A conceptual framework for real-time adaptive supply chain systems based on Internet of Things (IoT)

by

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Abstract

Supply chain (SC) systems are often subject to high operational dynamics due to the large number of resources involved, frequent interaction between them, exhaustive human participation and timely decisions being made. This dynamic nature of SCs can be organized more efficiently by adopting Internet of Things (IoT) to capture real-time SC information and its associated resources. Even though the modern industry has gained a remarkable benefit from IoT, the potential to improve Supply Chain Management (SCM) by integrating them into Enterprise Resource Planning (ERP) process, has not been fully explored. In response, this study examines how a robust information structure can be designed and real-time schemes for controlling the SCs inherent to real-life systems applied. Motivated by the comprehensive application of industrial Internet-of-Things (IoT) systems, this research investigates the typical SC execution processes to design cost-effective IoT solutions. The internal and external SC processes are first examined separately. A conceptual framework is proposed to study the capabilities of IoT on applied in SCM, starting with the IoT impact on SCM and then describes a theoretical framework that creates a system linking the four aspects of the supply chain (warehouse, supplier, logistics, and client) using IoT. It has been shown that the information sharing across the selected supply chain partners can be achieved using state-of-the-art technologies. This framework demonstrates how IoT could enhance SCM, which helps the members of the supply chain to improve their overall performance through improved information sharing, efficient resource utilization and reduced loss of merchandise along the supply chain. The significant components of the proposed framework are data collecting devices, the network for transmitting the received data and the integrated information management system where the data collected is processed and analyzed using big data analytical tools by end users. Additionally, this framework explores all possible supply chains for a product, and suggests an appropriate supply chain primarily, based on the client's desires and demands. The ability of the framework to discover the viable supply chains is accomplished with the aid of data sharing among the suppliers. This research also proposes a mathematical model to measure the manufacturer's SCM performance improvement by adopting IoT. The proposed mathematical model is expanded to measure the performance of the internal and the entire supply chain. Finally, the integration of the proposed frameworks with the existing ERP systems is discussed with the help of a case study.

Preface

Parthasarathi Ramakrishnan completes this thesis work under the supervision of Dr. Yongsheng Ma. The overall research direction was suggested by Dr. Yongsheng Ma; while the specific research topics, framework, proposed methodology, prototype development and paper writing were developed by Parthasarathi Ramakrishnan. The contents of this thesis will be published in the following journals or conference proceedings.

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Table of Contents

List of Tables

List of Figures

Chapter 1 Introduction

1.1 Supply Chain Management

Since the drastic growth of the modern industry, Supply Chain Management (SCM) has been seen as an operating root pillar in improving the overall performance of industrial companies. In recent years, SCM has gained a significant research consideration from angles of scholastics and specialists [1]. However, industrial users of SCM systems express that there are opportunities to ameliorate in enhancing the supply chain visibility and business process integration of the modern SCM system [2, 3]. SCM has been defined as "the integration of the key business process from end user through original suppliers that provides products, services, and information that add value for customers and other stakeholders" [4]. Monczka describes SCM as "A concept, whose primary objective is to integrate and manage the sourcing, flow, and control of materials using a total systems perspective across multiple functions and multiple tiers of suppliers." [5].

Supply chain (SC) is described as "dispersed facilities where raw material, intermediate products, or finished products are acquired, transformed, stored, or sold and transportation links that connect facilities along which products flow" [6]. SCs are required in the entire product lifecycle, from material procurement to manufacturing, distribution, customer service and eventually the recycling and disposal of the product [7].

Based on the functional scope, SCs can be further classified into two different types, one internal to the organization and the other external to the organization [8]. Internal SC is directly related to a manufacturer's internal production processes, e.g., materials being transported to and from warehouses or circulated in and between workshops in the form of work-in-progress(WIP) [9]. External SCs are logistic operations among several individual manufacturers, which includes the collection of production material or the distribution of finished products [10]. Independent execution of Internal and external SC operations are known as the SC execution units. The set of SC execution units of a production system constitutes the SC system. And the overall supervision of SC system can be referred as SCM. Figure 1-1 describes the overall execution of SCM.

SCM has intimately tied up with financial optimization by implementing SCM, and actual production can be integrated with information flow leading to maximized profit and minimized cost [11]. Supply Chain Innovation (SCI) is the belief and exercise of inventively discovering and uplifting the opportunities prevailing in SCM for inventing competitive advantages [12]. Innovation is considered as an invention in a supply chain network, rather than a firm because innovation comes from interaction and collaboration with other systems and supply chain members [13]. Knowing the significant value of SCI, the American Council of Supply Chain Management Professionals supports the industry experts with Supply Chain Innovation Award, annually [14]. Many academic researchers and industry experts believe SCI has the power to develop and improve the existing SCM paradigm. Moreover, the traditional SCM can be automated, and more efficient SCM systems can be designed with the help of emerging IoT technologies.

Although both industry and academia have fully realized the importance of SCI, further research into implementing a more practical SCI is still missing [15]. A lot of researchers have made qualitative improvements related to SC, and only very few investigations on the quantitative enhancements are available. Hence, section 1.2.1 elaborates a list of quantitative enhancements that are to be addressed for real-world implementations using IoT.

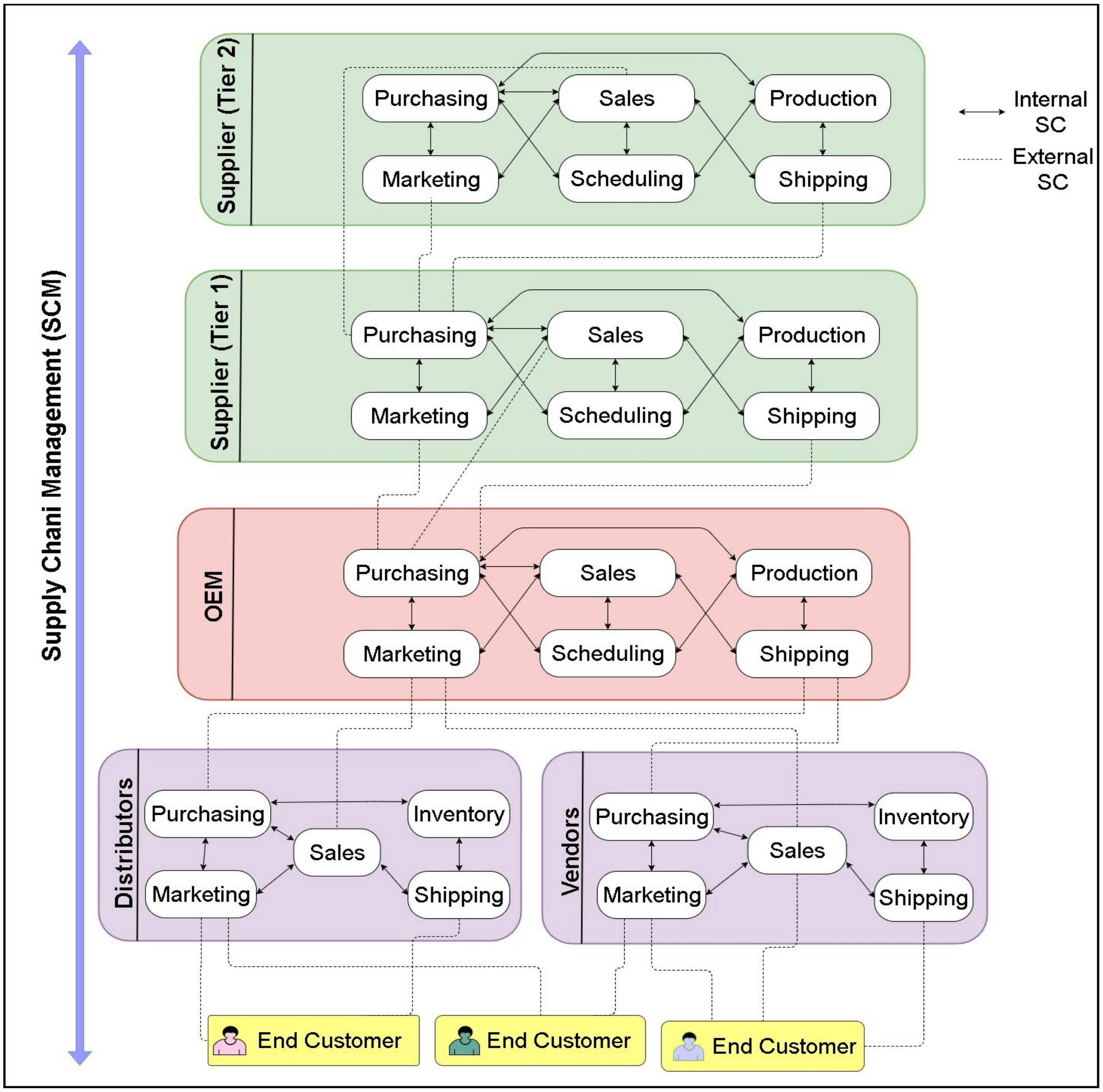


Figure 1-1The overall execution of the SCM system, consisting of the internal and external supply chain units

1.2 Internet Of Things

In the recent years, the internet has evolved into a global computer network providing a variety of information and communication facilities, consisting of interconnected systems using standardized communication protocols. It is challenging to conceive a real life without the Internet. Internet of Things (IoT) is a more advanced concept of the Internet that connects electronic devices, and sensors with people, products, and machinery together. This awareness has been recognized recently through the innovation in the new technologies such as sensor devices, abundant availability for data storage, intelligent data analytics, and decision-making tools. The term Internet of Things (IoT) was first coined by Ashton as "The inter-networking of physical devices, vehicles (also referred to as 'connected devices' and 'smart devices'), buildings, and other items embedded with electronics, software, sensors, actuators, and network connectivity which enable these objects to collect and exchange data" [16].

