Supply Chain Design and Performance Enhancement by Industry 4.0

M. B. Kiran
Associate Professor,
Department of Mechanical Engineering,
School of Technology,
Pandit Deendayal Petroleum University,
Gandhinagar, Gujarat-382007- INDIA
Kiranm.bhaskar@gmail.com

Abstract

Supply chain design is unique to a particular industry. Supply chain of a company consists of different elements (viz. Planning, Information, Sourcing, Inventory and manufacturing). Earlier elements of the supply chain used to work in isolation. Information sharing was very difficult and was not in real-time. IIoT has made information sharing across the elements of the supply chain possible and in real-time. IIoT has increased transparency in information sharing. This will make the supplier, manufacturer, and customer to be in synchronization. This has brought down inefficiencies in the supply chain. This has also increased trust among the members of the chain. This has reduced the wastes related to the communication gaps. IIoT has helped companies in making their customers happy, by supplying quality products on time. With the introduction of I4.0, many researchers have applying Industry 4.0 technologies for designing a company's supply chain. I4.0 is becoming popular among practitioners and researchers, in the design of an organization's supply chain (SC). This is mainly because, by using I4.0, sup-ply chain will become more flexible, efficient, quick and become transparent among SC elements. An attempt is made in this research work is to review the existing technologies and then present future research directions. This would help those who are interested in pursuing further research.

Keywords
SCM, Industry 4.0, SCM design

1.Introduction

This article intends to explain how the advent of I4.0 has affected the supply chain design. This article has been arranged into three sections. First section describes the supply chain concepts. Second section describes the relevance of SC design and its status as of today. Third section is dedicated for explaining the future directions for designing different components of SC using I4.0 technologies. The ultimate objective of using I4.0 in supply chain design is to achieve operational excellence, transparency.

A Supply chain (SC) consists of the process of buying raw materials from vendors for the manufacture of products through to their distribution and sale. Many companies have failed in terms of managing their supply chain challenges. Thus, effective management of company's supply chain is very much required for its survival. This has made many researchers to work on supply chain design. Research has shown that managing supply chain volatility has led to the success of a company (Fair et al., 1989; Blinder et al.,1986).

1 Literature review

I4.0 technologies may include - IoT, mobile, augmented reality, sensors, additive manufacturing, Big-Data, etc. (Ornig et al.,2016). These technologies are being used for designing a company's SC, by researchers. The main purpose behind using I4.0 (Figure 1) is to ensure operational excellence. Also, to make a company's supply chain quick, flexible, and to become transparent. This is going to make all the elements of SC (Figure 2) work in seamless fashion. This will make the company in meeting customer's expectations. An effort has been made to show how the different components of supply chain (Figure 3) can be designed by using Industry 4.0.

Planning: Many research works have shown the importance of planning while designing the supply chain of a company. This is true not only with regard to manufacturing but also any non-manufacturing and service industries. Every organization will have to design a right supply chain for meeting customer expectations. A marketing forecast helps a company in knowing its product demand. Success of a marketing forecast depends upon the accuracy of

