Chapter 3

Impact of Industry 4.0 on Inventory Systems and Optimization

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Additional information is available at the end of the chapter

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Abstract

With evolution of Industry 4.0, how should we operate our production lines and factories, how should we manage and optimize inventory, how should we deploy our workers, how should we run our businesses, how should we manage our supply chains? This chapter aims to highlight the impact of Industry 4.0 on manufacturing systems and services, as well as supply chains, in particular, on inventory systems and optimization. An integrative R&D framework for inventory systems modeling and optimization is proposed, which directs our R&D effort in modeling and optimizing inventory systems with Industry 4.0.

Keywords: Industry 4.0, cyber-physical systems, Internet of Things, Internet of Services, inventory systems, inventory optimization

1. Introduction

The world is experiencing Industry 4.0, the fourth industrial revolution. The first industrial revolution took place in the eighteenth century with the introduction of mechanical production machines powered by water and steam. The second industrial revolution started at the beginning of the twentieth century with mass production powered by electric energy. The third industrial revolution came in 1970s with production automation using electronics, computers and information technology. The current industrial revolution began in the early of this millennium with autonomous production using Cyber-Physical Systems (CPS), Internet of Things (IoT) and Internet of Services (IoS). This digitization not only enables the integration of processes and systems across companies and industrial sectors, but also creates new business models and value generation opportunities.

Industry 4.0 has been greatly influencing people's daily life in every aspect, from shopping to dining, from working to entertaining, etc. It is changing people's life styles and living behaviors, even thinking and mindset. Industry 4.0 has brought a revolutionary impact to manufacturing systems and services, as well as supply chains. In the environment of Industry 4.0, factories are smart, products are smart, and customers are demanding for being all round served with great satisfaction. Enterprises and businesses are digitalized, profitable and sustainable. Manufacturing systems and services are real time capable, interoperable, modular, decentralized, virtualized, and service oriented. Supply Chains are fully visible, connected and integrated.

Digitalization, visibility, connectivity and interoperability are the essence of Industry 4.0. With rapid growth of Industry 4.0 technologies, inventory systems and optimization are being transformed to a new state. This chapter explores what is the impact of Industry 4.0 on inventory systems and optimization, how Industry 4.0 enables the transformation of inventory systems and optimization to a new state and what are the benefits of such transformation to the industry.

We briefly review Industry 4.0 and enabling technologies in Section 2. In Section 3, we discuss the possible changes with factories, products, customers and businesses in the environment of Industry 4.0. Section 4 highlights the attributes of manufacturing systems and services with Industry 4.0. Section 5 discusses the benefits brought by Industry 4.0 to businesses. In Sections 6–8, we focus on inventory systems and optimization. Section 6 explores the impact of Industry 4.0 on inventory systems, and Section 7 discusses the impact of Industry 4.0 on inventory optimization. In Section 8, we propose a new integrative R&D framework for inventory systems modeling and optimization. Section 9 concludes the chapter.

2. Industry 4.0 and enabling technologies

Industry 4.0 is a transition to the digital transformation of industries, a merger of the physical and digital worlds. Industry 4.0 is also a fusion of technologies that clear the boundaries among the physical, digital, and biological spheres [1–3]. Those technologies include Artificial Intelligence, Robotics, Internet of Things, Autonomous Vehicles, 3-D Printing, Nanotechnology, Biotechnology, Materials Science, Energy Storage, and Quantum Computing [4–10]. In this chapter, we shall not detail the mentioned technologies, but briefly highlight how Industry 4.0 is enabled by the technologies.

Industry 4.0 is enabled by the technologies that integrate the digital and real worlds. As an illustration, the core technologies related to manufacturing systems and services, and supply chains, are elaborated as follows:

Big Data Analytics and Business Intelligence: Nowadays enterprises are embraced by huge amount of data from all kinds of sources. All decisions, either operational or managerial, have to rely on data analytics. All businesses cannot afford to ignore the data and data analytics. It has been proven that the data are very useful and much valuable when it comes to optimize production quality and services, reduce energy consumption, and improve efficiency in manufacturing. For example, data can be collected from various stages of the manufacturing process. The large amount of data can be analyzed in correlation with each other in order to identify the stages with redundant processes that need be streamlined. The data can be turned into actionable insights through early warning algorithms, predictive models, decision support, workflows and dashboards. In fact, the data have become the most valuable asset of an organization today. The data analytics is the essence to a success of enterprises and their businesses.

