Supply Planning Through The Industrial Revolutions

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Abstract

This paper scrolls over the milestones of the industrial revolutions and provides an overview of some events that marked the history of the industrial manufacturing system in general, and the supply planning in particular. Each event has surely contributed to improving the operations within the supply chain, starting from war times before Christ arriving at the current Industrial era known under the name of industry 4.0. the timetable leads to a comparison of the contributions of each industrial era on the supply planning and on its related components. The paper also can serve as a reference for researchers and practitioners interested in the history of supply planning and willing to find research tracks, as it includes feedbacks expressing the current market needs in terms of supply planning improvement.

Keywords

Supply chain, industrial revolutions, logistics, supply planning.

Introduction

Stages in the development of industrial manufacturing systems from manual work towards Industry 4.0 concept can be presented as a path through the four industrial revolutions Rojko (2017). The First Industrial Revolution took hold in Britain towards the latter part of the 18th century, the Second Industrial Revolution arose in Germany and especially in the USA in the later 19th century, while the Third Industrial Revolution emerged in a variety of industrialised countries in the later years of the 20th century Von Tunzelmann (2003). Within the first three industrial revolutions, humans have witnessed and created mechanical, electrical and information technology, which were aimed at improving productivity of industrial processes Zhou et al. (2015). The rapid pace of technological developments played a key role in the previous industrial revolutions Morrar et al. (2017), and paved the way to a new industrial era, where sensors, machines, workpieces, and IT systems will be connected along the value chain beyond a single enterprise Rüßmann et al. (2015) These connected systems (also referred to as cyberphysical systems) can interact with one another using standard Internet-based protocols and analyze data to predict failure, configure themselves, and adapt to changes Rüßmann et al. (2015). The supply planning process in turn was impacted by the four industrial revolutions, although it has started way before with the ancient army, thanks to intuitive logical and logistical skills of war leaders and generals. Infrastructure and roads born out of the need to perform a smooth supply planning for the army, then the steam machine granted the world transport means and production machines, mass production further enhanced the need to supply planning and borders opening. Then, Globalization and increased competitiveness have led to logistics becoming one of the key elements in international trade. Efficient logistics services facilitate the mobility of products, ensuring their safety and speed as well as providing cost reductions when trading among countries Martí et al. (2014).

The present paper covers some historical events that impacted either directly or indirectly the industrial manufacturing systems with a focus on the process of supply planning.

1. Supply planning before the first industrial revolution

The widespread use of the term “logistics” arose in the military. It is often argued that the study of logistics was born out of the necessities of war and the need to move troops, equipment and supplies to the battlefield M. Rutner, et al. (2016). During wars, the greatest concern of generals is to feed their troops to keep them in the battlefield the longest
possible, defeat the opponent, wider spread their power and authority, and conquer more lands. Supplies and provisions were whether gathered gradually as the campaign moves forward, carried with the army train, or sent to the army camp. Two examples of the strongest and robust army supply planning and logistics are considered below.

1.1 Macedonian army

The best and most illustrative example is the example of Alexander the Great and the Macedonian army, as he succeeded to become one of the greatest conquerors in history thanks to his logistician skills and intelligence. Starting from routes planning and assessing the risk of shortages, bad weather conditions, and so on. Before getting his army into danger he undertook extensive geographical studies of each point and area the expedition was going to cross, this was possible with the help of the travelers gathering military intelligence. For transport matters, because of restricted capabilities of the methods of land transportation available to Alexander, only a limited amount of supplies could be carried from one district to the next. Hence, Alexander would have to arrange the collection of provisions in advance, and this was done with the local officials, who regularly surrendered to him before the army marched into their territory W. Engels (1978). The difficulty arose when estimating the number of followers, troops, and animals with the expedition, and their daily consumption. But as the expedition moved forward Alexander started eliminating some companions like women and reduced the number of slaves per person to reduce the overall consumption, he also adapted the animals according to their loading capabilities, speed, and the land they were going to cross. This way, Alexander the great protected his troops from provisions shortages and lack of necessary elements for a successful expedition. Supply was indeed the basis of Alexander's strategy; and when the climate, human and physical geography, available methods of transport, and the agricultural calendar of a given region are known, one can determine what Alexander's next move will be W. Engels (1978).