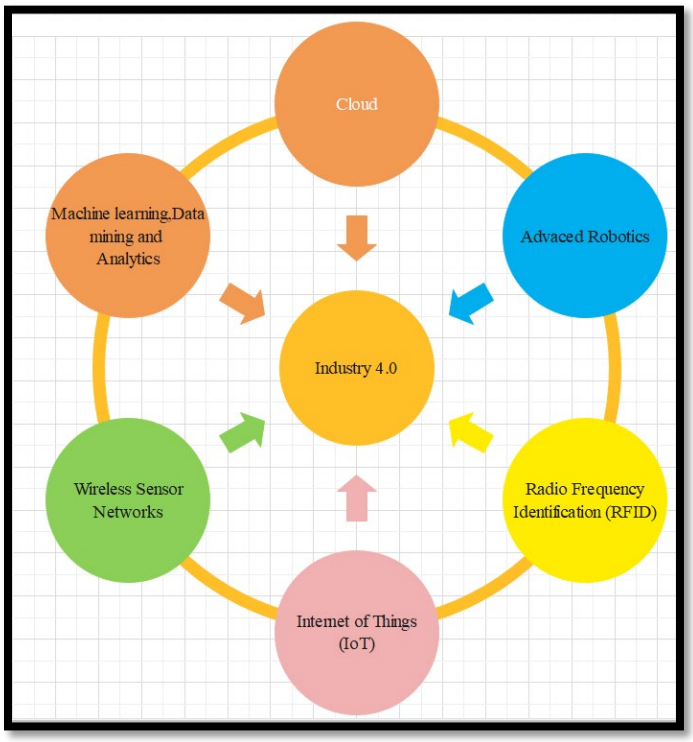

Figure 1. 4.0 Components

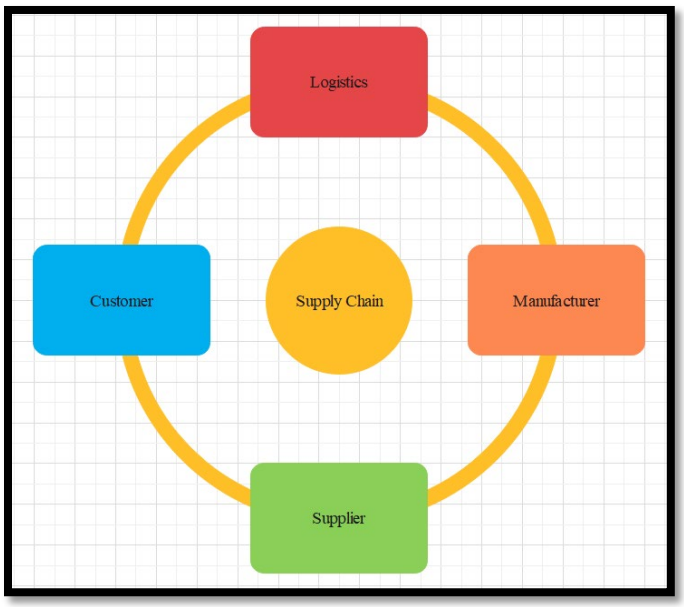

Figure 2 Company's supply chain composition

prediction. Accurate forecast is very much essential as it would help in buying required type of materials in correct amounts at the required time. This would also help a company buy required raw materials at the right price. Accurate forecast will also help suppliers. Many a times, suppliers may not have the right type of materials in their store, which is required by the manufacturers. Figure 1 shows IIoT enabled supply chain with sensors and antenna. Figure 4 shows the arrangement being made at the supplier, manufacturer and customer ends. As can be seen sensors are connected by using wireless network. The sensor output will be read by a reader. The reader is connected to the controller. The controller in turn is connected to cloud through antenna. Thus, the data and information exchange can happen among supplier, manufacturer and customer in a seamless manner. This will make the entire supply chain efficient. This clearly shows the importance of sharing marketing forecast of a manufacturing company with its suppliers. By sharing of marketing forecast of a manufacturing company, suppliers will come to know what type of raw materials, in what quantities are required by the manufacturing company and at what time. This is very important from the supplier's perspective.

