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What does Industry 4.0 mean to Supply Chain?

B. Tjahjono[a,*], C. Esplugues[b], E. Ares[c], G. Pelaez[c]

[a]*Centre for Logistics and Supply Chain Management Cranfield School of Management, Cranfield, Bedford MK43 0AL, UK
[b]School of Applied Sciences Cranfield University, Cranfield, Bedford MK43 0AL, UK
[c]School of Industrial Engineering University of Vigo, Spain

Abstract

The term 'Industry 4.0' was coined to mark the fourth industrial revolution, a new paradigm enabled by the introduction of the Internet of Things (IoT) into the production and manufacturing environment. The vision of Industry 4.0 emphasizes the global networks of machines in a smart factory setting capable of autonomously exchanging information and controlling each other. This cyber-physical system allows the smart factory to operate autonomously. For instance, a machine will know the manufacturing process that needs to be applied to a product, what variation to be made to that product etc., so that the product can be uniquely identifiable as an active entity whose configuration and route in the production line is unique. As the collaboration between suppliers, manufacturers and customers is crucial to increase the transparency of all the steps from when the order is dispatched until the end of the life cycle of the product, it is therefore necessary to analyze the impact of Industry 4.0 on the supply chain as a whole.

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Keywords: Supply Chain Management; Industry 4.0; Internet of Things; IoT; impact

* Corresponding author. Tel.: +44 1234 750111 ext 2852.
E-mail address: b.tjahjono@cranfield.ac.uk

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1. Introduction

Over the last three decades, Information Technology (IT) systems have undergone a significant revolutionary progress that has subsequently impacted every aspect of daily life. One of the most radical changes is the shift from computers to smart devices utilizing the infrastructure services based on cloud computing. This new beginning of the Internet era, marked by an integrated computer-based automation and ubiquitous computing systems, is moreover being connected to the wireless network by the Internet [1]. These recent developments have enabled not only the virtually endless possibilities of interconnecting human beings and machines in a cyber-physical system context using information obtained from different sources but also direct communications between machines. The implementation of this kind of network within the production and operations environment is termed Industry 4.0.

The introduction of Industry 4.0 into manufacturing has many impacts on the whole supply chain. Collaboration between suppliers, manufacturers and customers is crucial to increase the transparency of all the steps from when the order is dispatched until the end-of-life of the product. Furthermore, due to the introduction of digitalization and automation of processes, the whole supply chain management (SCM) structure. In order to understand the opportunities and possibly threats from the introduction of these new technologies, it is therefore necessary to analyze the impact of Industry 4.0 on the supply chain as a whole.

This paper presents a preliminary analysis of the impact of Industry 4.0 on SCM and aims to provide a thought towards Supply Chain 4.0. The scope of the analysis has been intentionally limited to include only four functions within a supply chain, i.e. procurement, transport logistics, warehouse and order fulfilment. This is presented with respect to the Key Performance Indicators (KPIs) of the SCM. It is hoped that the outcomes will open up future pathways to draw the bigger picture and thus conduct a fuller analysis of these impacts.

2. Fundamentals of Industry 4.0

Industry 4.0 specifically involves a radical shift in how production shop floors currently operate. Defined by many as a global transformation of the manufacturing industry by the introduction of digitalization and the Internet, these transformations consider revolutionary improvements in the design and manufacturing processes, operations and services of manufacturing products and systems. Though coined in Germany, the notion of Industry 4.0, to a large extent, shares commonalities with developments in other European countries where it has been labelled differently, for instance Smart Factories, Smart Industry, Advanced Manufacturing or Industrial Internet of Things (IIoT).

A smart factory is reffered to as the use of new innovative developments in digital technology including "advanced robotics and artificial intelligence, hi-tech sensors, cloud computing, the Internet of Things, data capture and analytics, digital fabrication (including 3D printing), software-as-a-service and other new marketing models, mobile devices, platforms that use algorithms to direct motor vehicles (including navigation tools, ride-sharing apps, delivery and ride services, and autonomous vehicles), and the embedding of all these elements in an interoperable global value chain, shared by many companies from many countries" [2].