1.2 Roman Army

There is not enough solid fact to attempt even confident conjecture concerning Roman's system of supply in wartime Goldsworthy (1998). But the researchers so far agree on the fact that roman army played a vital role and laid the first stones of supply planning process. Jonathan (1999) explained how the army was handling supply, transport topics of the main necessary goods at a time which are food and water and fodder for the animals. The army used supply lines that should not be confused with army's train that transports the equipment, supplies, and army itself. Supply lines means a continuous connection between supply sources and the army, using strategic operational and tactical bases, each one of them is considered as a different kind of logistical center. The operational base is where the army gathered supplies within the area of operations. Usually located in a port, it contained the warehouses and depots necessary to hold enough supplies to support the army for an entire campaigning season or longer P.Roth (1999). The operational bases contained infrastructure and included sophisticated greeneries to optimize the storage and to minimize food spoilage. After having supplies shipped to where the army is located, they are stored in a tactical base which is the far end of the supply line, it should ideally be near or within the army camp.

2. Supply planning in the first industrial revolution

the origin of the word "logistics" is based on the view that its genesis temporally correlates with the invention of steam engine in the eighteenth century (1764) Tepić et al. (2011). Steam engine invention gave birth to a new production era characterized by engines that use water steam as a source of energy replacing men and animal physical efforts, goods production became considerable and the factories replaced craft workshops. With English factories calling for supplies, such as American cotton, and sending goods to all parts of the world, better transportation was needed Wolfe (2016). Poor roads were not helping logistics operations to be done correctly, and the means of transportation at a time too. Thomas Telford and John McAdam each developed a method of road construction better than any that had been known since the ancient Romans built their famous roads Wolfe (2016). Early in the 19th century came George Stephenson’s locomotive and Robert Fulton’s steamboat James (2015). The industrial revolution drastically improved Sea and river transportation as well. Many canals were dug, they connected the main rivers and so furnished a network of waterways transporting coal and other heavy goods Wolfe (2016). All these inventions conspired to shorten transit times, Travel times were cut as vehicles went faster C. Allen (2017), and to destroy pre-industrial regions, largely cut off from one another because of poor communication Hudson (1992).
3. Supply planning in the second industrial revolution

3.1 Fordism and mass production

After the steam engine revolution, came the second industrial revolution, which emerged as a transition to mass production at the beginning of the 20th century and paved the way for the utilization of electrical energy Yildiz et al. (2019). One of the main historical events that impacted not only supply planning but the whole industrial manufacturing system is the mass production that appeared with the Fordism, deriving its name from Henry Ford's automated assembly line, Fordism describes the dominant industrial production form for much of this century Ioannides et al. (1997). The switch to production lines organization and specialized functions along the assembly line led to a massive resignation due to work conditions that became harder, as laborers worked for a long time in unsafe conditions. With a constant increase of produced cars and the restrained logistics solutions for storage and shipping at that time, Henry Ford thought about increasing wages according to individual output to encourage the employees to buy the cars they are themselves producing, this can be considered as the first marketing and logistics solution to avoid overstocks, foster and increase the sales of the Ford T.

Firms at the beginning of mass production focused on the product itself and internal manufacturing efficiency on the shop floor regardless of product development, handling, storage costs and space, shortages and requirements calculations accuracy, and so on. A quote of Henry Ford illustrates the situation 'You can have any colour as long as it is black'. The quote captures well the introduction of mass production but without the possibility of products' customization Rojko (2017). But with the increasing competition companies were compelled to seek ways to improve their operations and look over the whole supply chain instead of being limited to internal production, develop their products and stay in line with the market's needs.

From the supply point of view, as a first step to avoid out of stocks and to ensure customer deliveries is to determine the level of inventory which should trigger an action to replenish a particular inventory stock that should be held in the warehouse, the first method to be discovered is the reorder point.