IoT has transformed the modern world, leading to a more connected life, by communicating between various advanced technologies. Some of the advanced technologies includes Global positioning systems (GPS), Global system for mobile communication (GSM), Bluetooth, Controller area network (CAN), Wireless local area networking (Wi-Fi), ZigBee, Near-field communication (NFC), Radio-frequency identification (RFID), and Quick response code (QR-Code) scanners. Min et al., proposed an IoT system, using dynamic priority scheduling algorithm to deal with the problem of data concurrency and tasks scheduling [17]. This IoT system was built to support six types of standard communication protocols, including RS485, Zigbee, Bluetooth, GSM, CAN, and Ethernet. These technologies are present in almost all the smart devices (wearable fitness devices, heart-rate sensors, sleep monitors) available in the market and they are a part of everyone's life. These small wireless devices have been able to talk with each other and help human-beings to manage their life efficiently. From the angle of SCM structure, IoT is a revolutionary way of integrating real-world physical objects because these objects were often excluded from the SCM system due to the lack of unified connectivity. For example stocking shelves, distribution vehicles, warehouses among other suppliers, are usually on the receiver's end consisting many data points, but they are left unrecorded due to the lack of connectivity [18].

IoT enables physical assets to be equipped with smart technology sensors that are linked to an information sharing system to facilitate communication and collaboration through data analysis and decision-making tools. IoT is considered as the enormous wave in Technology Innovation [19]. The Wireless World Research Forum (WWRF) has predicted that 7 trillion wireless devices will be used by the end of 2017, serving 7 billion people (i.e., 1000 devices/person) [20]. By 2020, the IoT is projected to expand to about 26 billion connected devices (it was 0.9 billion five years ago), which aids in assisting and monitoring the activities of machines and humans, from how many steps we walk every day to the way cars run every second [21]. Cisco predicts the IoT boosts global corporate profits by 21% and its market is to be 19 trillion dollars [22]. Scholars have also been attracted to this rapidly growing technologies to access the impact on different sectors. IoT has several benefits which have a significant effect when used in the supply chain management [23]. These benefits have attracted some of the industries such the automotive industry to adopt IoT technology in their supply chain. In addition to the automotive industry, the application of IoT is spreading faster among other products and supply lines [24]. Figure 1-2 depicts the different uses of IoT in the modern world.

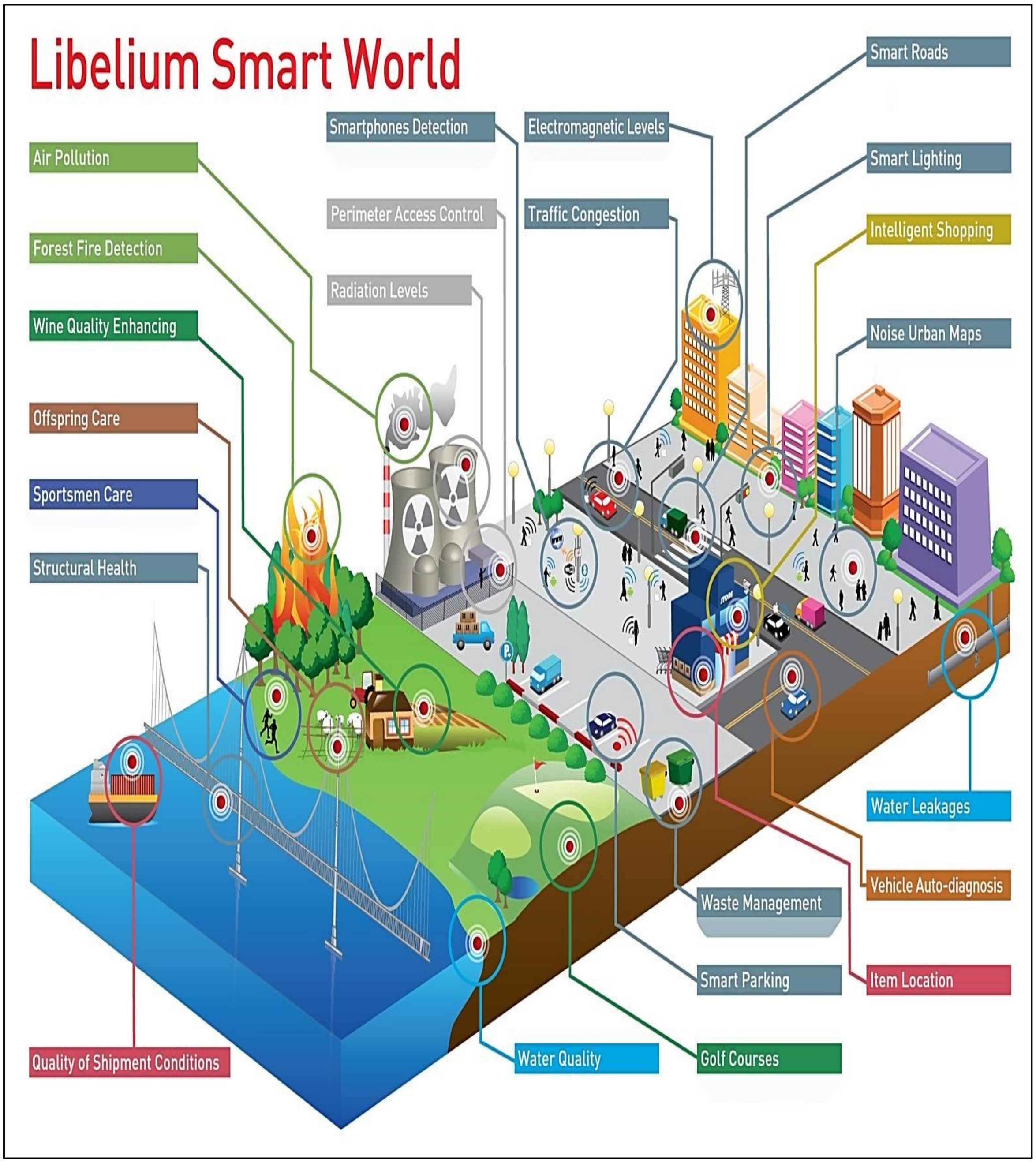


Figure 1-2 Different applications of IoT, enhancing activities in everyday human life [25]

1.2.1 Technological gaps in implementing the real-time IoT

Despite the technical innovation, bringing a vast potential for its rapid growth still, the complete use of IoT in SCM for better monitoring, production, and improvement remains mostly underutilized. One issue is that some companies still use traditional methods to track their products along the SC, it hinders information sharing which is unreliable and costly [26]. Lack of information sharing is a significant challenge which has impeded the growth and the innovation of SC systems. Also, it has promoted the inefficient utilization of the scarce resources by setting up individual monitoring systems for products along the supply chain [27]. This has substantially reduced the efficiency in the SCM and also hindered innovation due to the lack of standardized systems, which allows developers to come up with innovative applications and solutions to improve SCM practices [28].

This research aims to propose an IoT application framework, towards improving the overall performance of SCM, by integrating the functions of SCM, and the IoT devices across different supplier levels, enhancing information sharing, efficient resource utilization, and reduced loss of merchandise along the supply chain. The proposed framework potentially can enable manufacturers to access real-time information on the movement of their products, among different suppliers along the SC in a cost-effective way. The ability of the framework to achieve the cost-effectiveness is obtained by utilizing the power of IoT.

1.3 Supply chain network for information sharing using IoT

The primary objective of implementing IoT is to accumulate and share data when needed [29]. IoT can be more powerful when embedded with sensors that help in obtaining real-time awareness about its environment [30]. For example, a warehouse containing perishable food items can be implanted with sensors and can measure the temperature, and moisture levels which are channeled to a network and the state of goods stored there can be monitored [31]. Also, it can harmonize its data with that of closely related and relevant to IoT, thus formulating hypotheses and answering queries based on the data gathered. An alternative approach for collecting data is through the use of local area networks (LAN). Embedded barcode scanners and RFID enables IoT to collect real-time data from individual components [32]. Bluetooth technology can be used accurately to interconnect with close range IoT devices and allows information sharing between components. For example, in a production assembly line, data from different stations can be collected using IoT devices and information sharing between two various locations can be achieved using Bluetooth. Stock shelves installed with sensors can gather information related to the movement of inventory and their rate of replenishment [33]. WiFi can be used for to provide connectivity over a large area, which is another way of data gathering. WiFi can be enabled and used to collect and share information across different IoT components, where information sharing cannot be achieved using Bluetooth due to its short range use [34].

Another revolutionary way of gathering data is through the use of a tapped technology called LiFi which utilizes light emitting diodes to transfer packets of data rather than the radio waves used by other mechanisms. LiFi can be productive in warehouse and manufacturing settings where machines fitted with these devices gather data such as the rate of bottling in case of a convey belt or the status of package loads in the case of a forklift. Moreover, the efficiency and productivity of the organization are improved with the data collected using the IoT [35]. Due to the dynamic nature of SC environment, IoT demands a massive bandwidth for its effective communication and faster processing power. Another reason for the bandwidth demand is due to data being collected from numerous data points and are processed in real time to provide feedback. LiFi solves this with its high speeds up to 224 Gigabits per second [36].

1.4 Importance of data analytics in supply chain

The gathered information is only the first step in implementing a fully operational IoT. The crucial work is to analyze the enormous amount of data collected. Data refers to the general collection of variables that carry no meaning by themselves. Data mining techniques can be applied to translate data into information. Various data mining techniques such as clustering, classification, prediction, and association can significantly aid in the organization of data into logical information.

First, the tools are capable of filtering and analyzing the crucial data, focusing on gathering specific information relevant to an organization. This filtering process, not only helps in obtaining accurate information but also helps to reduce the massive volume of data considered for further investigations. Weka, an open source data-mining software, developed at the University of Waikato assisted in the feature-oriented cost estimation of a welding process [37]. Data analytics help in converting the vast ocean of data into manageable snippets that are easily understandable by the users. For example, supply chain manager, procurement officer, or the logistics controller has access to huge collection of inventory data, but cannot easily interpret that data into meaningful information for real-time decision making.