Within the context of Industry 4.0, the factory of the future will enable the connection between machines and human-beings in Cyber-Physical-Systems (CPSs). These new systems focus their resources on the introduction of intelligent products and industrial processes that will allow the industry to face rapid changes in shopping patterns [3].

Industry 4.0 also promotes the use of big data, IoT and Artificial Intelligence (AI) as one. This revolution envisages an environment whereby smart machines can communicate with one another, not only to enable the automation of production lines but also to analyze and understand a certain level of production issues and, with minimal human involvement, to solve them. Even though this revolution is initially considered to affect mostly manufacturing industries, these innovations will affect retailers, operations companies as well as service providers.

Because the term Industry 4.0, until now, has not yet been conclusively defined, neither are its features; nonetheless, generally speaking, among others there are four main features.

- Vertical networking of smart production systems: This type of networking is based on CPSs to build reconfigurable factories that are flexible and react rapidly to changes in the customer demand. Manufacturing processes in a smart factory enable the true mass customization. It enables "not only autonomous organization of production management but also maintenance management. Resources and products are networked, and materials and parts can be located anywhere and at any time. All processing stages in the production process are logged, with discrepancies registered automatically" [4].

- Horizontal integration via a new generation of global value chain networks [5]: The implementation of the CPS within the smart factory requires strategies, networks and business models to accomplish a horizontal integration, which subsequently provides high levels of flexibility, enabling the company to respond faster. The transparency within the value chain allows the manufacturer to identify changes in customer requirements and to reflect them in all of the production steps, from development to distribution.
- Through-life engineering support across the entire value chain: Innovation and technical improvements in engineering are present in the design, development and manufacturing processes. These enable the creation of new products and production systems utilizing a large amount of information (big-data).
- Acceleration through exponential technologies: The implementation of innovative technologies enables companies to reduce costs, increase flexibility and customize the product. Industry 4.0 involves automated systems including Artificial Intelligence (AI), robots, drones, nanotechnologies and a variety of inputs that enable customization, flexibility and rapid manufacturing [4].

This perspective of the analysis is believed to be relevant since there is no complete or concise knowledge of how to implement Industry 4.0 correctly or predict future problems to be prevented in advance

3. Research method

The research described in this paper has largely been carried out via a desk-based study utilizing various types of literature as primary data sources, including scientific papers, journals, articles, magazines, newspapers, government reports, EU reports, business reports from companies, consultants' reports, Internet blogs and YouTube videos. Throughout the development of this paper, the current state of scientific publications is regularly reviewed to identify any work being undertaken in a similar focus area.

The first step to be taken was to better understand the scope of SCM by identifying its components and KPIs for each of the components. A review of SCM was then performed to understand the area in which the supply chain has already been linked with Industry 4.0. The purpose was to focus on the analysis in these areas. Once the areas have been framed, the KPIs, also known as the influencing variables, used to evaluate the implications of different new technologies for these areas were identified.

The next analysis was to examine the impacts of the changes in technology on each KPI. The opportunities and threats exhibited in each of the technologies for each of the KPIs were then discussed by linking them with each area of the SCM under study.

Finally, in order to support all the propositions made in the previous stages, a hypothetical example of a supply chain with different KPIs which have an impact on the current state of the system was developed.

4. Analysis

Regardless the industry sectors, cooperation between the different functions involved in the supply chain is necessary. However, depending on the types of business and final products or services supplied to the customers, these functions can be distinct. The integration and coordination of all the processes in the supply chain is crucial to match the supply and demand.

Figure 1 shows the four supply chain levers considered in this research. These levers are interconnected: from move to sell, to buy and to store. Each of the levers is represented by an area of the SCM, and for each of these areas, KPIs are defined in order to obtain quantifiable measures to compare if there are changes over time.