3.2 Reorder Point

Reorders point systems exploit past data and make a projection in the future assuming that these past data are representative of the demand in the future. If at any time, an item's inventory level falls below some predetermined level, either additional inventory is ordered, or new production orders are released in fixed order quantities (FOQ) Rondeau (2001). The reorder point is calculated as follows: \( \text{Reorder point} = \text{Consumption during the lead time} + \text{Safety stock}. \) The reorder point being fixed, the system is considering a constant safety stock no matter what the demand at a given time is. However, when the demand during the lead time is uncertain, the relationships between the order quantity and the reorder point should be further explored, and the reorder point plays a role in balancing the costs between the inventory holding and shortage Wang (2010). What is to be highlighted is that, although most early ROP systems were manual, automated ROP systems soon followed when commercial mainframe computers were introduced in the late 1950s and early 1960s Orlicky (1975). Before the computer was available, companies took six to thirteen weeks to calculate the requirements manually- or with some help from tabulating equipment W.ight(1996).

4. Supply planning in the third industrial revolution:

During the 1960s, the term logistics was first used in the civilian sector in the trade industry. In the United States, the term logistics referred to planning and implementation of physical distribution Tepić et al. (2011). In 1974, Hans-Christian Pfohl provided the characteristic areas of logistics tasks, conceptualized and shaped logistic axiomatics and developed logistics as a science Jovan et al. (2011). According to Patrick et al. (2001), to gain a historical perspective, it is useful to look at the evolution of these systems. Five major stages were involved: (1) reorder point (ROP) systems, (2) materials requirement planning (MRP) systems, (3) manufacturing resource planning (MRP-II) systems, (4) MRP-II with manufacturing execution systems (MES), and (5) enterprise resource planning systems (ERP) with MES Patrick et al. (2001). When examined in detail, each stage represents the next logical step in manufacturing philosophy and technological innovation over the preceding stage Patrick et al. (2001).

The first method of the list, which is reorder point has been already covered previously, further methods will be explored below.
4.1 Materials resource planning and master production schedule

Materials resource planning was first developed by Joseph Orlicky in 1960, in 1975 the first edition of the book Material Requirements Planning—The New Way of Life in Production and Inventory Management was published gathering 15 years of the overall experience acquired while helping companies to implement this new method. Why was there such a lag between 1960 and 1975? Orlicky explains it: “in the field of production and inventory management, literature does not lead, it follows Orlicky (1975), that is to say, to have a deliverable piece of work, it may take years and years of practice in the field to scrutinize and build knowledge and not rely on observations emanating from theoretical researches only. Thus, the knowledge remained, for a long time, the property of scattered MRP system users who normally have little time to inclination to write for the public Orlicky (1975),

This method aims to enable MRP users to calculate the requirements for each component starting from the finished products using the bill of material. A bill-of-material of a particular product specifies, how this product, the parent, is built-up from its immediate components These components may have a bill-of-material of their own and so on Hegge et al. (1991).

The method takes as an input the master schedule for production and the forecast of the finished product. The master schedule for production MPS is a planning based on a demand forecast and the aggregate production planning. MPS indicates the quantity to be produced from a finished product on a weekly basis to fulfill customer demand, considering factors such as raw material availability, production lines capacity, The inventory strategy of the firm, and so on. The frequency of MPS Planning is still a topic of discussion and research, especially under demand uncertainty. Practitioners in general prefer to make the MPS weekly. Frequent changes in the MPS reduce productivity whereas a long-term frozen MPS results in a poor service level and an unfavorable inventory situation Tang et al. (2002). The length of planning horizon is also an important parameter in the master production schedule, this must be at least as long as the total cumulative manufacturing and purchasing lead time for the end items being produced. P.Adams et al. (1985). Usually, the period of the planning horizon guarantees a visibility between six months and one year. The MPS provides the important link between the forecasting, order entry, and production planning activities on the one hand, and the detailed planning and scheduling of components and raw materials on the other Sridharan et al. (1987)

4.2 Manufacturing resource planning and Sales and operations planning

MRP II is a sophistication and an evolution of MRP, from raw materials requirements calculation and planning to capacity requirements calculation and planning that is to say that MRP II is able to schedule the production considering the available workforce and machines. Although MRP II implementation is complex and is not successful in all cases, companies invested their money and took the risk of implementation failure.