Internet of Things (IoT): Embedded computing and networking connect sensors and devices. The Internet of Things connects more and more systems, devices, sensors, assets and people through networks ranging from wireless, low-power wide-area networks to wired high-capacity networks.

Cloud Computing: Many small enterprises cannot afford to own the storage for an increasing amount of data. Some of them lack the analytical and computational capabilities of processing the huge amount of data. However, the data and the capabilities of analytics and computation are even more important to them. Cloud service providers are offering a growing opportunity to small enterprises through data storage and data processing with affordable costs.

Cyber-Security: Industrial systems are becoming increasingly vulnerable to threats as there are various devices and large amount of data sets. The cyber-security has to be put in place, which can recognize new vulnerabilities and challenges, and ensure industrial systems and businesses free of attacks.

Autonomous Robots: The use of robots in manufacturing is no longer new. In Industry 4.0, robots are self-sufficient, autonomous, and interactive, which are no longer simply tools used by humans, but are the integral work units.

Additive Manufacturing: Additive manufacturing, in particular, 3D printing enables manufacturers to dramatically reduce the design time and cost, and increase the variety and customization of products. The benefits and values brought by additive manufacturing are even more evident in the high mix low volume (HMLV) manufacturing.

Augmented Reality: Customers are now more and more demanding. Businesses have to provide customers all round services, from personalized product design, dedicated manufacturing process to individualized after-sales services. Augmented reality based systems are able to assist enterprises to gain their competitive edges and win more business opportunities in such a competitive marketplace.

3. Factories, products, customers and businesses in the environment of Industry 4.0

Industry 4.0 uses digital technologies to make manufacturing more agile, flexible and responsive to customers. It is able to create a smart factory where the Internet, wireless sensors, software and other advanced technologies work together to optimize the manufacturing system and improve customer satisfaction. Industry 4.0 enables a business to react more rapidly to market changes, offer more personalized products and increase operational efficiency in a cycle of continuous improvement.

Industry 4.0 is creating intelligent products, processes and procedures. In a smart factory, workers, machines and resources easily communicate via the ubiquitous connectivity of people, things and machines. Products, transportation equipment and tools cooperate in order to create better each following production step. It leads to the connectivity of virtual world and physical objects in the real world.

Factories: With Industry 4.0, not only all manufacturing facilities in a factory, such as sensors, actuators, machines, robots, conveyors, etc., are connected and exchange information automatically, but also the factory becomes conscious and intelligent enough to predict and maintain its operational performance, to control its production process, and to manage its manufacturing operations. In addition, manufacturing processes, such as product design, production planning, product services, etc., are controlled by a decentralized system but working fully independently as self-functional modular. Such a factory with Industry 4.0 is known as a smart factory.

Products: With Industry 4.0, a product is embedded with sensors, identifiable components, and processors which can carry information and knowledge to convey the functional guidance to the customers, and transmit the users' feedback to the manufacturing system. More importantly, it allows the manufacturer to monitor the product performance and provide information to customers, such as when and which parts need to be replaced, and generate more revenue by shifting to a product-as-a-service business model. Such a product with Industry 4.0 is named as a smart product. A smart product has all information about itself, manufacturing time, production conditions, delivery time, utilization, life time, location, and other important information [11].

Customers: Industry 4.0 provides customers a new purchase means with a lot of advantages. It allows customers to order whatever function of products, with any number even if only one. In addition, customers could change their orders and ideas at any time during production even at the last minute with no extra charge. On the other hand, the benefit from the smart products enables the customer not only to know the production information of the product but also to receive the advice of utilization depending on their own behaviors.

*Business*es: With Industry 4.0, there is a complete communication network existing among various entities such as suppliers, factories, customers, products, logistics, resources, etc. Every entity optimizes its configuration in real-time, based on its demand and state in the network so as to maximize the profit for all the entities with the limited sharing resources, and at the same time, to reduce the costs and pollution, raw materials, CO_2 emissions, etc.