The identification of these KPIs is, however, rather complicated because there are no clear boundaries between the levers. For instance, by ordering larger batches of raw materials, the demand cycle could be reduced, simultaneously reducing purchasing and delivery costs. However, warehouse costs could increase due to the growing inventory level [6].

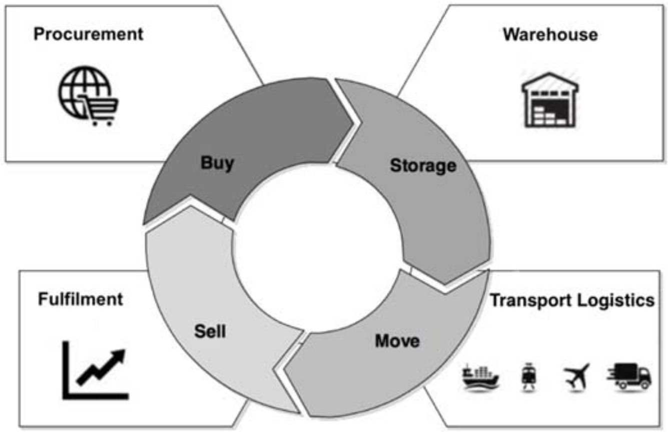

Fig. 1. Supply chain levers.

The “buy” lever mainly involves procurement. It is the business lever in charge of all the processes and tasks necessary to purchase services or goods from suppliers. The performance parameters are, for instance: quality standard for the raw materials, reject rate, service level, order accuracy etc. [7, 8].

The term “make” means the production of goods or creation of services. It defines the operations required to transform inputs into outputs or final products. The inputs are the raw materials, resources, technologies and information needed, and outputs are what the customers receive from the company [9]. Nonetheless, within the scope of this paper, the production function has been omitted.

The store functions or warehouse operations, particularly inventory management, have advanced in the last few decades due to the short product life cycles and more demand fluctuation. The performance parameters selected are for instance truck time at the dock, accurate receipts received, time from receiving to pick location, labor hours consumed per order, time from picked order to departure, etc. [10, 11].

The term “move” refers to the transport logistics that are responsible for delivering and transporting inventories from one place to another at the right time. The KPIs to be analyzed are for instance: truckload capacity, turnaround time, shipment visibility, on-time pickups, on-time delivery, etc. [12, 13].

The “sell” or fulfilment process ensures the orders are delivered within the agreed schedule. This function of the supply chain generally makes a significant difference between companies, depending on their reliability and the on-time deliverables. Correct order fulfilment management enables both gaining market share and maintaining current customers [14]. The KPIs selected are for instance: product availability, customer experience, response time, time to market, etc. [6].

5. Results

Industry 4.0 implies changes in the way companies work and organize themselves. Currently, there are many theories about the general repercussions of Industry 4.0; however, there are only a few stipulated examples of the impacts on SCM. For this reason, with the main objective of evaluating the opportunities (and possibly threats) as a result of the introduction of Industry 4.0 at each function of the SCM selected, this theoretical analysis has been undertaken.

An analysis of how each KPI was affected by each technology was first carried out. The next step was the formulation of propositions. Based on the results obtained, the research establishes the opportunities for each function in SCM. In order to link each technology with each KPI, an initial template was built (Table 1).

Table 1. A template to list the technologies potentially impacting the KPIs.

Technologies	Impact?	If Yes, Why?
Virtual and augmented reality		
Additive manufacturing – 3D Printing		
Simulation		
Big Data analytics		
Cloud technology		
Cybersecurity		
The Internet of Things		
Miniaturization of electronics		
Automatic Identification and data collection (AIDC)		
Radio-frequency Identification (RFID)		
Robotics, drones and nanotechnology		
Machine-to-Machine Communication (M2M)		
Business Intelligence (BI)		

With the main purpose of assessing whether there were "changes" or not, nouns were added to most of the KPIs to make them more descriptive. The *nouns* were added based on what every company expected to improve to reduce costs and increase benefits. For instance, the KPI "*Truck time at the dock*" became "*Reduction in truck time at the dock*". In this way, 'YES' was added in case the introduction of the new technology would affect (positively or negatively) the KPI. Similarly, 'NO' was added when the KPI was not affected. Finally, the third column is filled only if there is an impact to the KPI. In such cases, the arguments or examples of why the technology affected the KPI will be described.