Starting from 1990, companies realized that it is useful for the whole supply chain to be on the same wavelength and be aware of demand variations resulting from marketing plans such as promotions, successful advertisings...The sales department started elaborating a forecast as an anticipated response to the aforementioned marketing plans which was called Sales and operating planning. As in MPS, the planning horizon is a key element for the forecasting process. Planning horizons typically range from 6 months to over 3 years, but the most common horizon seems to be 6-18 months Thomas et al. (2015). S&OP generally creates plans for the next 1-18 months, it is often applied to product families rather than to individual stock keeping units (SKUs). Thomas et al. (2015).

4.3 ERP Enterprise resource planning

No one would dispute that information technology (IT) has become the most important cornerstone of an enterprise’s ability to successfully compete in the global marketplace Yusuf et al. (2006). In fact it seems that the use of IT is crucial, especially in fast-moving industries, and particularly for managing contemporary supply networks Auramo et al. (2015). According to Simchi-Levi et al. (2003), the objectives of IT in SCM are:

- providing information availability and visibility;
- enabling a single point of contact for data;
- allowing decisions based on total supply chain information; and
- enabling collaboration with supply chain partners.
The industrial system took advantage from IT and came with a new resource planning system, called Enterprise resource planning. ERP is a centralized system and a computerized database allowing to each department or ERP Module to store and retrieve data and giving to each user real-time access to information. Not only internal data are integrated, ERP attempts to integrate suppliers and customers with the manufacturing environment of the organization Gupta (2000). The emergence of ERP in early 1990 led to the inclusion of other functions such as accounting and sales management Gupta (2000). ERP increased accuracy and responsiveness, by making real-time data accessible to every user, everyone in the firm can check by their own the financial parameters of component X, price, terms of payment, They can also have access to data related to the vendor, address phone number, transport route, and organization of this Component, the storage locations where it can be found, production lines where this component is used.. this remains a small example illustrating the ease ERP added to industrial operations and manipulations.

5. Supply planning in the fourth industrial revolution

The phenomenon of Industry 4.0 was first mentioned in 2011 in Germany as a proposal for the development of a new concept of German economic policy based on high-tech strategies Mosconi (2015), it 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 Tjahjono et al. (2017). That is to say that things, machines people, and so on will form an interrelated system, each entity is provided with a unique identifier in order to allow data transfer over the network without human interaction. Furthermore, with recent developments that have resulted in higher availability and affordability of sensors, data acquisition systems and computer networks, the competitive nature of today’s industry forces more factories to move toward implementing high-tech methodologies Lee et al. (2014), and tend to become a smart factory, Products in such factory are also ‘smart’, with embedded sensorics that is used via wireless network for real-time data collection for localization, for measuring product state and environment conditions Rojko (2017).

The impact of the technology on the supply chain is emphasized with the fourth industrial era. The proper alignment and integration between the main actors of the supply chain and the increasing level of visibility and transparency will ensure an adequate forecast of resources (people, materials, equipment) which will potentiate the optimization of resources/processes, the time to market alignment and raise the asset employment Barreto et al. (2017)

6. The main impacts of industrial revolutions on the supply planning:

The following table consolidates some marking events over the history, that impacted the supply planning process and a brief description of the impact and improvement made:

