servitization so as to survive in the more competitive and dynamic business environment. In recently years, an increasing number of manufacturers in developed countries adopt the concept of servitization in order to compete with the low-cost manufacturers from the developing and emerging economies, i.e., China, India and Brazil, etc.

A successful story of the adaptation of servitization is from the Rolls-Royce Group. Rolls-Royce is one of the world's most important manufacturers of aircraft engine, and the company has transformed itself from an engine supplier (traditional business model) to a product-service provider through the "power by the hour" programme. Traditionally, the maintenance cost of aircraft engine is extremely high, and if the engine fails at an airport located in a remote area without the qualified repair function, the aircraft engine has to be removed and transported in a long distance for the repair and maintenance, and this process is extremely expensive. Besides, the airline company has also to send another aircraft to perform the route planned, and this will further increase the operational cost.

In order to solve this problem and better serve its customers, Rolls-Royce established the "TotalCare" scheme. Different from the traditional business model in which the value creation is obtained through selling the aircraft engines at a fixed price, the "TotalCare" achieves the value creation through charging the hour use of the aircraft engines. Besides, Rolls-Royce established a technical support team for monitoring the use and key indicators of the engine performance and providing the suggestions to the pilots. By doing this, Rolls-Royce achieves a continuous and sustainable value creation process. Meanwhile, the airline companies reduce the operational and maintenance cost through a better monitoring and proactive maintenance of the aircraft engines. An example showing the benefit of this "TotalCare" servitization scheme is given in Chrisopher and Ryals [36]. A flight performing the route from Singapore to New York was struck by lightning, and the technical team of Rolls-Royce thoroughly examined the status of the aircraft engine through the key indicators, and then suggested the pilot to continue with the flight and the engine is without a problem, and this has saved more than 1 million dollars for the airline company [36].

C. *SIMS-based intelligent, digitalized and resource-sharing supply chain*

SIMS-based supply chain involves the most advanced manufacturing technologies, ICT and management methods, which enable the timely decision-making and rapid product design, fabrication, production and delivery. With the help of the big data analytic tools, the customer demands can be predicted in a real-time and more accurate manner, and the decision-making process will be accelerated with the data analysis [42]. The customer order, production scheduling and supplier requirements become more visualized and transparent through the players of the whole supply chain so that the alignment of the supply chain will be enhanced [43]. The CPS and cloud computing-based intelligent manufacturing system equipped with 3D printer, laser cutting as well as other advanced manufacturing machines ensure the rapid fabrication and production of highly personalized products, and the information sharing also accelerates the operations of the transporters and distributors.

Resource integration and sharing are one of the most important parameters determining the success of SIMS-based supply chain. SIMS aims mainly at dealing with the highly personalized customer demands with high responsiveness, however, the increase of supply chain responsiveness usually leads to an increase in supply chain cost as well [44], and this will significantly influence the customer decisions. Due to this reason, the resource sharing among different companies and different industries within the supply chain becomes important for reducing the supply chain cost while simultaneously maintaining a high responsiveness, and Fig. 4 illustrates the development of resource sharing of the manufacturing systems. Today, the reverse logistics in garment industry is a very good example of resource sharing. With the development of internet, the on-line sales of fashion clothes have increased dramatically during the past decade, however, the number of returned product from on-line purchases also increased significantly, so the sharing of collection facilities and transportation resources, e.g., retailer store, becomes popular for those companies to manage the returned clothes in an effective and cost efficient manner. One example is the on-line sales of Zara products in Norway. For return a product from the online shop of Zara in Norway, some collection points are provided at the local shopping malls or other retailers, and the returned clothes from Zara are handled by the post system combined with other goods from the collection points in order to maximize the utilization of transport capacity and minimize cost.

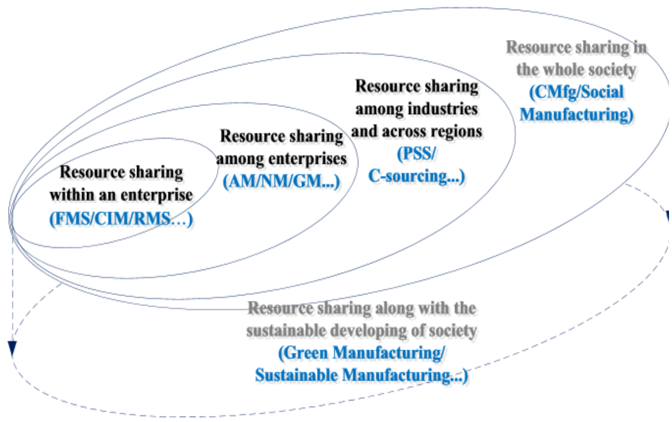

Fig. 4 Development of resource sharing of the manufacturing systems [20].