Second, data analytical tool helps in organizing data into logical and sensible groupings that are understandable by the users [38]. Some of the data analytical tools include the boxplot, flow charts, fishbone diagrams, area chart, and spark line tables. These data analytical tools are used to organize data into a coherent structure. Software tools such as Hadoop and Spark are very efficient in offering visualization of abstract data based on simple queries, which rearrange the data misperception collected by IoT into actionable; creating foundations for solving problems and making real-time decisions [39].

Once data is organized, the next step is to analyze the data. Data analysis involves the formulation of models and testing various hypotheses using inferential statistics. They mostly enable the protraction of conclusions from abstract information [40]. There is a descriptive statistics which analytical tools utilized to conclude possible scenarios related to the data gathered [41]. Also, there is the measure of dispersion which is done through the action of variance, standard deviation, skewness, and kurtosis [42]. Correlation analysis is also carried out by analytical tools, and it is beneficial when looking for cause and effect among the data [43]. The other step involved is database management, which can be enabled by having a database management systems that aid in retrieving information for decision making and utilizing the connectivity of IoT through crosslink information and achieve broad range results [39]. Query mechanisms can be to obtain the blocks of data stored in the system and present it logically to enable decision-making. Queries involve the arrangements of data into relevant clusters which contain similar and related variables.

Depending on the objectives of analysis, hierarchical method, density based method, and model-based method among other can be utilized to group data into an informative cluster [44]. IBM and Oracle have systems that support this kind of analysis for information gathered. They include SQL lite, Microsoft Access, My SQL [41]. The acquisition of this data is not the end; data should be translated into decisions. Decision Support Systems (DSS) assists in transforming data into decisions and can respond to specific queries [45]. The primary purpose of the DSS is to incorporate the business logic and rationalization of questions to achieve the intended objectives [46]. They enable the sifting of colossal information and consolidate it to a manageable level that is later used by the decision makers.

1.5 Problem statement

In a typical manufacturing world, a product consists of different parts. Each part is either built in-house or outsourced to a supplier. These suppliers are immediate to the Original Equipment Manufacturer (OEM). Today all the OEMs have a direct relationship with their immediate suppliers. They don't have access to the supplier's suppliers and their suppliers (tier 2, tier 3 or higher tier suppliers) as well as the consumers of their products.

Therefore, the OEM lacks access to the critical information which can enhance the efficiency of the product along the supply chain. Lack of access to necessary information is a problem because the end customer or the OEM doesn't have the control over the supply chain path, which the product has to take. OEM has the choice only to choose their immediate suppliers.

Based on the number of parts required for manufacturing a product, there can be some multiple and different supply chain paths. As a result, the amount of product recalls has increased in the recent years significantly affecting public confidence on the manufacturers [47]. Numerous vulnerabilities exist along the supply chain through which the safety and security of products can be compromised. Supply chains with multiple suppliers have many potential vulnerable points where an occurrence of a disruption can shut down an entire supply chain creating a huge impact or many consequences. Supply chains are responsible for 60-70% of a company's cost structure, hence disruptions along the supply chains which may affect a company's products are a considerable threat to its profitability [48]. A vast percentage of this cost is incurred in transit due to late or non-delivered products, as well as on the product destination due to factors related to product quality such as defective goods. These problems increase as the number of supplier's suppliers involved in a product supply chain increases, some of whom have no direct relationship with the manufacturer. Expanding the information accessible by manufacturers along with the supply chain, beyond their immediate supplier's is critical in enhancing effective decision making. This rich details on the entire supply chain pave a way to address the vulnerable areas regarding location, condition, quality, and other attributes related to the status of the products.

Currently, as manufacturers only relate with their immediate suppliers in the supply chain, the amount of data they collect and the process is low [49]. This implies the existing frameworks cannot maximally utilize the benefits brought by the rapidly growing IoT technology. Similarly, supply chain efficiency can be improved when the manufacturer obtains information about other entities of the supply chain. Hence, there is a need for a system which pays attention to such details and acts as an integrated system linking the different aspects of the supply chain. The proposed framework can address these challenges and shortcomings by providing a unified information sharing platform, connecting all the suppliers along the supply chain. Also, the proposal offers visibility of the entire chain and suggests better alternative supply chain path based on the requirement or needs of the customer or OEM.

1.6 Objectives and scope of the study

The primary aim of this research is to provide a conceptual framework to enable information sharing between different suppliers in the supply chain. By integrating the shared information and the customer demands, this study intends to provide a conceptual solution to the manufacturers. This theoretical elucidation will offer the ability to consolidate their supplier characteristics, resource capacity, and manufacturing information while interacting with their current ERP systems. A more technical objective is to store real-time supply chain information correctly and efficiently using well-defined data structures incorporating the latest IoT technology.

1.7 Road Map of the Thesis

This chapter introduces the general context of the supply chain management and IoT. The remainder of the thesis is organized as follows.

Chapter 2 summarizes the literature review on the different features available from IoT such as in-transit visibility, SCM operational efficiency, information sharing, improving customer services, and inventory management.

Chapter 3 recaps different IoT manufacturing and IoT communication technologies that have been developed till date and identify the missing research elements for are addressed in this research.

Chapter 4 defines the research methodology and explains how the system adaptiveness is achieved. Later part of this section develops a basic architecture required for implementing this research.

Chapter 5 elaborates the different IoT technologies that considered are for the implementation.

Chapter 6 modularizes the proposed methods into a prototype system, and a case study is developed in a Door and Window manufacturing company to validate the proposed methodology.

Chapter 7 concludes the research with highlights of the contribution of the study and proposes some recommendations for future work.

Chapter 2 Literature review

2.1 Enterprise Resource Planning

Successful execution of a business process is possible only when an ERP management system is in place [50]. ERP is a management technology for handling business systems, which supports in the controlling of different enterprise resources such as accounting, manufacturing, and sales, etc. [51]. The primary goals are to integrate and maintain separate isolated business units using real-time resource accountability across an organization. The ERP system empowers manufacturing, planning, and controlling to be more efficient and accurate [52]. During the earlier stage of the ERP, it contained only accounting, inventory and few amount of administration information [51]. Afterward, when technology developed other functionalities, such as order information and customer service, are integrated via the comprehensive application of the internet [53]. The capability of the ERP system to integrate information between vendors and other departments, such as manufacturing, customer service, and human resources has made it a more favorable business management technology. ERP has become the pioneer in the real-world implementation with more influence, and fastest growing players in the software industry software [54].

Leading ERP vendors include SAP, Oracle, Infor, and Peoplesoft; are developed to serve different business needs [51]. Some of the manufacturing-oriented ERP software tools were designed that include SAP, Oracle, Infor Syteline and Visual Manufacturing™.

However, ERP systems available today are not capable of integrating with IoT technology due to the conflict in data structures, security, the and integrity of the data. Further detailed review on the history of ERP technology and current ERP capabilities, is discussed in section 3.1.

2.2 Supply Chain Management

SCM is defined as “A set of three or more companies directly linked by one or more of the upstream and downstream flows of products, services, finance, and information from a source to a customer” [55]. The role of SCM is to make sure that “right items in the right quantity at the right time at the right place for the right price in the right condition to the right customer [56]. This makes the SCs more complex and uncertain to implement and has led to supply-demand mismatch problems such as inventory overstocking, understocking, and delivery delays and has been popular research topics in the area of business management [57]. To compensate these increasing challenges, SC has to be more efficient and intelligent [58]. It can be achieved incorporating the advancement in computer science and other engineering technologies. For example, SC objects equipped with IoT devices can provide real-time inventory data and location tracking information that aid in addressing the challenges discussed earlier [59, 60].

2.2.1 Advancements in SC visibility

SCM has undergone significant change over the past decades. Technology is a significant contributor to this change, creating a cost-effective, reliable and predictable service [67]. Among the recent developments in SCM, most preeminent advancements are due to the implementation and integration of IoT and big data analytics in the SCM process, which has demonstrated a significant impact in improving the SCM [68]. Incorporating IoT systems has helped to achieve better visibility and responsiveness in the SCM [69]. These connected methods and devices have made businesses smarter by providing useful information and intelligence, aiding to improve the decision making processes. Advancements in the IoT technologies have improved location and identity tracking, enhancing the in-transit visibility of products along the supply chain. With such rapid growth, IoT serves a driving force in transforming the supply chain management system, with its impact felt across essential sectors and industries [70].

About 63% of companies agree that prioritizing and improving supply chain visibility helps to reduce the cost and enhances the operational performance of the supply chain [71]. According to Heaney [2], the majority of the companies are looking for opportunities that reduce logistics cost, while maintaining responsiveness to customer demand. Improving the supply chain visibility will improve responsiveness to meeting customer demands. Other benefits of enabling and enhancing supply chain visibility include, companies can optimize the operations of their supply chain members such as suppliers and logistics service providers, and strengthen their inventory management practices, leading to more efficient and effective overall supply chain.

IoT has the potential to resolve many companies demand to address supply chain visibility. SC visibility can be accomplished by using IoT sensing devices discussed earlier [2]. Modern IoT technologies provide decision makers with the real-time data to visualize different supply chain processes and enhancing supply chain visibility. Using

IoT devices, it is possible to automate the supply chain process, hence increasing the visibility of products along the supply chain. Automation enables faster verification and inspection of products during transportation from the warehouse to the client, making logistic services more accessible to coordinate. It is more accurate to predict the location of an item during tracking, therefore reducing instances, such as theft of goods in transits [72].

2.2.2 Advancements in SCM operational efficiency

The improvement in the interconnection between supply chain members and devices provided by IoT enables secure information sharing across the supply chain members. Supply chain complexity can be addressed by increasing the visibility of products along the supply chain will reduce operational pressures, and reduce costs in logistics.

Technology has played a significant role in solving the operational problems that occur due to supply chain. IoT devices such as RFID have made it possible to track and manage inventories more efficiently [73]. Hence reducing the required resources and saving time [74]. Moreover, IoT devices increase the operational efficiency of various supply chain processes such as manufacturing, logistics services, and inventory management [75]. As a result, completed products reach the customer at the right time with reduced cost. Technological advances in supply chains are becoming more flexible, and faster [76]. Some of the significant benefits of this modern technological innovation in IoT include integration of different supply chain processes [77]. The timely critical decision can be made with the availability of real-time information, which helps in improving the operational efficiency [78]. IoT devices play a crucial role in the identification, authentication, and automatic data acquisitions, enhancing the operation efficiency of the supply chain [79]. As technology expands, its price will also decline, therefore becoming more economical in the supply chain where some of the members are reluctant to replace modern systems with traditional systems.