4. Manufacturing systems and services with Industry 4.0

Industry 4.0 is connecting systems, machines, and work units in order to create intelligent networks along the value chain that can work separately and control each other autonomously

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but in a cohesive manner. In the Industry 4.0 environment, the key attributes of manufacturing systems and services are real time capability, interoperability, modularity, decentralization, virtualization and service orientation.

Real-Time Capability: Industry 4.0 enables everything real time, which requires that the manufacturing process, data collecting, monitoring and maintenance are in a real time manner.

Interoperability: Interoperability refers to the capability of all entities to connect, communicate, and operate together via the Internet of Things. This includes the humans, the smart factories, and the relevant technologies. Interoperability requires an entire environment with smooth interaction and flexible collaboration among all the entities. For example, assembly stations are not separate or isolate from the products created or the people who are working on them.

Modularity: Modularity enables smart factories to easily adapt the changing circumstances and requirements. Modularizing products and manufacturing systems ensures a minimum disruption to other products or manufacturing processes when there is a need to replace, expand or improve an individual product or production line.

Decentralization: Industry 4.0 supports decentralization, which enables the different systems within the smart factory to make decisions autonomously, in alignment with the ultimate overall organizational goal.

Virtualization: A virtual twin or digital twin can be created for a smart factory to greatly enhance the existing processes and products, and reduce the time to profit of new products. What are actually happening in the physical factory is exactly mapped to the virtual digital factory. Engineers and designers can work on the virtual digital factory, then customize, alter, and test changes or upgrades in complete isolation, without affecting the physical factory operations.

Oriented Services: The Internet of Things creates potential services that customers desire to consume, which include those services within or outside a smart factory, or before or after sales of a product. The Internet of Services is an important component of Industry 4.0.

5. Benefits to businesses

Industry 4.0 is making it easier for companies to collaborate and share data among customers, manufacturers, suppliers and other parties in supply chain. It improves productivity and competitiveness, enables the transition to a digital economy, and provides opportunities to achieve economic growth and sustainability.

In the environment of Industry 4.0, all the parties in the supply chain share the data from their production sites, vehicles, warehouses and databases in real time. Real-time POS (point of sales) and inventory data are available to understand the business situation. Customer urgent orders can be attended timely with customer satisfaction. Condition and location of products are trackable and controllable. Product quality is better controlled. Inventory is better managed. Equipment settings are self-adjusted based on materials used, products being made and other ambient conditions. Mass-produced products are customized according to the needs of an individual customer. Equipment can be monitored remotely and malfunctions can be predicted accurately. Whatever business is, a fluid digital continuum is able to connect customers, suppliers, partners, production equipment and products throughout the lifecycle of the product and services. The benefits brought by Industry 4.0 to businesses are specifically summarized as follows:

Increased Business Competitiveness: Industry 4.0 enhances global competitiveness through cooperation and a confederation of firms. It can be seen that products will no longer be built by a worker in future, but by a robot or programmer.

Increased Productivity and Revenue: With the increase in efficiency, lowering of operational costs leads to increased revenue and profits. This also drives forward improvements in productivity. Industry 4.0 is one of the key drivers for companies' revenue increase and nations' GDP growth.

Optimized Manufacturing Processes: Smart factories are all connected. The necessity is a network connecting smart factories, smart products, and other smart production systems. Cyber-physical production systems enable factories and manufacturing facilities to quickly and properly react to the changes in customer demand levels, stock levels, machine defects, and unforeseen delays. Marketing intelligence, smart logistics and intimate customer services are also crucial in the entire value chain. The integration facilitates the establishment and maintenance of networks that create and add value. It could also mean the integration of new business models across countries and even across continents, making for a global network.

Accelerated Technology Development: Industry 4.0 provides a platform for the basis of further innovation with developing technologies. Manufacturing systems and services can be further developed. For example, with mobile phone applications, more and more developers are using open APIs to mash up applications, and looking into technologies that will be an improvement on the current GPS, RFID, NFC, and even accelerometer sensors embedded in the standard smartphone [12, 13].