D. *SIMS-based sustainable supply chain*

Sustainable development has been focused due to the increased environmental concerns from the public [45]. One of the most important responsibilities of future manufacturing system and supply chain is to minimize the negative impact on the environment. Therefore, the design and planning of SIMS-based supply chain should consider not only economic issues but also the environmental sustainability issues.

First, the reverse logistics should be integrated in the traditional forward logistics system in order to maximally recover the remaining values through reuse, repair, remanufacturing and recycling of the end-of-life and end-of-use products. The utilization of resources can be significantly improved through the reverse logistics, and the waste sent to landfill can be reduced as well. Besides, the environmental and social risks posed by hazardous components of the used products in the reverse logistics should be considered and properly treated in order to minimize the negative influence on the local people [46].

Second, the environmental influence of the operations of SIMS-based supply chain should be considered when the system is designed. Today, the most common indicator used to assess the environmental influence of a supply chain is the carbon footprint, and a great number of literature is published for developing both theoretical frameworks and mathematical programming in order to balance the economic performance and carbon emissions in an optimal manner [29-31, 47-50]. The results from the literature show that the decrease of carbon emissions is usually achieved by the increase of supply chain cost, so the focus of the design of environmentally sustainable supply chain is to determine the network configuration under which the trade-off between economic performance and environmental impact is optimal.

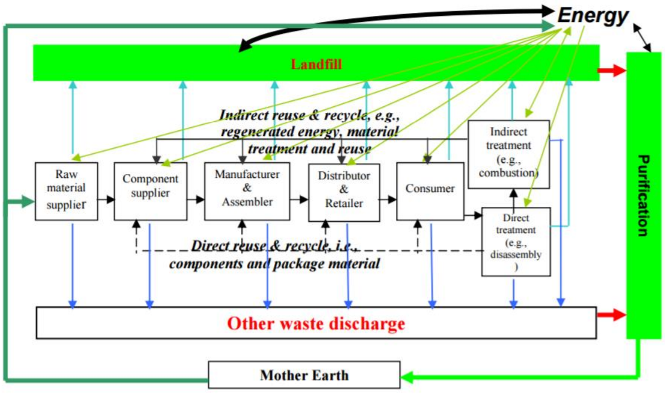

Fig. 5 A closed-loop supply chain model [51].

Based on the discussion above, the design of SIMS-based supply chain should involve both forward and reverse logistics, and the environmental impact of the supply chain activities should be taken into account. A conceptual model for the closed-loop supply chain is given in Fig. 5. As shown in the figure, the waste of resources and energy should be minimized in a closed-loop supply chain, and the environmental impacts of both forward and reverse logistics should be taken into account when an integrated and sustainable supply chain is planned.

IV. Summary and Future Outlook

This paper has presented an introduction of SIMS and a discussion of the characteristics of SIMS-based supply chain. First, the development and evolution of modern advanced manufacturing systems are reviewed, and then the concept of Industry 4.0 is introduced. In order to enhance the competitiveness and sustainability of the manufacturing companies in Industry 4.0 era, the concept of SIMS is defined in this paper. The most important contribution of this paper is that, different from the previous literature which only focuses on the technological challenges and integration, this paper aims at presenting a discussion from the supply chain perspective. Today's ever-changing and dynamic business environment requires manufacturing companies have a higher responsiveness to the highly personalized customer demands while simultaneously maintaining at a lower price and being environmentally friendly. Due to this reason, the SIMS-based supply chain should be characterized as demand-driven with high responsiveness, servitization-based, highly intelligent and flexible, highly resource-sharing, environmental sound and sustainable. In this paper, each of the aforementioned features are briefly introduced and discussed.

This research provides an extensive literature research on the development of modern advanced manufacturing systems and the supply chain, so it is the initial step for the future research in SIMS and SIMS-based supply chain. For future improvement of the current research, three suggestions are made as follows. First, the interaction and inter-relationship of the features and characteristics of SIMS-based supply chain should be focused. That means how does the performance of the SIMS-based supply chain be affected while improving of those feature. Second, a more comprehensive framework for SIMS-based supply chain may also be developed. The conceptual framework should focus on how the characteristics of SIMS-based supply chain affect the material flow, information flow and capital flow across the different players within a supply chain. Third, the enabling technologies and management methods for realizing SIMS-based supply chain should also be focused in future research.

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