2.3 Internet of Things

IoT is a subversive idea to integrate supply chain systems that help many companies in the logistics and manufacturing industry to migrate to the digital world. Expenditure on integrated logistics solutions currently stands at $9 billion. It is projected that the current expenditure may ascend to $12 billion in 2018 and afterward, $15 billion and $20 billion in 2019 and 2020 respectively [61]. This has increased the awareness that many companies have the potential to use IoT technology for improving their SC performance. As Andrew Meola points out in a journal on retail logistics [61], many of the supply chain services are outsourced to third parties (3PLs) and are fully integrated with the operations of the company. This is only achievable through the use of IoT technologies like Low Power WAN, RFID tags, Bluetooth, and beacon trackers for fleet management, etc. According to one business research facility, the magnitude of interconnected fleet management services will reach up to 90% of total commercial vehicles by 2020 [62]. This expectation has created a promising future for IoT. IoTs prevalence in in-house operations is also showing a huge impact.

As of 2017, the number of devices connected through IoT was estimated at almost 7 billion and predicted to extend to 26 billion by the year 2020 [20]. This rapid growth is influenced by improvement in cloud-based information sharing and RFID technology, which forms the backbone for IoT [63]. However, despite this massive potential by IoT in connecting products and different members of the SCM such as suppliers, clients, manufacturers and logistics, the majority of the companies have not benefited from its tremendous competitive advantages. This has been primarily due to lack of frameworks that illustrate how business can integrate IoT with various supply chain processes to promote efficient and effective SCM systems and increase revenue [64]. Hence, as IoT advances in innovation, there is a need for business to enhance their SCM practices through appropriate frameworks that enable them to leverage opportunities created by this rapidly growing smart technology.

A traditional survey by logistics expert DHL and IT specialist company Cisco shows that IoT technologies like assets tracking will have an impact of close to $1.9 Trillion in SCM [65]. GT Nexus and Capgemini concluded that close to 70% of all retail services are already immersed in this digital transformation [66]. This affirms a growing trend that this framework seeks to drive.

2.3.1 IoT in promoting information sharing

Information systems researchers have advocated that efficient information sharing brings business value to firms by obtaining essential knowledge [67, 68] and enhancing organizational capability [3, 69]. As the modern IoT technology replaces the paper-based information exchange, companies are putting more emphasis on the value of information to gain a competitive advantage in the market. Therefore, different entities such as suppliers can gather necessary information from other entities of the supply chain such as manufacturers and clients the increase their operational efficiency. This exchange of information between the different supply chain entities brought by the modern technology such as IoT increases productivity, reducing the rate of error and promotes improved billing, all which contribute to an efficient and effective supply chain [70].

Furthermore, information sharing is classified into internal and external information sharing [71]. Internal information sharing provides abilities to identify opportunities and innovations within the manufacturing firm [72, 73]. As a result, information sharing brings more homogeneous information and helps in improving the efficiency of exploitation. Internal information sharing improves organization's operational efficiency by controlling cost, quality, delivery, and flexibility [74].

Meanwhile, external industry information sharing provides access to new ideas, bringing more heterogeneous information and helps firms to improve the efficiency of exploration [72, 73]. An empirical study exploring information sharing across multiple supply chain tires identified 22 factors that impose challenges to multi-tier information sharing [75]. Despite the obstacles, external information sharing is more likely to gather a rich array of information which "enriches the knowledge pool by adding distinctive new variations" [76]. Information sharing among external supply chain partners emphasis on SCM programs such as Customer Relation Practices (CRP), Technology & Innovation, and Strategic Supplier Partnership [77].

2.3.2 IoT in improving customer services on SCM

IoT has a positive impact on the supplier and customer relationships along the supply chain, through improvements in logistics across the supply chain systems. The data collected using IoT systems can be used to prevent unplanned downtimes among other logistical operations, saving both time and money [60]. Recent innovations in the IoT has transformed supply chain systems with the capability to collect, analyze and present information, related to product supply and demand [78]. More optimized, flexible and responsive logistics systems were developed enabling, customers, suppliers, and the manufacturers to track and share real-time information on the movement of their products [79]. IoT has promoted innovation in supply chain processes by reducing the cost and time required to order and receive products from the customer [80]. This is because the new technology enables companies to monitor the status of the products.

Moreover, IoT enables manufacturers to forecast demand and plan accordingly. Manufacturers can focus on areas where demand is highest and helps to employ adequate resources to ensure supply chain is not broken. As a result, trust on the manufacturer and the product increases, at the same time increasing the profit. Also, through smart devices such as smartphones and various applications, consumers can provide product feedback through these tools which are used by the manufacturer in decision making to improve customer service [81]. IoT devices can transmit the product data directly to the manufacturer, therefore enabling efficient customer services that are tailored to fit consumer's needs [82]. However, IoT can only benefit companies that are ready to adopt the advancing technology. Therefore, this implies that some business would have missed out the opportunities created by IoT in improving the logistics systems, and promoting good relationships with customers. It demonstrates a need for more innovative frameworks that helps companies to leap on the enormous benefits of the modern technology.

2.3.3 IoT in improving inventory management

Inventory management has been one of the most challenging aspects of the supply chain management. However, IoT innovation has significantly improved how companies handle their inventory by providing real-time information on restocking and reordering inventories [83]. In addition to an efficient inventory management practice introduced by the IoT, it also has an added advantage in keeping cost low and operations in control. For example, IoT devices such as Rasberry Pi uses an ultrasonic transducer to obtain inventory status and automatically sends email to the corresponding supplier and the company personnel for order placement [84]. IoT enables companies to update their inventories in real time according to their replenishment orders, promoting efficient inventory management practices [18]. Therefore, the delay that occurs from the traditional inventory management practices is no longer a challenge for companies who have integrated IoT technology and innovation in their supply chain systems. Unfortunately, companies which are left behind on adopting and utilizing the IoT technology to improve their SCM miss out on the vast potential. However, with the adequate framework, such companies can benefit widely and become part of the growing network of users already using the IoT technology.

Chapter 3 Technological review of ERP, SCM, and IoT

3.1 Review of ERP systems

All ERP systems do not follow one single architecture; this is beside the fact that the goal of the different ERP systems differs depending upon the purpose and requirements of the customer. In other words, ERP systems do not share a common framework; functionalities and implementation of various ERP systems differ focused on different solutions. Since the introduction of ERP systems in the 1990s, multiple ERP systems such as Infor, Microsoft Dynamics, Oracle Business suite, Sage, ERP Next, and SAP, etc., have been developed. Each of these ERP systems differs on design architectures and data platforms for the integration and merging of the business activities.

ERP vendors are compatible with various frameworks and their operating systems such as Windows, Linux, and Mac. For example, Microsoft Dynamics, and Infor Syteline have access to the Microsoft's .NET framework and can interact with Microsoft products, such as Outlook, Excel, and Word, etc. Most of the ERP systems are compatible with the Microsoft SQL server data engine for database access. However, the SAP ERP system supports data connectivity with multiple databases, such as DB2 and Oracle.

Open source ERP software packages such as Postbooks, WebERP, ERP5, and Compiere are available in the market that provides access to the ERP software source code, where the software developers can modify depending upon their needs. The open source ERP systems encourage innovation, as it attracts more people for development.

3.1.1 SaaS ERP systems

A wide range of ERP software packages exists today that has provided the businesses, an option to choose the suitable package that best fits their needs. For smaller and medium-sized organizations, who cannot afford the whole ERP software package, software-as-a-service (SaaS) ERP solutions are possible [85].

In a SaaS environment, the ERP software modules are centrally hosted on the vendor's servers and are licensed to organizations upon request. This feature is not available in traditional enterprise ERP systems. Different functionalities in the ERP software are modularized into individual units in the SaaS environment. Hence, it provides a way for companies in choosing only the modules that they need. For example, a logistics company does not require the ERP software that focuses on manufacturing but can make use of customer and inventory management modules. This ERP structure reduces the cost of investment on software and hardware packages.

3.1.2 Cloud-based ERP systems

Cloud-based ERP systems have been gaining more motivation as industries explore ways to reduce the implementation and maintenance costs of enterprise ERP systems, fasten the deployment process and the increase the flexibility to customize the software for their individual needs. The traditional enterprise ERP systems are installed on servers and computers located on a business's premises, whereas cloud-based ERP software is installed on remote servers located outside the organization and accessibility to the software is provided in the form of a service, through the use of cloud computing technology. Some of the main players of traditional ERP systems such as SAP, Oracle, Infor, and Microsoft has already started migrating from traditional on-premise software to cloud services [86].

ERP vendors such as NetSuite, Epicor, FinancialForce, Acumatica, and Ramco are some of the leaders in providing cloud-based ERP solutions. NetSuite has combined different ERP modules such as Customer Relationship Management (CRM), e-commerce, inventory, and order management into one cloud ERP suite [87]. Epicor has developed an End-to-End cloud ERP solution that helps organizations to reduce ownership cost, increase mobility and provide global access [88]. Acumatica has developed solutions for document management, that can run on major mobile and desktop platforms such as iPad, iPhone, Android, Windows, Linux, and Mac, encouraging BYOD (Bring Your Own Device) policy [89].

3.2 Review of SCM systems

A variety of literature reviews on the state of research and application Supply chain management has been studied in the last decade. Supply chains were introduced when issues related to material flow were first identified in the 1930s [54]. Before the introduction of SCM systems, logistics was the terms used to describe the movement of military equipment [55]. This view for logistics started diminishing during between 1940 and 1950 when industries begin to explore solutions for improving the labor-intensive material handling process [56]. Many of the supply chain activities such as "warehousing" and "materials handling" were viewed as a part of industrial engineering, rather than a discipline of the SCM [57].