Better Customer Service: Industry 4.0 is able to monitor real time customer feedback so as to provide better service to customers.

In a summary, Industry 4.0 enables a digitally integrated and intelligent value chain offering almost limitless possibilities. Industry 4.0 solutions improve operations efficiency, productivity, product quality, inventory management, asset utilization, time to market, agility, workplace safety and environmental sustainability. In the following sections, to be more specific, we highlight the impact of Industry 4.0 on inventory systems and optimization, and propose a new integrative R&D framework for inventory systems modeling and optimization in the Industry 4.0 environment.

6. Impact of Industry 4.0 on inventory systems

In the business world, inventory is very important, which is directly linked to cash and cash flow. Inventory appears everywhere, in a visible form or non-visible form. In manufacturing, there are raw material inventory, work in process (WIP) inventory, and finished goods inventory, which are all in a visible form. In communication, for example, bandwidth, server and memory card capacity can be considered as inventory, in a non-visible form. Thus, to efficiently and effectively managing inventory, either in a visible or non-visible form, is the winning formula to businesses.

In the context of supply chain, suppliers have raw material inventory, manufacturers have raw material inventory, work in process (WIP) inventory and finished goods inventory, distributors have semi-product inventory and finished goods inventory, retailers have finished goods inventory. In each stage, inventory need be kept so as to improve the satisfaction level of its downstream stage, reduce certain costs and ensure efficient and effective operations of the supply chain. It is not favorable to hold inventory in each stage because of carrying cost, cash retention, product depreciation, etc. Inventory optimization is to keep the minimal inventory to maximally fulfill the downstream demand, that is, to keep the right balance between the supply from the upstream and the demand from downstream [14–17].

The impact of Industry 4.0 on inventory systems can be summarized as four aspects: inventory process, inventory classification, inventory system parameters, and inventory system review.

Inventory Process: Industry 4.0 enables the purchase process and fulfillment process digitalized and automated. For orders to suppliers, based on real time information and data, inventory systems are able to automatically trigger the orders with the right quantity at the right time. For the fulfillment to customers, inventory systems are able to foresee when and how much each customer needs which type of product through data analytics and business intelligence.

Inventory Classification: ABC inventory classification is popularly used in inventory management. ABC inventory classification is to start with the products ranked by dollar value in descending order, and plot the cumulative dollar value in inventory versus the cumulative products in inventory. For example, Class A is referred to the set of those 20% products cumulated 80% dollar value in inventory, and Class C is the set of 50% products cumulated 10% dollar value in inventory. As such, Class B is the set of the remaining 30% products cumulated 10% dollar value in inventory. In the environment of Industry 4.0, products are smart products which are carrying the information on their locations and dollar values. It enables the automation of ABC inventory classification of smart products. The inventory classification profile is dynamically and automatically updated in real time.

Inventory System Parameters: For an inventory system, its key system parameters include supply lead-time, purchasing price, carrying cost, ordering cost, customer demand and product selling price, which collectively determine the dynamics of the inventory system and its performance. It is difficult to estimate some of these system parameters, such as supply lead-time, customer demand, etc. When modeling the inventory system, it is conventional to take a rough estimation due to the lack of information for calculating their exact values. For example, the shipping time from the United Stated to Singapore is about 2–4 weeks. It means that the supply lead-time from a supplier in the United States to a manufacturer in Singapore may vary between 2 and 4 weeks. There is a huge difference to the production plan of the manufacturer when the supply lead-time is 2 or 4 weeks. It has been very challenging for the manufacturer to gauge the exact time to receive what it has ordered. Besides the supply lead-time uncertainty, inventory management is also facing other challenges from suppliers, such as minimum order quantity (MOQ), dynamic pricing, etc. In the environment of Industry 4.0, all the parties and entities are able to share the information in real time. In the example, the manufacturer in Singapore will be informed timely where the vessel is and when it will reach in Singapore. Then the manufacturer can plan its production accordingly at the right time. In this case of the supply lead-time parameter, the impact of Industry 4.0 on inventory system parameters has been evident. Industry 4.0 has similar effects on other inventory system parameters as well.