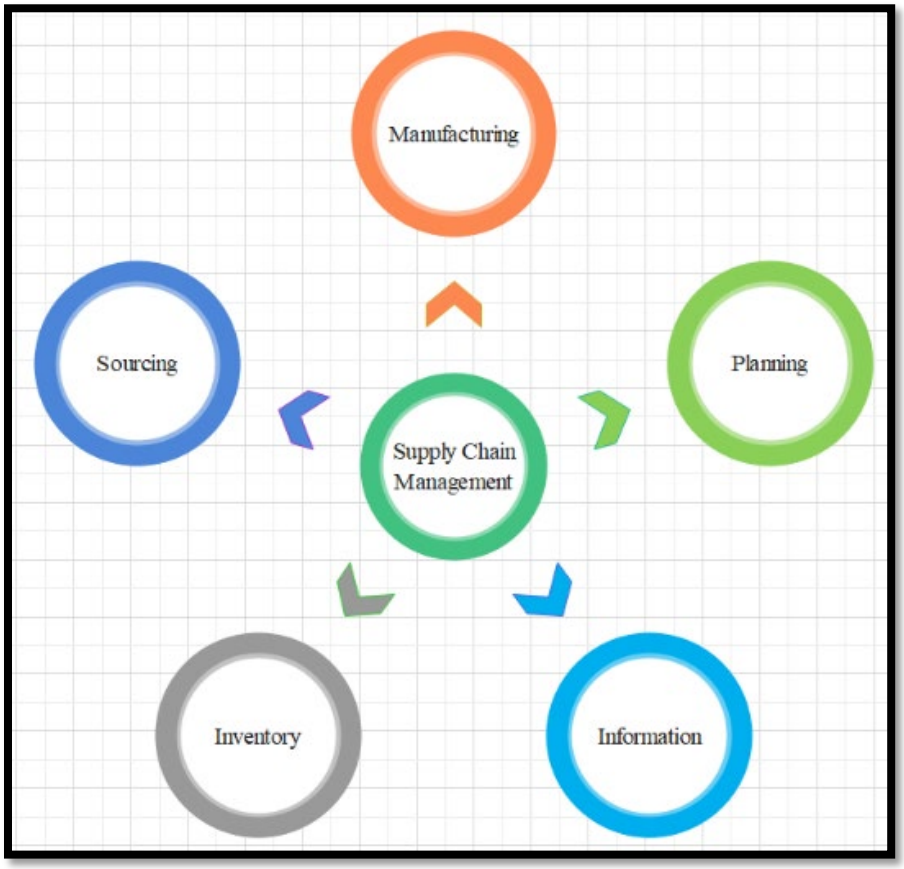

Figure 3. Components of a company's supply chain design

Ekren et al. (2021) have designed a supply chain for e-commerce companies. They have studied how difficult it is to manage food supplies in the event of natural disasters such as pandemics and earth quakes. They considered a case where all the groceries are interconnected by Internet of things. In this scenario, they tried to design a sustainable supply chain for minimizing wastes. They have designed a supply chain by using a lateral inventory.

Volatility is posing the biggest challenge to the managers of SC (Handfield et al.,2013). One of the reasons for the volatility in the SC is that the different elements of the SC are not aligned with one another. That is different elements of the SC have multiple objectives (Chang et al., 2006). Other reasons for volatility may include long lead times, not

fully understanding customer requirements, errors in marketing forecasts, changing government policies etc. This clearly shows how complex it is to deal with the supply chain volatility. As managing supply chain volatility is important, many methods have been proposed by many researchers (Engelhardt-Nowitzki et al., 2012). Christopher et al. (2017) has demonstrated that the existing practices for addressing the supply volatility are not efficient. Many novel methods have been designed for addressing SC volatility.

- Sharing the goals of company with all departments
- To provide encouragements to customers for required data for creating accurate sales forecasts
- Reduction in time required for buying raw materials, by knowing the lead time deviations from the suppliers at the earliest
- To design dependable business processes
- Introducing a new organization culture where people can discuss the problems openly and in implementing best practices.
- To develop a habit of long-term partnership with competitors in order to address severe competition.

Additionally, the managers dealing with the management of SC have constraints with regard to limited number of resources/ or limited bandwidth. In this context, the managers cannot explore the effect of all influential factors that affect SC volatility. Thus, the managers would prefer knowing those factors which have significant impact and require more attention than others. This problem was properly addressed by a researcher (Saaty, 2017) who proposed the Analytical Network process (ANP).

ANP is a decision support technique (Figure 5). ANP is getting more attention from researchers studying supply chain volatility problem (Ramanathan et al., 2007). ANP is also used by a researcher (Chan et al., 2003) for assessing the performance of a company's SC. Experienced SC managers are required for managing SC volatility.

If the sales forecast gives under estimates then, the company cannot meet customer's expectation. On the other hand, if the demand forecast is high then this would make large number of products in company's warehouse. Thus, there would be loss in revenue. For designing an effective digitization strategy,