In the 1960s, migration of freight transportation from rail to truck resulted in the emergence of the term "Physical Distribution." [58]. All supply chain related transactions were monitored, recorded and processed manually. As a result, data availability and accuracy could not be achieved. Hence, leading to the development of the Computational Optimisation Centre and the Georgia Tech Production and Distribution Research Centre at Columbia University. These centers have paved the way for innovation in supply chains and logistics by introducing inventory optimizations and route tracing. More commercialized computer software started emerging in the 1970s, eliminating the need for handling the supply chain transactions manually. This commercialized software was later called as ERP systems. Material Requirement Planning (MRP) systems were developed in the late 1980s, as it aims to integrate and interact with multiple databases in almost all the companies [59]. MRP systems introduced more bottlenecks such as the inability to accommodate capacity constraints and provide flexible lead times. These bottlenecks have to lead to the introduction of ERP systems. MRP systems were expanded into an ERP system, leading to better planning and integration among logistics databases and components globally. The terms "Logistics", and "Supply Chain Management" were widely accepted by the industries in the 1990s.

3.3 Review of IoT Systems

3.3.1 History of IoT

IoT is an extension of the Internet [90]. Internet of things was evolved as an effect of combining different technologies, which includes wireless communication, embedded systems, machine learning, data analytics, etc. [91]. The idea of smart device communication came in 1982 when the coke vending machine at Carnegie Mellon University was modified to connect to the Internet and enabled programmers to collect inventory information and check the coldness of the drink [92]. After that in 1990, first IoT device was considered when John Romkey created a toaster that could be turned on and off over the Internet for the October '89 INTEROP conference [93]. Then in 1999, the term Internet of Things was first coined by Kevin Ashton, executive director of Auto-ID center as: "I could be wrong, but I'm fairly sure the phrase "Internet of Things" started life as the title of a presentation I made at Procter & Gamble (P&G) in 1999. Linking the new idea of RFID in P&G's supply chain to the then-red-hot topic of the Internet was more than just a good way to get executive attention. It summed up an important insight which is still often misunderstood." [16]. It was during this time, the Electronic Product Code (EPC) was developed, a global RFID-based item identification system intended to replace the traditional Universal Product Code (UPC) barcodes.

After that in 2000, LG announced plans to develop its first Internet-enabled refrigerator. Between 2003-2004, the term IoT has gained its attention and was mentioned in major publications such as The Guardian, Boston Globe, and Scientific American. At the same time, RFID was deployed on a massive scale by the US Department of Defense. IoT reached. IoT hit another level in 2005 when the UN's International Telecommunications Union ITU published the first report on IoT. Between 2006 – 2008, first international conference on IoT was held [94]. In 2009, major companies such as Cisco, IBM, and Ericsson took large educational and marketing initiatives related to IoT. Nest invented self-learning Wi-Fi-enabled thermostat at the end of 2011. Later, during 2012 Arduino, Raspberry Pi, and other hardware platforms attained its maturity, enabling people to build their own IoT applications.

Between 2012-2017, low-power chipsets with built-in Wi-Fi and 3G/4G connectivity were developed. These devices are smaller in size, consume less power, has more processing power, and are available at lower price. IoT has become one of the trending technologies in the world which are shown in the Google trends graph, Figure 3-1. Figure 3-2 depicts the Granter hype cycle, that tracks the life cycle of different technologies, identifies the IoT platform at its peak during 2017.

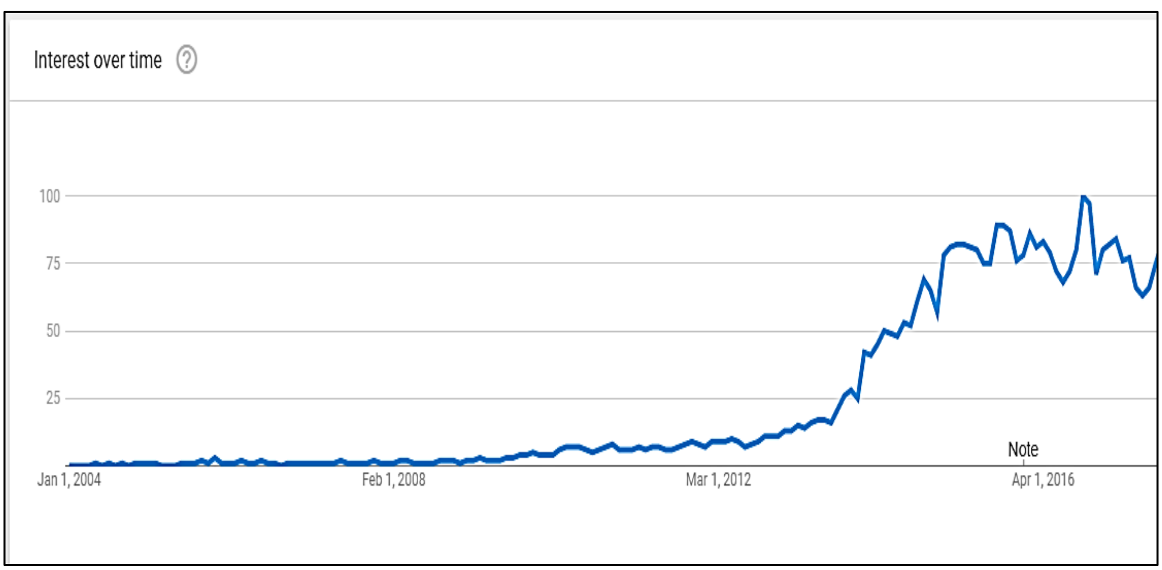


Figure 3-1 Google trends - showing on IoT from 2004 – 2017 [95]

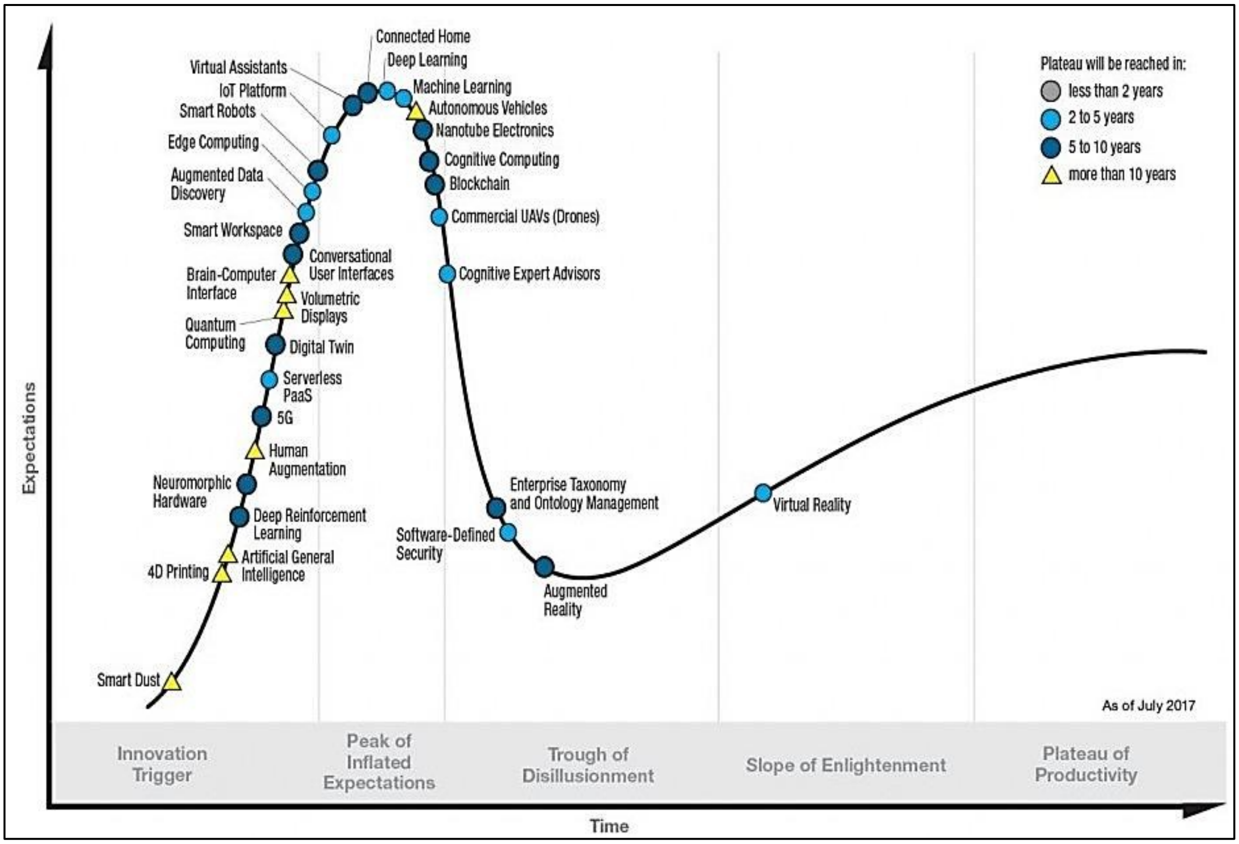


Figure 3-2 Granter hype cycle for 2017, identifying IoT platform at its peak [96].

3.3.2 IoT related Manufacturing Technologies

IoT-based applications have been developed to be used in industries to capture real-time execution of information. IoT serves as a critical facilitator in transforming the traditional manufacturing into digital manufacturing such as Industry 4.0, Cyber-physical systems (CPS), Industrial IoT (IIoT), Cyber Manufacturing systems (CMS) [97]. Academia and industry have started using real-time information for planning and dynamic control of administrative systems. An IoT-enabled intelligent assembly system for mechanical products (IIASMP) was developed [98]. An analysis of three successful IoT implementation in manufacturing industries has been identified for efficient product-service systems [99]. IoT has provided a solution for controlling and monitoring of additive manufacturing processes [100]. The IoT-based collaborative framework has been identified, forming a base for cyber-physical interactions with advanced manufacturing domains [101]. ERP systems, when integrated with modern IoT manufacturing technologies such as holonic manufacturing, agent-based intelligent manufacturing, reconfigurable manufacturing, and agile manufacturing, increases the system adaptability and flexibility [102]. A visual platform has been developed allowing manufacturing applications to be controlled and monitored using a wireless sensor network (WSN) [103]. An intelligent multi-objective decision-making system was proposed, that uses RFID for production planning and optimizing transportation [104].