Inventory System Review: Conventionally there are two types of inventory reviews: periodic review and continuous review. The periodic review is to review the inventory on a regular basis, at fixed point of time, and a new order is placed only at these time epochs. The continuous review is to continuously monitor and review the inventory over the time, and a new order is placed when the inventory reaches a critical point. The periodic review does not need real-time information on the inventory while the continuous review needs real-time information about the inventory. That is, the continuous review needs a sophisticated advanced information system in place. Due to the high cost involved in the advanced information system, the most companies are adopting the periodic review in practice. However, with Industry 4.0, all the information is available and shared in a real-time manner. It provides the most convenience and great incentive for companies to start using the continuous review. Thus, Industry 4.0 is shifting the periodic inventory review to the continuous inventory review in practice.

7. Impact of Industry 4.0 on inventory optimization

The purpose to keep inventory is to buffer the uncertainties which may come from the upstream (e.g., suppliers) and the downstream (e.g., customers) so as to timely fulfill customer demand if any. However, to keep the inventory too high will incur a higher inventory cost, while keeping the inventory too little will compromise the customer satisfaction level. It is utmost important to keep the right inventory at the right time in the right place with the right price and the right time duration. Thus, inventory must be optimized to minimize the inventory cost and maximize the customer service level.

Inventory optimization is to decide when to order and how much to order, which constitute an inventory policy. The optimal inventory policy is determined by solving an optimization problem that is composed of an objective function and a set of constraints. The objective function and constraints define the relationships of the system parameters. The objective is either to minimize the total operational cost, or to maximize the customer service level. The decision variables are the time to place an order and the quantity of an order. The optimization problem is formulated based on the assumption of the system parameters. Some of the system parameters are constant, some are variables which change over the time, and some are random variables which change according to a certain probabilistic distribution. The main challenges to optimize an inventory system are how to accurately characterize the system parameters, how to formulate the relationships of the system parameters and construct the objective function and constraints, and how to derive the optimal solution to the optimization problem.

For an inventory system in the environment of Industry 4.0, the values of some system parameters are directly captured in the information systems [18–20]. Through data analytics, these system parameters can be well modeled and characterized. For some system parameters which are not directly recorded in the information systems, they can be analyzed and described based on their relations to other system parameters. It is very difficult to analytically formulate the relationships of the system parameters, in particular, when the inventory system is complex. With all available data and analysis, it might not be necessary to come out with mathematical formulas for the system parameter relationships. Through extensive deep data analytics, the optimal inventory policy is expected to be achieved as well.

8. New R&D framework for inventory systems modeling and optimization

Industry 4.0 enables digitalization, visibility, connectivity and interoperability across supply chain. The impact of Industry 4.0 on inventory systems and optimization is huge. Industry 4.0 is shaping a new R&D paradigm for inventory systems and optimization. As an initial attempt, we are proposing a new integrative R&D framework for inventory systems modeling and optimization in this section.

There are various types of inventories, in a visible or non-visible form. As an illustrative example, we consider the finished goods inventory in supply chain, where the upstream is suppliers and the downstream is customers, end-users of products, as shown in **Figure 1**.

The primary function of the inventory is to purchase the products from the suppliers and sell the products to the customers. Through such trading, buy and sell, the revenue will be generated. The main purpose to manage the inventory is to maximize the sales to the customers by holding the minimal stock on hand. Thus, inventory management need to clearly know its customers and well understand its suppliers. Industry 4.0 provides all opportunities for the inventory management to achieve its ultimate goal, maximizing its revenue.

To clearly know the customers is the first important to managing the inventory. Customer is a king, no customer no sales, no sales no revenue, no revenue no business. Through data analytics and market intelligence, customers' behavior is modeled, and future customer demand is forecasted. The product selling price might have great influence on customer demand. Similarly, the customer satisfaction affects customer demand as well. The analysis on the customer sensitivity to pricing and the effect analysis of the customer satisfaction are able to improve the accuracy of future customer demand forecasts.