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Table 1. Some industrial events contributions to supply planning
<table>
<thead>
<tr>
<th>Industrial Era</th>
<th>Some historical events</th>
<th>Contributions to supply planning</th>
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<tbody>
<tr>
<td>Before the first industrial revolution</td>
<td>Roman wars</td>
<td>infrastructure and robust roads building, which made easy the supply of provisions using supply lines.</td>
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<td>the use of logistical centers and bases to store and ship the supplies.</td>
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<td></td>
<td>Macedonian Wars with Alexander the great</td>
<td>Routes planning, shortages, and overloading risk assessment.</td>
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<td>assessing the impact of bad weather conditions on the gradual stock replenishment.</td>
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<tr>
<td>The first industrial revolution</td>
<td>Steam engine invention</td>
<td>Resumption of roads and canals construction following the need for land and oversea shipping.</td>
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<td></td>
<td></td>
<td>Transit times are reduced, and supply sources are easily reachable.</td>
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<tr>
<td>The second industrial revolution</td>
<td>Fordism and mass production, the establishment of the machine tool industry</td>
<td>The emphasis on the need to supply and ship manufactured products and enhance upstream and downstream materials flow.</td>
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<tr>
<td></td>
<td>The computer and mechanized processes invention</td>
<td>Raw materials ordering time manual calculations are reduced.</td>
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<td></td>
<td>Reorder quantity</td>
<td>the beginning of making a linkage between the inventory level and its handling costs, minimizing the quantity on hand, and avoiding out of stocks first systematized trials.</td>
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<tr>
<td>The third industrial revolution</td>
<td>Materials resource planning &amp; Master production schedule</td>
<td>Bill of material explosion at multiple levels of the finished product, fast gross and net dependent requirements calculation with MRP.</td>
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<td></td>
<td>The planning horizon expanded to give visibility on independent requirements linked to customer forecasts.</td>
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<td></td>
<td>Manufacturing resource planning &amp; sales and operations planning</td>
<td>Raw material call-offs are restrained and adapted according to the output of MRP II which now considers the shop floor capacities, machine, and workforce.</td>
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<td></td>
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<td>responsiveness to demand variations is increased thanks to the sales and operations planning and the aggregate plan which reflects the market's reactions to marketing plans.</td>
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<td></td>
<td>Enterprise Resource planning</td>
<td>a shared and a common vision on demand up to 3 years of the horizon. The forecast delivered by the S&amp;OP is reflected among the supply chain to enable each part to check their production capacity and their ability to be aligned to demand variations.</td>
</tr>
<tr>
<td>The fourth industrial revolution</td>
<td>Industry 4.0</td>
<td>Business costs further decreased and excessive inventories are reduced thanks to real-time access to data, and integration of internal departments, suppliers, and customers in the same loop.</td>
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<td>data transfer among the supply chain without human interventions, less workload for supply planning, and more focus on efficiency of the process of supply planning itself.</td>
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According to the summary in table 1, we can identify seven major components linked to supply planning that was directly and positively affected by each of the above-mentioned stages of industrial revolutions which are: Transport and routes planning improvement, Inventory management and accuracy, Forecast accuracy/responsiveness to market fluctuations, Workload reduction, Lead time reduction, Transit time reduction, Data processing and sharing time reduction.

The radar graphic below plots a qualitative comparison of the contribution of each industrial era on these seven components.

<table>
<thead>
<tr>
<th>Transport and routes planning improvement</th>
<th>Inventory management and accuracy</th>
<th>Forecast accuracy/responsiveness to market fluctuations</th>
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<tr>
<td>Data processing and sharing time reduction</td>
<td>Workload reduction</td>
<td>Lead time reduction</td>
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<table>
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<th>Before the first industrial revolution</th>
<th>The first industrial revolution</th>
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<tr>
<td>The second industrial revolution</td>
<td>The third industrial revolution</td>
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<td>The fourth industrial revolution</td>
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High sensitivity to market behavior, demand fluctuations are directly shared with the whole supply chain without being forced to wait for MPS and S&OP meetings, this will help the suppliers to gain time and faster adapt their planning, the capacity to convoy market variations with more accuracy.

Transport matters and delays are avoided, milk runs are going smoothly, and invoices are shared with each affected party after they are edited from the supplier.

Strong traceability and tracking of raw material in every stage of the production and supply process and in every storage location, warehouse, wip...