The primary function of IoT devices is to gather data about its environment, serving as source data points. Apart from collecting data, IoT devices act as sharing points, by dividing the information obtained. The data collected from one point becomes a source for another. The benefit of information sharing is that it liberates access to information which helps in better decision-making. For example, when a purchasing manager has real-time updated inventory details, he/she can take timely decisions to create purchase orders for stocks that are running out. This eliminates the need for updating the inventory manually, yet building an active system. Scheduling new orders can also be synchronized with demand forecasts, at the same time considering internal operations [105]. The status of goods is monitored in real time while stocking and retrieving is made more efficient [106]. This enables the optimization of storage space considering different factors such as product type, dimension, quality, quantity, expiry date, receiving date and production load.

3.3.3 IoT related Communication Technologies

Information sharing is one of the key benefits from IoT. Information sharing is possible only when there is a communication between objects. Communication between devices within the manufacturing unit can be achieved via various networking technologies such as LAN, Wi-Fi, Bluetooth, barcode scanners, RFID, etc. These networks are advantageous, in factory settings where distance is limited by the factory floor [107]. Communication helps in the interconnection of machines to a centralized hub, enabling data sharing, preserving data integrity by avoiding redundancy, and accessibility of shared data. An intranet allows the interconnection of the various departments to the SC allowing coordination between internal processes and operations [108]. WAN is a form of an extranet, used for communication between objects that are physically separated by a long distance [109]. An extranet is a platform similar to the intranet that enables communication between the OEM and the external players such as suppliers, logistics companies, and dealers. Information sharing creates visibility in the supply chain. For instance, a manufacturer can access suppliers' inventory to predict the expected receiving date. IoT can share information like production termination enabling automatic halt of the successive machine(s) and other related processes [110]. Smart IoT platform allows retailers to detect stocks that are running out from shelves and can notify the suppliers to responded accordingly [111]. Also, this updates can be used for procurement and accounting purposes where the updates automatically reflect the orders and their corresponding accounts [112].

Furthermore, frequently used communication mechanisms such as emails, and text messages can be incorporated into IoT to share information to the human beings. This incorporation can be achieved by using software tools and electronic gadgets available today [113]. For instance, when a truck enabled with IoT communication devices can notify the operations manager that the delivery has been made, saving time and resources spent in tracking orders shipments especially when the volume is significant [114]. Also, an empty shelf may notify the ordering department about the availability of free space for restocking, or if the material is not available, it can be ordered automatically [115].

3.4 Literature summary and motivation

The researches on information sharing among individual SC nodes rest on independent study at present; however, the research on adaptiveness of the whole supply chain system is still scarce. Most scholars focused on single SC sub-system or static SC, while there is no specialized study considering the performance of the overall SC system. Adaptiveness of the SC to react to customers' demands is not explored thoroughly.

The SC system based on IoT needs a model-based methodology to analyze the flexibility and relationship in integrating the whole supply chain system. Considering both the internal and external SC processes, following research questions are to be answered.

1) How to use IoT to construct an adaptive SC system, enhancing both internal and external processes?
2) How to use IoT to simulate and evaluate different schemes, regarding data collection, processing, and usage by both internal and external SC systems?

3) How to design an optimal IoT solution for an SC system to comprehensively optimize the logistics flow and information flow to increase production yields and reduce inventory and transportation cost.

This research aims to find solutions accomplishing the above questions.

Chapter 4 Methodology

4.1 The operation flow chart in a Supply Chain

Various types of enterprise systems enjoy rapid development in the recent years, including industrial parks, specialized towns, etc. [116]. The operation flow chart of a typical supply chain system of a manufacturing industry is illustrated in Figure 4-1.

The upper part is the internal SC system, and the lower part is the external SC system. The operational effectiveness and efficiency of the SC are affected by the dynamics inherited from the real-time operation of the environment. The inadequate material, missed orders, lost product, neglected process, machine failure, employee absence, etc., are some examples of internal dynamics. While for the external dynamics, changes in material pick-up or delivery schedules due to the changes in the supplier's production plan. It is argued that part of these problems are due to lack of real-time information sharing among the suppliers and manufacturers. Both internal and external SC systems are analyzed independently in sections 4.3 and 4.4 respectively, and models were developed to solve the SC dynamics.

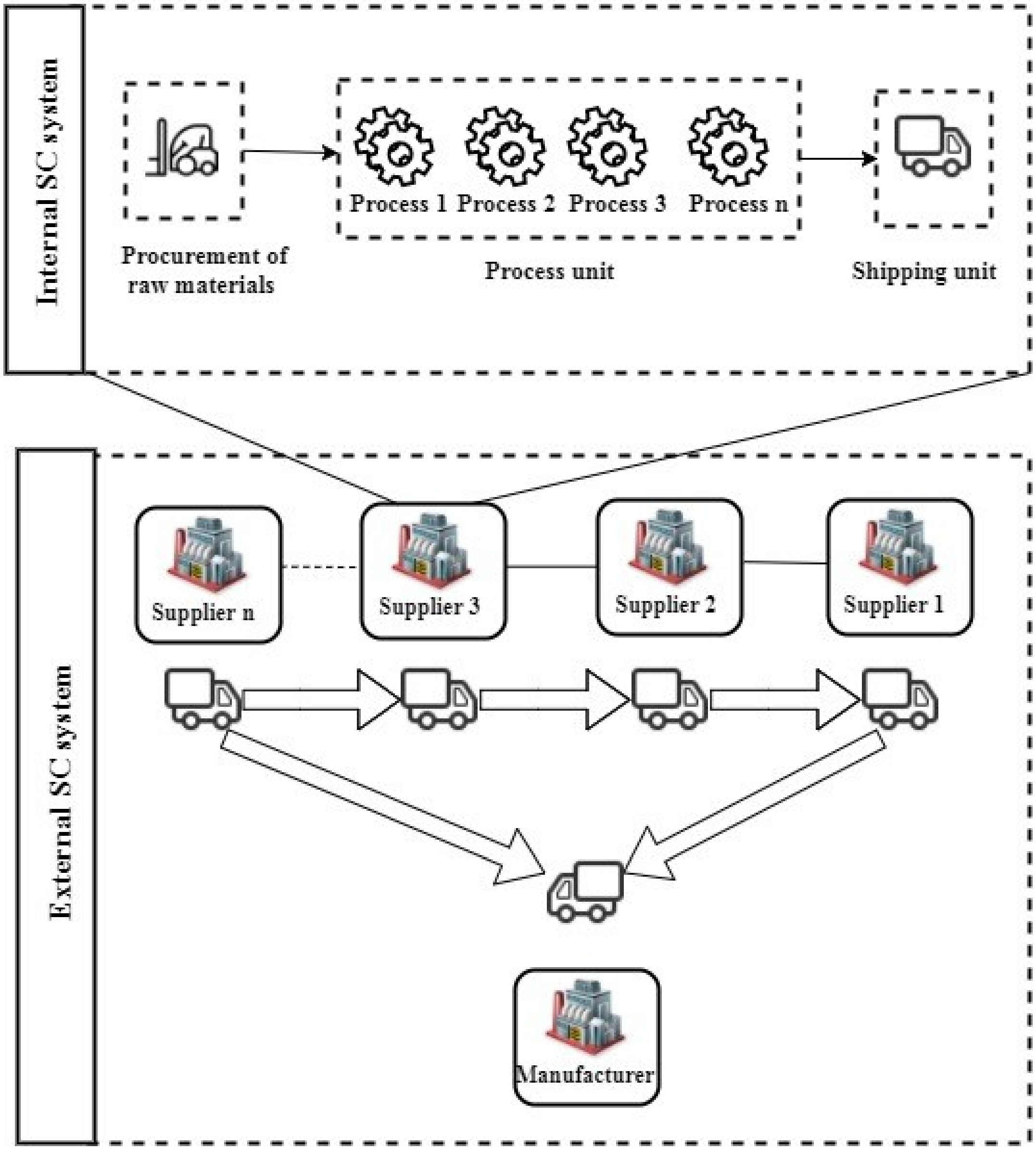


Figure 4-1 Operation model of SC system

4.2 IoT-based supply chain network

4.2.1 Underlying Architecture

This section presents an overview of the underlying architecture that is required for implementing an IoT infrastructure. Firstly, the structure of IoT is expounded and how it can be successfully applied in the supply chain. The underlying architecture of the IoT is illustrated as shown in Figure 4-2.