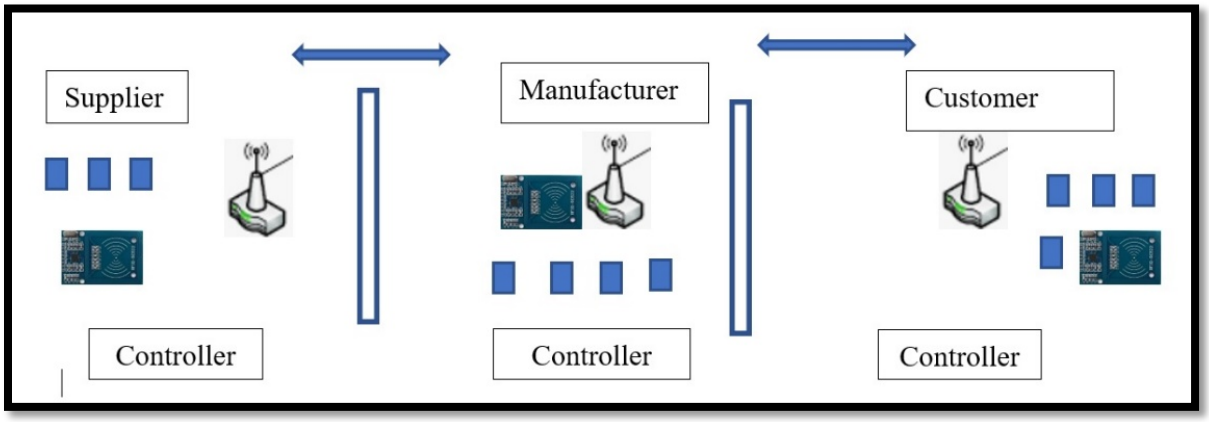

Figure 4 IIoT enabled supply chain with sensors and Antenna

companies will have to study information such as the need for digitization, components of the SC that are to be digitized, the technology to be used, project duration etc. Selection of proper technologies will result in seamless integration a company's supply chain elements, for meeting customer's expectations.

Information: Companies are in need of right information at all points in time. Companies are interested in knowing the availability of raw materials, people, equipment, tools for taking right decisions. A company would also require information regarding the date of dispatch of raw materials by the supplier. As this would help in knowing

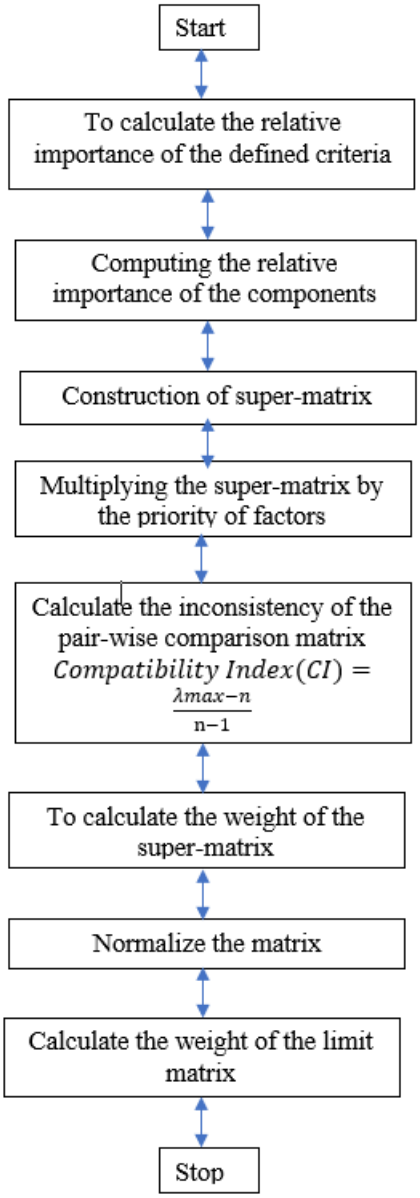

Figure 5. Steps in Analytical Network Process (ANP).

whether a customer's order can be met or not. By using, Internet of things (IoT), all these problems can be addressed and this would make a company's supply chain more flexible and transparent and work in a coordinated manner.
IoT was first implemented in 1999, for monitoring of manufacturing process (Kirk, 2015; Zhang et al., 2011), as well as after-sales management, in automobile companies. By using Industry 4.0, many physical systems are being transformed into cyber-physical systems. Radiofrequency identification devise (RFID) has made tracking of elements of the supply chain in real time possible. This will assist manufacturers, suppliers and buyers in making appropriate decisions. This is going to enhance the transparency as well as visibility of the entire SC. Thus, many of the problems of the conventional supply chain could be solved by using the I4.0 technologies. In addition, in a latest supply chain using I4.0 technology, real time sharing of information among all the elements of the SC is possible.