Table 2 shows an example of how to use the template.

Table 2. KPI affected by the technology – Warehouse. KPI: Reduction in truck time at the dock

Technologies	Impact?	If Yes, Why?
Virtual and augmented reality	YES	It standardises how to perform the different processes involved when the truck arrives at the dock. It enables the reduction of the time.
Additive manufacturing – 3D Printing	NO	-
Simulation	NO	-
Big Data analytics	NO	-
Cloud technology	NO	-
Cybersecurity	NO	-
The Internet of Things	YES	All the devices and sensors enable the obtaining of data that can be used to increase the efficiency of the load and unload of the truck. It would result in reducing the time the truck is at the dock.
Miniaturization of electronics	YES	By using these elements, there is no need of checking the quality of the products received or the ones which are going to be delivered. This occurs because it is known in advanced the conditions of the products transported. It avoids "last time surprises" like inadequate quality or non-compliance of requirements.
Automatic Identification and data collection (AIDC)	YES	The exact position where items are located/need to be located at the truck are known in advanced. Moreover, the location and position of items inside the truck is also pre-established. It enables to save time.
Radio-frequency Identification (RFID)	YES	The exact position where items are located/need to be located at the truck are known in advanced. Moreover, the location and position of items inside the truck is also pre-established. It enables to save time.
Robotics, drones and nanotechnology	YES	Loading or unloading is done more efficiently and safely, for instance being able to transport different products of different sizes with one single pallet truck.
Machine-to-Machine Communication (M2M)	YES	It helps for instance to know the type of truck arriving with the number of carriers, the amount of items and the type of product among others. By using this information plan the materials required to unload or load in advanced is possible.
Business Intelligence (BI)	YES	By using all the information collected from different sources of the organization, it can be reduced the time the truck is at the dock by having all materials required in advanced. Helps to plan automatically and change plans if unexpected situations occur.

Once this process was done for each of the KPIs, general tables[†] (like in Tables 3 and 4) were created for each area (e.g. warehouse and transport logistics), giving a general idea of which technologies affected that specific area of the SCM; √ represents the YES mentioned above.

So far, the tables already explained which technologies affected which areas; however, there was no indication if this "change" was an opportunity or a threat. Table 5 illustrates the opportunities and threats a technology might have on each KPI, + being opportunities and – being threats.

Table 3. Technologies vs KPIs – Warehouse.

	Reduction truck time at the dock	Accurate receipts received	Reduction time from receiving to pick location	Increase putaway per man hour	Inventory storage per square foot	Consumable usage	Reduction labour hours consumed per order	Reduction time from picked order to departure	Reduction times running out of stock
Virtual and augmented reality	√		√	√	√		√	√	
Additive manufacturing – 3D Printing							√	√	
Simulation								√	
Big Data Analytics						√	√	√	√
Cloud technology		√							
Cybersecurity									
The Internet of Things	√	√	√		√	√		√	√
Miniaturization of electronics	√	√			√	√		√	√
Automatic identification and data collection (AIDC)	√	√	√		√	√		√	√
Radio-frequency identification (RFID)	√	√	√		√	√		√	√
Robotics, drones and nanotechnology	√		√	√	√		√	√	
Machine-to-machine communication (M2M)	√		√	√			√	√	√
Business Intelligence (BI)	√	√	√	√	√	√	√	√	√

Table 4. Technologies vs KPIs – Transport logistics.