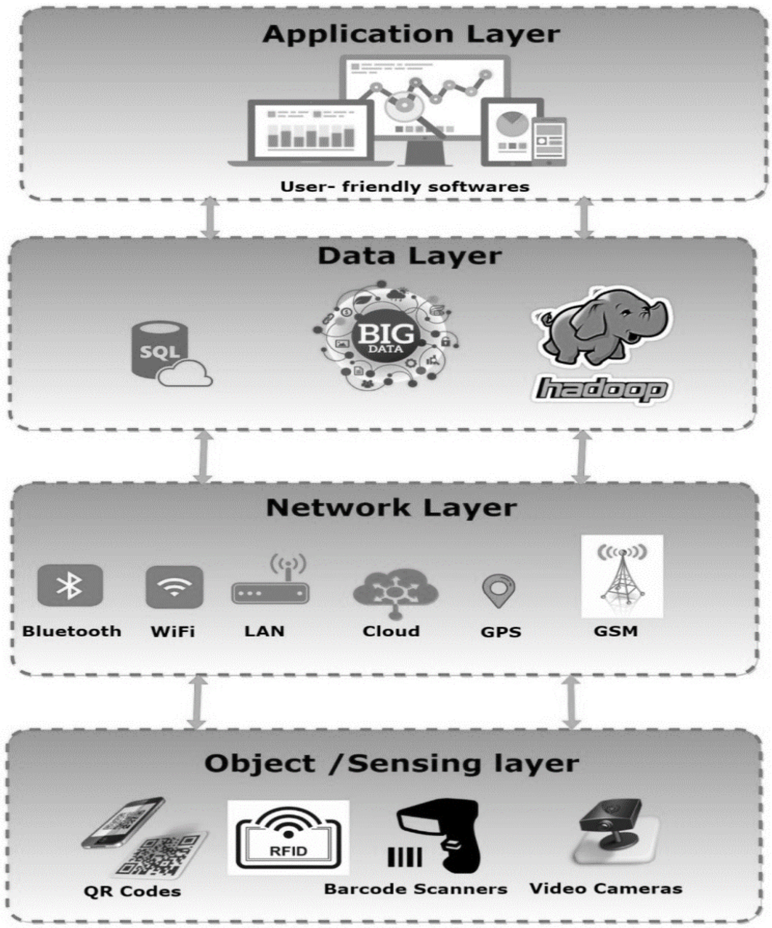


Figure 4-2 Basic architecture of IoT

The underlying architecture of IoT is made up of four layers, which includes the object layer, network layer, data service layer, and the application layer. The first layer is the object or sensing layer. The primitive function of the object layer is to collect data about its environment. The object layer consists of devices and sensors that are used to gather information. Object layer is the layer where IoT interacts with the real-world objects that present in the environment. The second layer is the network layer. The network layer is responsible for enabling communication between the object layer and the data layer. The network layer consists of networking technologies such as the internet, intranet, extranet, Wi-Fi, LAN, WAN, Bluetooth, GPS, GSM, and the cloud. The network layer is responsible for the transmission of the collected data from the object layer. The object layer transmits the received data from the devices in the object layer to the data center layer. The next layer is the data layer. The primary function of the data layer to retrieve and store data. The data layer consists of databases such as SQL, DB2, Oracle, and big data analytical tools like Hadoop, Tableau, Gridcoin, etc. The data layer is responsible for filtering and querying the data to match the requests from the application layer. The last segment is the application layer. The application layer consists of software that is used to present the gathered data in the user-friendly form. The application layer is the layer which enables human or end-user interaction with the IoT framework.

The proposed framework connects suppliers at different levels and the manufacturer via centralized cloud-based information sharing system. The centralized cloud system consists of real-time information collected from the IoT devices. The manufacturer and the suppliers can access the real-time product information such as the location, cost, quality, lead time and manufacturer details along the SC, with the help of relevant network and information gathering technologies. The model is illustrated in Figure 4-3.

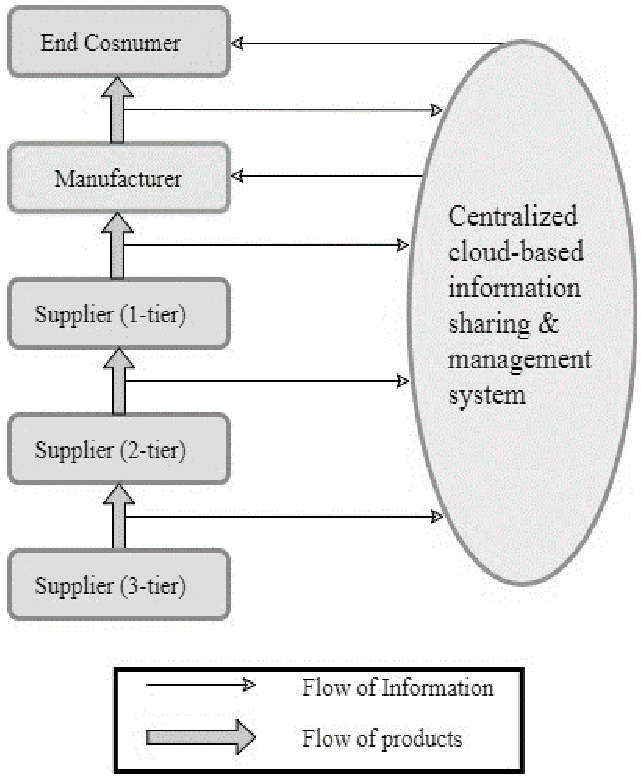


Figure 4-3 General model of the proposed framework

The proposed framework is based on the power of information sharing using the modern technology. All the suppliers share their information with the centralized cloud-based system. The shared data is analyzed and processed using big data analytical tools and clusters are formed containing the most relevant data. The clusters are defined based on what would be beneficial for the suppliers and manufacturers. With the clustered data and rule sets, intelligent business decisions can be taken by the management or the suppliers to achieve their goal of their interest. Some examples of goals include reducing costs, improving customer satisfaction, and producing a quality product, etc., therefore promoting a more efficient and efficient supply chain. Furthermore, the manufacturer can track information along the different levels of suppliers on the supply chain in real time.

4.2.2 Framework implementation

The sensor devices enabled with web connectivity are placed on the objects, collecting data from the surrounding environment and send to the connected cloud-based storage system. The collected information includes temperature, quality of the goods, and security of the products among several other attributes relevant to the condition of the goods. Information collected by the device under different supplier along the supply chain and is sent back for analysis. The information is shared through a network such as Wi-Fi, cellular, internet or a WAN depending on the bandwidth and the specifications of an IoT application being used. Once the data is shared to the cloud, it is processed using big data analytics and data mining software. The software checks the data provided against the appropriate requirement. For instance, if the temperature information sent by the IoT device is not within the acceptable temperature for the product, the system raises the alarm. This information is made accessible to the end user in a user-friendly way, through an interface where the user interacts with the system. The information is processed in real time. Therefore manufacturers can determine the location of their goods along the supply chain beyond their immediate supplier whom they have a relationship. Also, this information can also be shared with the end product user as shown in the Figure 4-4.

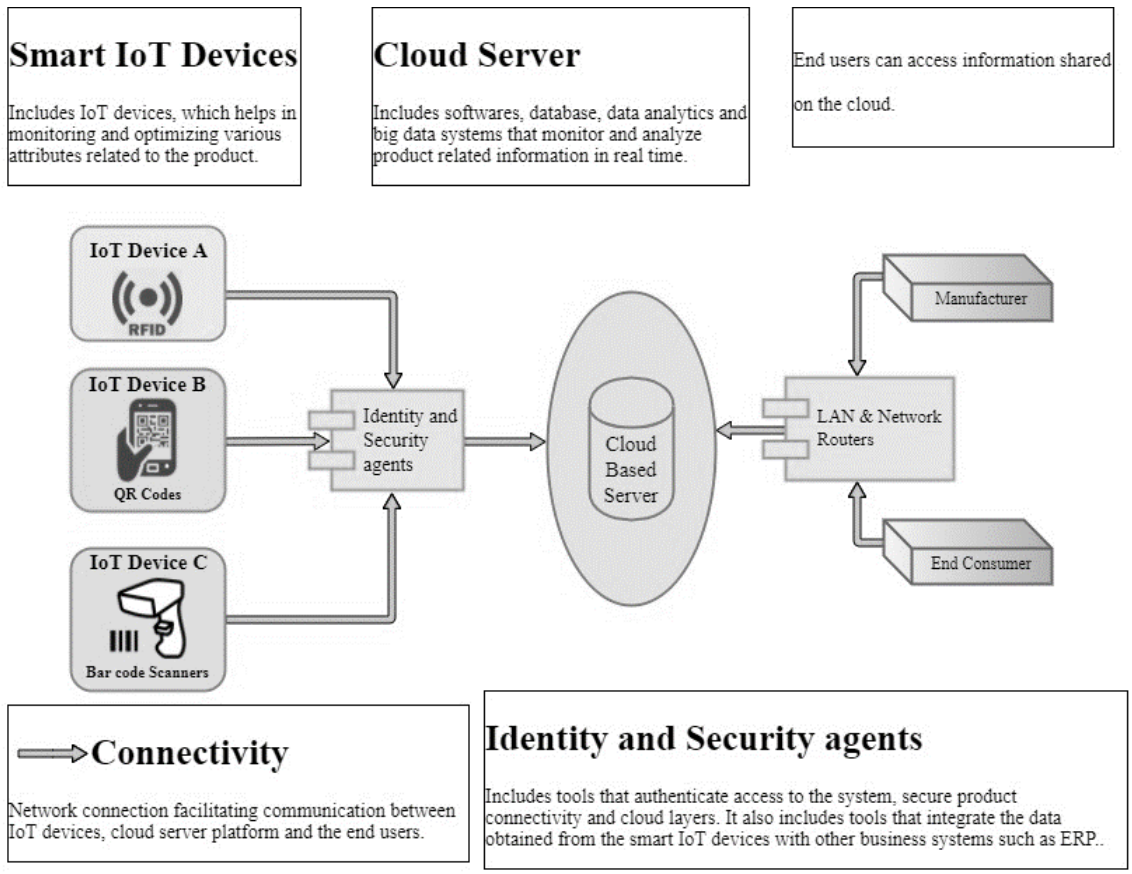


Figure 4-4 Specific model proposed framework

This framework uniquely proposes a brilliant supply chain, especially between manufacturers and suppliers on various areas of their business, including financial, operations, sales, and customer support among several others. The application of smart IoT technology will grant manufacturers a hyper-efficient ability to ensure efficient supply chains with minimal losses, stability in product conditions, significantly saving time and cost. The big data analysis strategies examine sizeable varying data sets to identify hidden patterns such as market trends, correlation, preferences from different clients, hence enabling members of the supply chain to make more informed decisions. The framework can be perceived as three levels with each level carrying out a different function as shown in the Figure 4-5. There are various types of information collection, processing, and storage, which may influence the performance of the proposed framework.