In a conventional SC because of un availability of real time information manufacturing suppliers used to make many mistakes, such as, delivery of in correct quantity of raw materials, in correct type of raw materials etc. This would

result in significant amount of waste of time as well as production effort and manufacturing cost. Thus, with the advent of I4.0, existing supply chains require redesign. Both RFID and IoT technologies are being used for solving privacy problems and security problems from RFID technology.

With this a modern supply chain not only makes it possible for exchanging necessary information among the components of the supply chain, but also is smart enough for protecting the cyber physical systems.

Sourcing:
Sourcing process helps companies in locating, assessing and interacting with the vendors for acquiring materials as well as services. Earlier, companies were owning all the components of SC. But, in modern days, the companies focus more on core services and they depend on many vendors and contractors for acquiring spare parts and raw materials. The traditional methods used for vendor selection and assessment methods are purely manual and are prone to make mistakes. Results of many critical decisions made during the management of supply chain by managers depend to a large extent on vendor selection and assessment. This clearly shows the significance of supplier selection and their assessment.

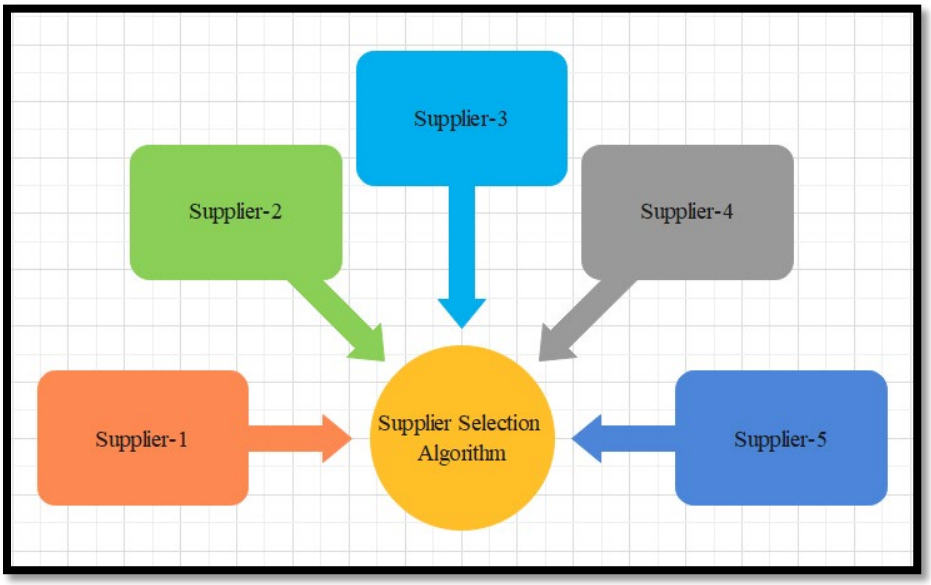

Figure 6 Supplier Selection Algorithm-Inputs

Many researchers have been working on supplier selection problem (Figure 6). Aissaoui et al. have studied the SC in detail and gave the classification of SC. In the single vendor problem, a single vendor can meet company's all requirements. So, here the question is who is the best supplier? (Golmohammadi et al. 2012, Chen et al.2015, Tavana et al. 2016). In case of multiple vendor or supplier model, every supplier will have certain constraint, that is one supplier cannot fulfill all the demands of a manufacturer (Figure 7).

The problem here is to choose the best vendors and to decide about the quantity of items to be ordered (Kamalahmadi et al.2017, Alfares et al. 2018, Sawik 2014). Vendor identification (Firouz et al. 2017, Ware et al. 2014) models can also be classified into Quantitative and Qualitative approaches. In Quantitative model different approaches are available- linear programming method (Pan 1989, Anthony et al.1977), linear (Basnet et al.2005, Chaudhry et al.1993, Demirtas et al. 2008) mixed-integer programming, Non-linear (Esmaeili et al. 2019, Hu et al. 2018) mixed-integer programming, Goal (Buffa et al. 1983) programming, stochastic (Hammami et al.2014) programming, Dynamic programming (Masella et al. 2000, Mendoza et al. 2010)