To well understand the suppliers is able to reduce the operational cost in managing the inventory. Leveraging all available data and business intelligence, the supplier performance is evaluated and analyzed. From the performance analytics, it is ready to know that which

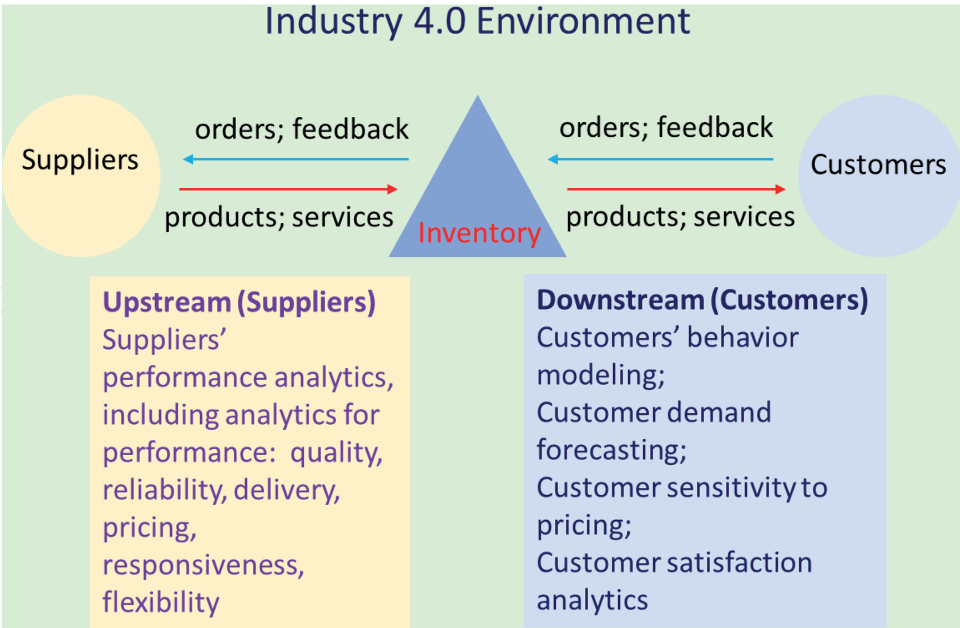

Figure 1. Integrative R&D framework for inventory systems modeling and optimization.

supplier can provide the best quality of products or the best service at which price, which supplier is most reliable, which supplier can deliver the products timely, and which supplier is most responsive and flexible to attend the last minute urgent order.

Conventionally, after estimating the system parameters and forecasting the customer demand, an inventory optimization model is built up to derive the optimal inventory decision in terms of the objective function. With Industry 4.0, all the data about the suppliers, customers and the inventory itself are available to be utilized for establishing an integrative data driven inventory optimization model. Instead of the conventional sequential approach with the assumptions on the system parameters, an integrative data driven approach is applied without the assumption on the system parameters. By knowing the customers and understanding the suppliers, the inventory can be managed efficiently and effectively so that the maximal revenue can be achieved with the maximal customer satisfaction.

9. Conclusions

Industry 4.0 enables factories smart, products smart, and supply chains smart as well, and makes manufacturing systems and services more agile, flexible and responsive to customers. Through a brief overview on Industry 4.0 and enabling technologies, this chapter discussed the possible changes with factories, products, customers and businesses in the environment of Industry 4.0. The attributes of manufacturing systems and services with Industry 4.0 were highlighted, and the benefits brought by Industry 4.0 to businesses were discussed. To be more specific, the chapter focused on inventory systems and optimization. The impact of Industry 4.0 on inventory systems and optimization was explored, respectively. The new integrative R&D framework for inventory systems and optimization was proposed in this chapter.

How to efficiently and effectively manage inventory is a common challenge for all businesses and companies. It has been a long standing issue in industrial practice, and there is no universal solution to all businesses and companies. It is probably because the conventional approaches and methods for inventory systems modeling and optimization have their limits, or there is lack of the information on knowing customers and understanding suppliers. With Industry 4.0 implementation and progress, it is anticipated that there will be more and more breakthroughs in approaches and methods for inventory systems modeling and optimization.

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