From the origin of the axe to the name of the component; if 25% is reached it is equivalent to low contribution, 50% means medium contribution, and 100% high contribution. The polygon that looks more regular is the one of industry 4.0 as this industrial revolution highly improved the supply chain in its entirety and has a low impact on transport and routes planning, as the improvements brought to this field day after day are not totally related to the industry 4.0 but to the globalization and the need to link different points of the globe within a minimum of time and cost.

Figure 1. Comparison of the contribution of industrials revolutions on supply planning major components.
Supporting this analysis, and for further researches related to the industry 4.0 viewed from the logistics angle, I conducted an interview with two professionals in the supply chain management with over 20 years of experience in the field, especially in the automotive industry.

Both professionals witnessed the following transitional phases in the supply planning, Reorder point $\rightarrow$ MRP1 $\rightarrow$ MRP2 $\rightarrow$ ERP, their feedbacks and a brief description of these transitional phases converged and both agreed that in ROP it was necessary to consider the production plan vs previous safety stock used regardless of the current and future requirements, with MRP1 and MRP2 the supply planning was sophisticated and the mastery of the process increased, many rules emerged and many supply chain management fundamentals appear such as BOM, MPS S&OP where we consider past present and future data to come up with a more reliable forecast and representative of the market state. As to ERP, it integrated data from entry point customer order till endpoint purchase order to suppliers which centralized the processes and further improved the operations within the supply chain.

Professional 1 explained that each time, the switch from a phase to another brought inventory decrease since correct parameters and settings are used, as well as major adherence to forecast variability for production planning. ERP had all data in one place, forecast variability better integrated, and checked. According to professional 2 In the last years the forecast accuracy became better, but still not good enough. and as a result of this companies are seeing improvements in inventory management. The better the forecast of the customers are and the better the supplier-customer relationship and the trust between the entities is increased, the more lead times are improved. Despite the huge improvements the current supply chains are still facing redundant issues such as longer lead-time for raw material if we take the textile industry as an example, Asian material with long transit time vs variability of customer forecast either increase inventory with safety stock to be used (blocking cash-flow) or increase potentially premium freight to cover gaps (additional expense).

According to the Figure 1, Industry 4.0 if implemented will have a radical impact on the above-mentioned issues, this should foster the implementation of such a revolutionary concept in all the industrial companies, according to Professional 1, Industry 4.0 will lead to avoiding human errors, guarantee a fast reactivity on changes, foster the automatization, increase transparency, and allow decentralized decisions as they will be done based on algorithms.

The implementation has its costs also such as cost, privacy issue, lack of human contact, major impact on head-count reduction, as consequence lack of jobs for many people. As the concept is new to companies it will be necessary to go through an experimental phase since there is a lack of rules, regulation which lead to a “pioneer phase” and from here the reluctance of parties. But still, the companies are procrastinating the implementation due to a major obstacle which lies in the financial reasons and implementation costs.

For Professional 2 the most important advantages of industry 4.0 are transparency and communication as well as the simplification of processes. With all the data which are produced and used the efficiency can be improved a lot. This leads to disadvantages. One big risk is data protection. Not only this protection but also other facts can lead to high costs when implementing industry 4.0. Furthermore, it is not sure if all necessary partners will implement industry 4.0, accept and work in the way it is needed from all involved parties in the supply chain. Obviously, many risks will accompany the implementation of Industry 4.0 both professionals confirmed that the main risk with this concept is linked to IT lack in general: security of data, technology skills, to the transfer of the "know-how" of a particular business, and to low top management involvement.

**Conclusion**

The industry contributes to nations growth, by increasing the international trade level and providing work opportunities and so on. Therefore, each county is brought to keep good industrial performances, and further improve the infrastructure to make easy logistics operations. The focus on the supply was a part of this paper, where different stages of the supply were covered, and the contribution of each stage was discussed. Practitioners and researchers should align their efforts in order to make the supply chain as resilient as possible to face any disruptions that may accompany the industrial success that we notice and witness nowadays.


Wang, C., Some remarks on an optimal order quantity and reorder point when supply and demand are uncertain, *Computers & Industrial Engineering*, vol. 58, no. 4, pp. 809-813, 2010.


**Biographies**

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