	Truckload capacity	Reduction turnaround time	Shipment visibility	Reduction carriers per shipment	On-time pickups	On-time delivery	Complete and damage free delivery	Reduction Average transit time	Customer communication	Order accuracy and completeness
Virtual and augmented reality	√	√					√			
Additive manufacturing – 3D Printing										
Simulation										
Big Data Analytics							√		√	√
Cloud technology			√			√	√	√	√	√
Cybersecurity									√	
The Internet of Things	√	√	√		√	√	√	√		√
Miniaturization of electronics	√				√		√			√
Automatic identification and data collection (AIDC)	√	√	√		√		√			√
Radio-frequency identification (RFID)	√	√	√		√		√			√
Robotics, drones and nanotechnology		√		√	√		√	√		√
Machine-to-machine communication (M2M)			√		√	√	√	√	√	√
Business Intelligence (BI)		√		√		√	√	√		

[†] The entire tables are available upon request

Table 5. Opportunities and threats on supply chain levers.

	Procurement	Warehouse	Transport Logistics	Fulfilment
Virtual and augmented reality	+	+	+	+
Additive manufacturing – 3D Printing	+	+	+	+
Simulation	+	+	+	+
Big Data Analytics	+-	+-	+	+
Cloud technology	+	+	+-	+-
Cybersecurity			-	+-
The Internet of Things	+-	+	+	+-
Miniaturization of electronics	+-	+	+	+-
Automatic identification and data collection (AIDC)	+-	+	+	+-
Radio-frequency identification (RFID)	+-	+	+	+-
Robotics, drones and nanotechnology	+	+-	+-	+
Machine-to-machine communication (M2M)	+-	+-	+-	+
Business Intelligence (BI)	+-	+-	+-	+

6. Discussion and Conclusions

The aim of this paper is to fill the gap in the implementation of technologies involved in Industry 4.0 within the supply chain, particularly the warehouse, transport logistics, procurement and fulfilment functions. Through the analysis performed, the results showed that the areas which will be most affected by the introduction of Industry 4.0 are the order fulfilment and transport logistics. Regarding the order fulfilment, 53.84% of the impact of the technology will be opportunities, while the reminders could be opportunities or threats, depending on the context of the implementation. Transport logistics has 61.54% of the impact can be identified as opportunities, 7.69% being threats and the rest being opportunities or threats. Concerning warehouse, 66.6% can be opportunities and 33.3% can be opportunities or threats. Finally, within the procurement function, Industry 4.0 shows 71.43% of opportunities, the remainder being opportunities or threats.

From the analysis performed, it can be seen that the implementation of certain technologies, such as virtual and augmented realities, 3D-Printing and simulation, results will all result in opportunities. On the other hand, big data analytics, cloud technology, cybersecurity, the IoT, miniaturization of electronics, AIDC, RFID, robotics, drones and nanotechnology, M2M and BI could be opportunities or threats for the organizations. The fact that some technologies can result in both of opportunities and threats is because all the different areas are interconnected, with no clear boundaries between them, depending on where it was analyzed, it could have a positive or negative connotation.

Some clear benefits can be identified from the implementation of Industry 4.0. The most relevant benefits are increased flexibility, quality standards, efficiency and productivity. This will enable mass customization, allowing companies to meet customers' demands, creating value through constantly introducing new products and services to the market. Moreover, the collaboration between machines and humans could socially impact the life of the workers of the future, especially with respect to the optimization of decision making.

Despite the fact that the impacts of Industry 4.0 have been discussed in this paper, due to its theoretical nature, there remain some questions to be answered which consequently limit the generalizability of this paper, not only in its implementation, but also for its management. We therefore call for empirical research in this area. Due to the fact that the implementation of these technologies will be accompanied by a new environment where people work with machines, we believe that legal aspects, liabilities, insurance and ethics should be considered. This paper has been our first attempt to support companies in better understanding the implications of Industry 4.0 and its relevant technologies towards the achievement of the Digital Supply Chain or Supply Chain 4.0. Our work continues with some empirical work and assessment of how companies should digitally integrate their supply chain.

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