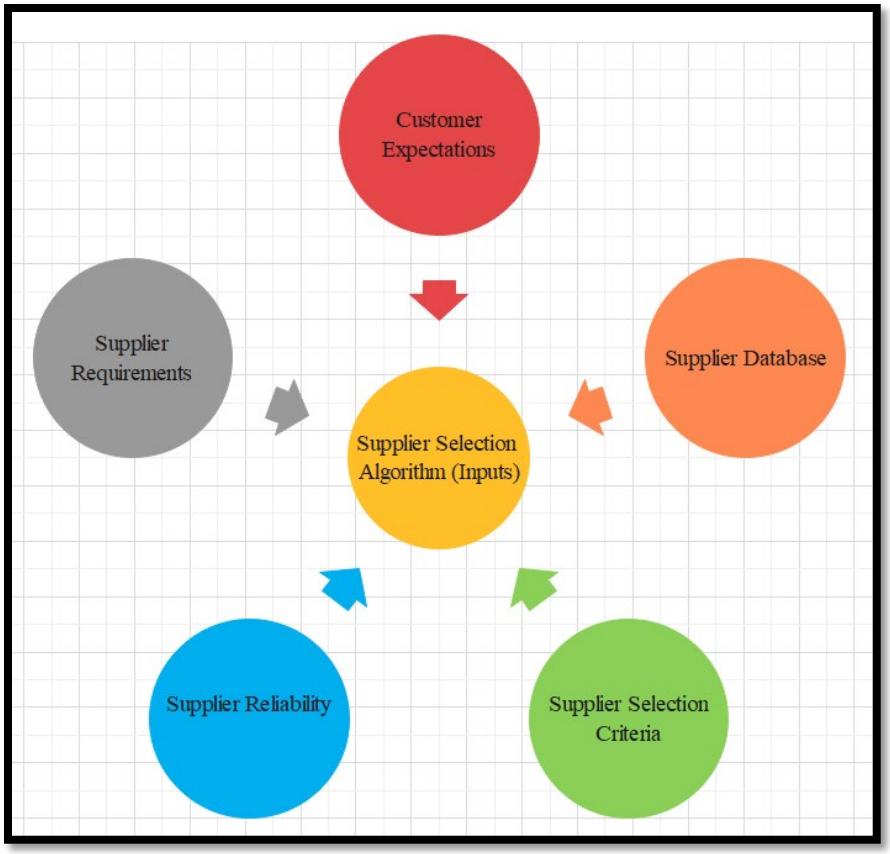

Figure 7. Supplier Selection Algorithms-Inputs

With the availability of I4.0 technologies, many researchers have proposed new methods for both vendor identification and vendor assessment. Modern day supply chains are geographically distributed as well as dynamic and interactive.

Many research works have explored how different factors can affect vendor selection and assessment (Ghadimi et al., 2018). The User interface layer is basically a set of forms used by product manufacturer as well as vendors for providing necessary data. The user interface layer was implemented by Java. Using internet, MAS system establishes the connections between the vendors and manufacturers. One of the best features of MAS is that any vendor can be added or removed on need basis. MAS system also helps in exchanging the information from among the supply chain elements. Thus, all elements of the supply chain will have latest information. Using MAS system companies can rank their vendors based on the pre-defined criteria. Thus, MAS system would help in enhancing the operational excellence of the entire supply chain.

Inventory:
Manufacturing companies are doing lots of investment for buying and storing necessary raw materials from their suppliers. This is required for meeting the customers' expectations. Thus, the inventory of raw materials is required for protecting company against supply side volatility as well as for meeting customer's order on time. However, maintaining huge inventory is costly as well as risky. If inventory (Figure 8) level of a manufacturing company is high, then this would require huge investment. Large inventories also consume large space. High inventories will have high inventory carrying costs (Pezhman Ghadimi et al., 2019).

