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Tactical supply planning in smart manufacturing supply chain

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ABSTRACT

With the fast change of information and communication technologies and global economics, manufacturing industry faces the challenges in both market and supply sides. The challenges in the market include short product life cycle, demand uncertainty, and product customization. Accordingly, supply challenges are the dramatic increase of flexibility in productions and complexity in the supply chain, which result from the changes in the industry and rapid development of ICPT (Information, Communication, and Production Technologies). In this study, we consider a supply chain converged with ICPT, called Smart Manufacturing Supply Chain (SMSC). By investigating the attributes of SMSC, we identify the functional and structural characteristics of SMSC. Tactical supply planning in SMSC recognizes the ability of a pseudo real-time decision-making constrained by the planning horizon. In order to take advantages of SMSC, this study develops a profit-effective and response-efficient tactical supply planning model to find an optimal trade-off between profit and lead time. The model determines the optimal supply throughput during a planning horizon, called Smart Supply Chain Performance (SSCP) as a performance measure for SMSC. The proposed model is investigated and validated using comprehensive numerical experiments and managerial insights are addressed.

1. Introduction

In the past decade, global manufacturing and supply chain have faced the challenges of future manufacturing environments where products in the market are rapidly customized and service-oriented with a very short life cycle, and new manufacturing technologies have been emerged and converged with information and communication technologies called ICPT (Information, Communication, and Production Technology).

ICPT is expected to be used in the next generation manufacturing environment such as smart factories and includes the Internet of Things (IoT), big data analytics, cloud computing, the Cyber-Physical System (CPS), Artificial Intelligence (AI), Virtual and Augmented Reality (VR & AR), and 3D printing technology. Apparently, these have converged in the manufacturing industry and are creating new values that are different from conventional ones. ICPT is also referred to as an overall technology with abilities of visibility, flexibility, responsiveness, integrity, and automaticity for a new manufacturing paradigm. The 4th industrial revolution owes its characteristics to the attributes of ICPT. To catch up on the new paradigm, Industry 4.0 is proposed and adopted by the manufacturing industry in Germany as part of the High-Tech Strategy 2020 Action Plan [1] by implementing a smart factory based on connection and visualization. Similar strategies have been found in the U.S.A. with the Industrial Internet [2], China with the Internet plus [3], and Industry Innovation 3.0 in the Republic of Korea [4]. The common purpose of these strategies and policies is so that the manufacturing industry can be enhanced by adopting ICPT and realized in a ‘hyper-connected’ and ‘demand-driven’ manufacturing environment such as smart manufacturing, which ensures the competitiveness of the manufacturing industry. All components can comprehend their status and flexibly produce customized products by adopting ICPT across an entire supply chain. A component includes everything in the supply chain such as the supply chain members, managers, staffs, facilities, machines, transportations, products, and so on. These components are connected, converged, and collaborated by ICPT.

Moreover, the convergence of ICPT tends to be integrated not only in the manufacturing industry, and also in the logistics and retail industries. A smart factory using ICPT is able to manage information and has multi-functional components. Workers can check the status and information of the components via AR and VR, machines and facilities are fully automated with AI and robotics, and a smart factory can produce customized products more easily using 3D printing technology. ICPT is introduced in logistics as smart logistics [5,6], and retail as smart retail [7,8]. Smart logistics and retail converged with ICPT can trace products and inventory in the supply chain, collect real-time information of operations, optimize decision-making problems, and interact with customers for a customization service to ensure the competitiveness of their businesses. In this way, ICPT is converged through

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the entire supply chain where real-time data are collected, classified, analyzed, and transformed in a self-operating way. In addition, the supply chain produces a customized product using a 3D printer, which still needs to improve its process time and operation costs technically.

This study considers a Smart Manufacturing Supply Chain (SMSC), which is converged with ICPT in the conventional manufacturing and the entire supply chain. We define SMSC and investigate the attributes and characteristics of SMSC to effectively achieve the goals of the supply chain, and quickly respond to unexpected variabilities in the supply chain environment as well as decision-making environment. Next, we mathematically develop a tactical supply planning model containing SMSC characteristics. The proposed model determines production and transportation quantity, transportation routes, and supply chain capacity for each member in a pseudo real-time decision-making. We consider a deterministic model with discrete demand in a single period. In particular, the model finds the optimal trade-off between profit and lead time using Smart Supply Chain Performance (SSCP). SSCP is the profit rate of SMSC and the significant factor in real-time data collection. Finally, using comprehensive numerical experiments, our validation shows excellence in terms of SSCP when we compare optimizing cost and time. The contributions of this study are the definition of SMSC, attributes, characteristics, and decision-making for the mathematical programming model of SMSC.

The rest of this study is organized as follows. In the following section, we review the previous literature on Industry 4.0, smart manufacturing and factories, future supply chains, and planning model. Section 3 defines SMSC and presents its attributes and characteristics. In Section 4, we present problem a pseudo real-time decision-making process by following SMSC logic, and we formulate a tactical supply planning model. Section 5 is devoted to numerical experiments and analyses to illustrate and validate the proposed model. Finally, the conclusions and discussions are presented in Section 6.