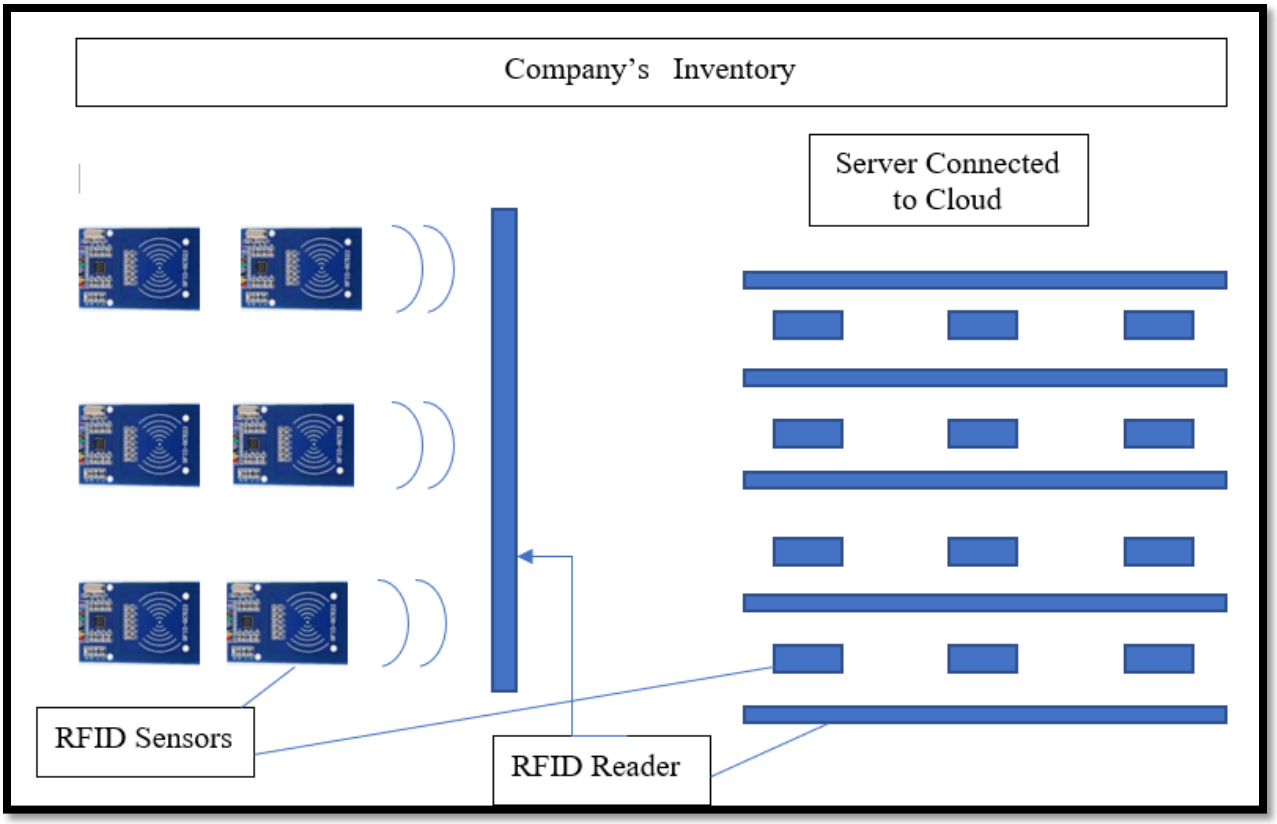

Figure 8. Configuration of IIoT enabled Inventory System

Toyota manufacturing company of Japan, were the first to propose and implement the lean philosophy. According to lean practices, inventory is considered as a form of waste. Lean philosophy recommends elimination of all types of waste. Lean philosophy has identified different types of wastes, such as, unnecessary transportation, inventory, unnecessary movement of workers, high work-in-process, overprocessing, overproduction and delay in processing components. Many companies would aim for waste elimination by executing lean projects.

In aerospace companies too, spare parts storage management is very significant (Kilpi et al., 2009). Atzori et al. (2010) have explored location tracking of inventories, using IoT. Researchers have been exploring about enhancing the accuracy of inventory estimates by using IoT (Da Xu et al., 2014; Sun, 2012). Lee et al. (2015) have explored a new technique for reducing the inventory carrying cost by supplier-managed storage system. Researchers have demonstrated how IoT and RFID could be used in managing a company's inventory (Zheng et al., 2017).