2. Related literature

While most references on smart manufacturing and supply chain are based on the convergence and integration of ICPT including Industry 4.0, the literature on SMSC has rarely been published and posted. A representative concept of convergence is Industry 4.0 by the German government. Industry 4.0—called the fourth industrial revolution—aims to make industrial progress towards a smart factory, which is equipped with networked manufacturing components and an efficient manufacturing system. As Germany starts next-generation manufacturing, most countries in the world have adopted a similar concept and policies to secure their manufacturing competitiveness. Recent studies on Industry 4.0 have investigated areas regarding related government policies, company strategies, industrial applications, and the technology itself. Also, most studies on smart factories have emphasized data connection and the collaboration of components and product customization for market using ICPT. Glas and Kleemann [9] provided qualitative analysis of smart factory and Industry 4.0 through in-depth explorative interviews with seven procurement managers. They analyzed the influence of Industry 4.0 through experimental insights into procurement and supply management. Schmidt et al. [10] generated some interesting findings on the potential of Industry 4.0 and dealt with issues surrounding implementation. They investigated the importance of data connection and customization by looking at significant managerial factors such as mass customization, improved process time, and utilization of idle data. Ivanov et al. [11] proposed the information connection of product flow based on integration with systems by CPS, which are the critical success factors for management in Industry 4.0. Schuh et al. [12], Lee et al. [13], and Frazzon et al. [14] proposed information connection frameworks and collaboration. They investigated influence caused by adopting CPS to the manufacturing industry. Based on the above literature, connection and collaboration are key issues in Industry 4.0 using IoT, CPS, and cloud computing. In this context, we uncover two basic attributes of smart manufacturing and SMSC: connection and collaboration.

The smart factory is considered as an advanced factory using ICPT to improve productivity and efficiency in resource-use and allocation, scheduling, control, optimization, and so on. Through a real-time decision-making process, a factory can improve in process time [15]. Shellshear et al. [16] pointed out various issues related to the connection of data and collaboration among the components in the smart factory, these being to improve efficiency in the use of resources and the flexibility of the production system [17], to optimize partner selection with collaboration [18], and to design a strategic plan and system with data connection and its utilization in a real-time manufacturing environment [19]. Aside from connection and collaboration, a smart factory enables the manufacturer to produce customized products for their own competitiveness. For demand-driven manufacturing in the customized market, researchers have been concerned with how to efficiently adopt 3D printing and Additive Manufacturing (AM) [20,21]. From the literature, we can conclude that customization, along with flexibility, is one of the crucial attributes of SMSC.

Several kinds of the literature of a smart supply chain are found in 'the smarter supply chain' of IBM [22], Cooke [23], and Dassault Systemes [24]. Cooke [23] addressed the trends of the smart supply chain such as customer segmentation and omnichannel for sustainable business, and Dassault Systemes [24] characterized the smart supply chain as gaining key benefits of the supply chain such as the faster time-to-market and flexible re-optimization of plans. Some researchers suggested enablers to provide improved capability to the supply chain; Tachizawa et al. [25] asserted that smart city and smart technologies provided the infrastructure for the smart supply chain. Dawid et al. [26] proposed manufacturing processes where customers are able to participate. A common observation of the future supply chain is that all components are interconnected, decisions are made autonomously, and flexibility is essential to respond to variabilities to the environment.

Most planning models in supply chain look at minimizing the total cost of the supply chain [27], and to minimize cost and environmental factors considering sustainability [28–32]. The studies consist of maximizing profit (or minimizing cost) and minimizing time—like this study—are published in optimization. Melachrinoudis and Min [33] considered maximizing the total profit and aggregated location incentive for facilities and minimizing total transit time to determine optimal quantity and location. Du and Evans [34] studied two factors: minimizing the overall costs and total tardiness of cycle time for reverse logistics. For a planning model, Liu and Papageorgiou [35] addressed the production, distribution, and capacity planning of a global supply chain considering minimization of total cost, flow time, and lost sales. Additionally, to find the optimal solution for planning, Tzeng et al. [36] and Liang [37] developed multi-objectives of total cost and lead time. For a flexible supply chain [38–41], the minimization of lead time is rarely found. Furthermore, the references regarded factors of profit or lead time to be achieved respectively.

However, we propose a performance measure, SSCP, with the result that we combine two factors to carefully manage. SSCP represents a profit rate involves a trade-off between profit and lead time, which are directly proportional to quantity (profit = unit profit × quantity and lead time = unit required time × quantity). SSCP is an estimation of profit rate, so it plays a different role in SMSC under real-time data collection. In addition, it can provide a profitable strategy by maximizing profit and the responsive operation by minimizing lead time.

3. Smart manufacturing supply chain

3.1. Definition

The meaning of 'smart' is the ability of an object to recognize by itself the purpose to be achieved, to understand and work well, and to flexibly respond to any variability. For the supply chain to be 'smart' as