Manufacturing:

Material availability is very important in manufacturing. Companies are increasingly using Industry 4.0 technologies for ensuring the timely availability of raw materials. Smart manufacturing units are using cyber -physical systems (CPS) for providing data as well as information sharing among machines without human assistance. The objective of I4.0 enabled manufacturing is to achieve operational excellence.

2 Conclusion

This research article attempted to review the literature regarding using IoT in the design of a company's SC. A companies SC is unique. In that, a SC is specific to an organization. SC design is a very difficult task. Many companies have failed in the design of a proper SC. This clearly shows the importance of SC design.

Research work showed that a company's supply chain is comprised of many components-inventory, planning, manufacturing, sourcing, and information. Earlier companies have had problems while dealing with each of these components. Companies were looking for ways for addressing many of the problems related to these components. The article also shows how researchers have implemented Industry 4.0 technology in enhancing the performance of the components of the SC. By using I4.0 technologies, researchers have made the supply chain flexible. The supply chain also became, quick and efficient, and also work seamlessly, for meeting the requirements of the customers. Despite all these advantages, IIoT enabled supply chains to have many challenges. Organizations will become successful only if these challenges are properly managed.

RFID-based sensors are becoming very popular in managing a company's inventory system. Nowadays, real-time information about the type, number, and location of raw materials, semi-finished goods, and finished goods, can be made available with the help of RFID-based sensors and IIoT infrastructure. This was not possible earlier. This has enhanced the transparency and accuracy of information. This can make company's take the correct decisions at the required point in time.

Earlier elements of the SC used to work in isolation. Information sharing was very difficult and was not in real-time. IIoT has made information sharing across the elements of the supply chain possible and in real-time. IIoT has increased transparency in information sharing. This will make the supplier, manufacturer, and customer to be on the same page. This has brought down inefficiencies in the supply chain. This has also increased trust among the members of the chain. This has reduced the wastes related to the communication gaps. IIoT has helped companies in making their customers happy, by supplying quality products on time.

Sensors used in IIoT implementation are heterogeneous. Thus, there is a need for dealing with vast amounts of structured and unstructured data. As data have different formats, it becomes very difficult to manage these types of data. Especially, storing vast amounts of data in a meaningful way is becoming very difficult. Many of the existing database systems cannot be used. Separate data warehouses are required. They also demand huge requirements concerning the hardware. Industry 4.0 offers Big-data analytics for managing a vast amount of data. Industry 4.0 also offers cloud-based technology for achieving connectedness and flexibility.

Though many researchers have demonstrated how supply chain efficiency can be enhanced. Still, much research work needs to be done in the area such as the protection of CPS. This is because CPS are vulnerable to cyber-attacks. The cyber-attacks do differ from one another. This shows that solving problems related to cyber-attacks are very dynamic. Every cyber-attack is unique and varies across domains. What is secured today may not be true for tomorrow. This will add up to the complexity of the problem. Intruder detection, and locating, the position and posture of an intruder is done by using machine learning and CNN. However, much research work remains to be done in improving the accuracy of intruder detection and in making the system robust.

The main advantage of additive manufacturing is that complex products can be made. The products made by additive manufacturing are relatively costly. Thus, there is much scope for reducing the cost of manufacturing. This will go a long way in making AM useful in many un-touched areas. The additive manufacturing process consumes more energy than the conventional manufacturing process. Thus, presently additive manufacturing is not eco-friendly. Much research work is needed in making the additive manufacturing eco-friendly.

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Biography

Dr. M. B. Kiran is an Associate Professor in the Department of Mechanical Engineering, School of Technology, Pandit Deendayal Petroleum University, Gandhinagar, Gujarat, INDIA. He earned his graduation (B.E.) from the University of Mysore in 1987. He did his post-graduation (M.E.) in Production Engineering from P.S.G. College of Technology (1991) and Doctoral degree (Ph.D.), in Surface Metrology from Indian Institute of Technology (I.I.T.), Madras in 1997. He has Industry/Research/Teaching experience of 25 years. He has published technical papers in many reputed national/international journals and conferences. He is a member of the Project management Institute (P.M.I.), U.S.A. He is a certified project manager (P.M.P.) from P.M.I. He has completed many mission-critical projects. He has conducted many training programs for working executives.