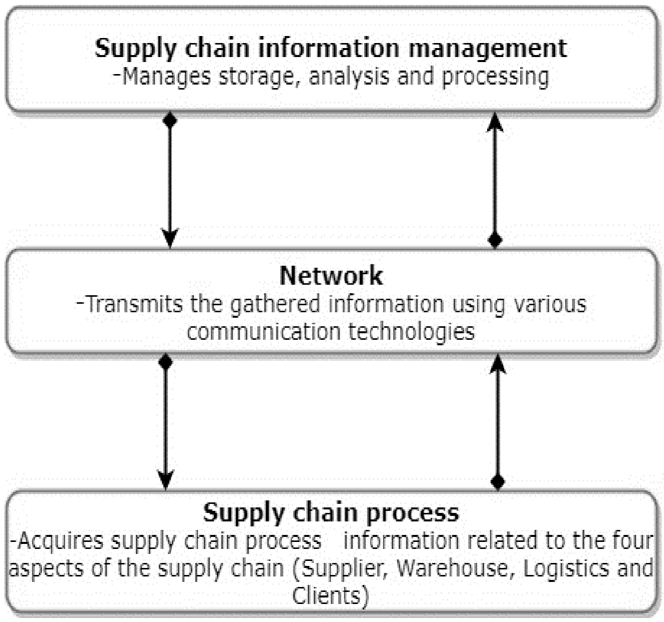


Figure 4-5 Three levels of the proposed framework

4.2.3 The supply chain information management

This level analysis and presents all the information transmitted to the system. It is the level through which the users interact with the system and access the useful information. The accessed information assists in the decision-making process. The centralized cloud-based information management system is the significant part of the proposed framework, as its analyze and present the data to the user in a readable format. A UML diagram representing the proposed framework's sample data structure is shown in the Figure 4-6.

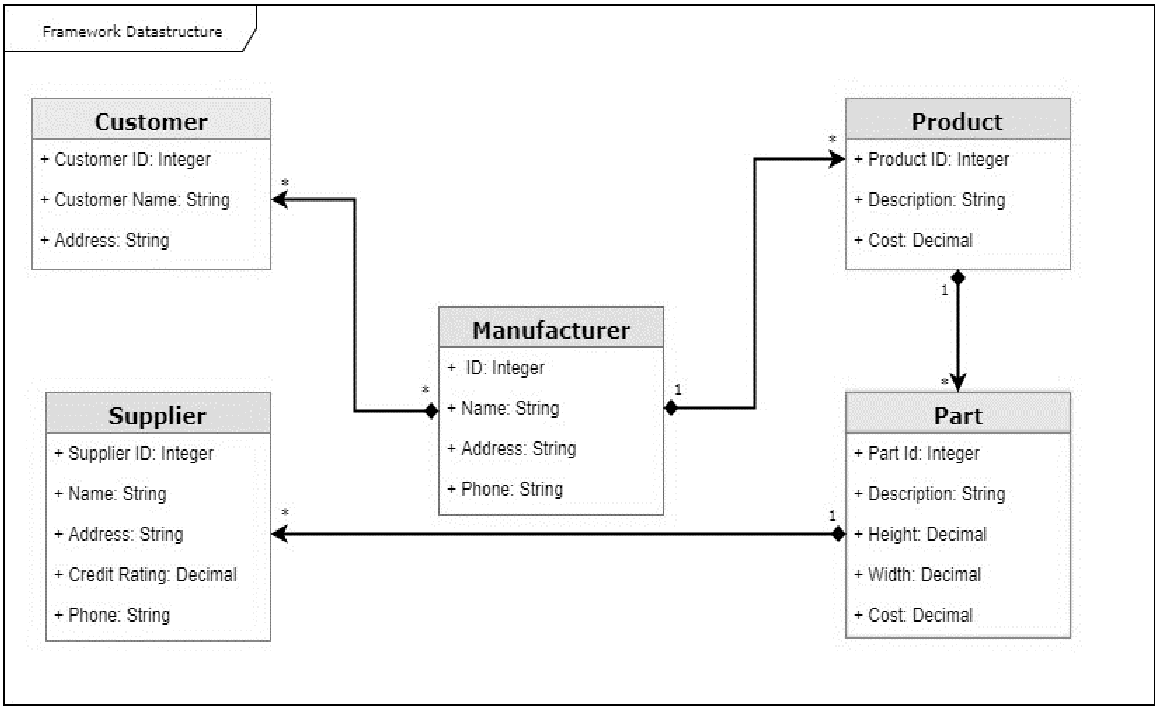


Figure 4-6 UML representation of the data structure

4.2.4 The Network

The network plays a crucial role in transmitting information collected by from the supply chain processes in the system for processing and analyzing into a form which the user can use it. The network can be the internet as well as other wireless networks such as Wi-Fi, Bluetooth, which transmit information to the system. This layer transfers the data from the device to the data center.

4.2.5 Supply chain process

In this level, the information from different aspects of the supply chain such as the warehouse, supplier, logistics, and the client is collected using IoT devices. The devices are used to gather information. This is at the bottom of the structure, and all the information that is transmitted to the system is collected from this level. In general, the three levels together form the proposed method. The internet network transmits the information generated by the supply chain processes to the supply chain management level, where the data is analyzed, processed and accessible by the user in a meaningful form. The framework is, therefore, more resource efficient and easy to share information across suppliers irrespective of their level. This framework is different from the existing framework where manufacturers have an only direct relationship with their immediate suppliers and have to come up with limited systems to track the movement of products beyond this level.

4.2.6 Application of IoT in the supply chain

Currently, GPS signals are used for tracking or fleet management in the logistics aspects of the supply chain. However, the rapid growth of dense urban areas and underground tunnels is creating a challenge to GPS for accurately track the location of vehicles [117]. Therefore, with the current development of the IoT technology, it is possible to utilize radio-frequency indication (RFID) for short-range communication and mobile communication GSM enabled devices for accurate tracking of products along the supply line where GPS is inapplicable, resolving the challenge of high cost and regions where GPS signals are non-existent. GSM communication technology has the capability of sending high data quantity and the most applicable for IoT applications over the GPS because it’s the most ideal for sensor-based projects with low bandwidth [117]. GSM is also easy to integrate with other data transmission networks when compared to the GPS and therefore the most ideal for the proposed framework.

4.2.7 Tracking products along supply chain

In SCM, IoT is applicable in sharing information, monitoring and controlling the movement of products along the supply chain and data analytics. Therefore, sensors are suitable for the monitoring and managing goods to reduce theft. Also, navigation devices are installed in vehicles, provide information on the location of assets, making logistics more efficient. With additional sensors mounted on the vehicles, they are capable of providing information about the condition of the cargo such as temperature and humidity. This real-time information is essential in making efficient and applicable decisions regarding cargo storage and other logistical requirements. With information sharing, the data collected by IoT devices can be shared among different members of the supply chain in real time for their decision making. It is, therefore, possible to monitor and forecast the demand for a specific product and optimize its delivery time, thus improving customer service.

One of the current significant challenges with the SCM is the efficient utilization of resources. Without an integrated system, different members of the supply chain management are forced to come up with their systems to track the movements of their products across the supply chains, which is not only inefficient regarding resources but also unreliable [2]. Therefore, for the members of the supply chain to address the current challenges of wasteful resource usage, there is the need for firms to collaborate to share their scarce resources. This has the advantage of achieving a higher performance gain, especially for non-natural resources such as technology, equipment, and transportation. Also, information sharing among different firms that are members of a supply chain will create a more efficient supply chain. It is based on information and resource sharing to achieve the effectiveness of the SCM by utilizing the modern power of the IoT. The proposed system addresses this challenge through the use of IoT by having smart tracking devices fitted across a product from the manufacturer, which collects information on the location, condition and the state of the products along the different levels of the supply chain. This information is transmitted to an integrated information management system where the end user can easily track the state and the condition of the product in real time. Therefore, the proposed framework creates an efficient resource system that links the different aspects of the supply chain in an integrated system, enabling the user to quickly access information on the movement of products along the supply time in real time for decision making. It enhances information sharing among different members of the supply chain and reduces the many supply chain fragments having to come up with their product tracking system.

4.3 Internal SC System

4.3.1 Operation analysis

After the introduction of advanced process technology and implementation of IoT, the traditional way of manufacturing has changed to intelligent and automatic production. Traditional manufacturing systems are passive; meaning that they are not designed to adapt to the dynamically changing nature of the manufacturing process. In a conventional manufacturing system, obtaining real-time information is tedious. Even if the real-time data is collected, it would be outdated when the information reaches the user. The passive nature of the traditional manufacturing system is illustrated in Figure 4-7. However, manufacturing systems can be useful if they can adapt to the rapidly changing environment. This is possible when access to real-time updated information is enabled. Figure 4-8 shows how an IoT-enabled manufacturing system assists in accessing real-time information.

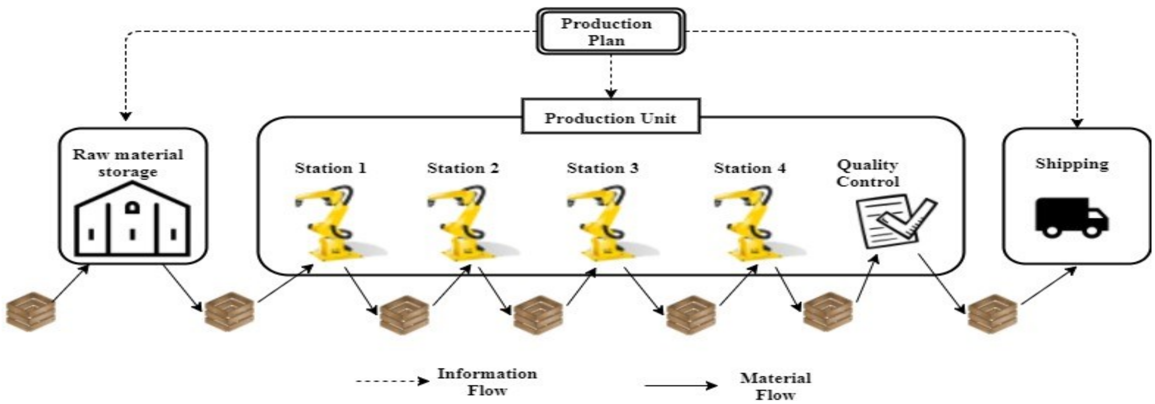


Figure 4-7 Traditional manufacturing system

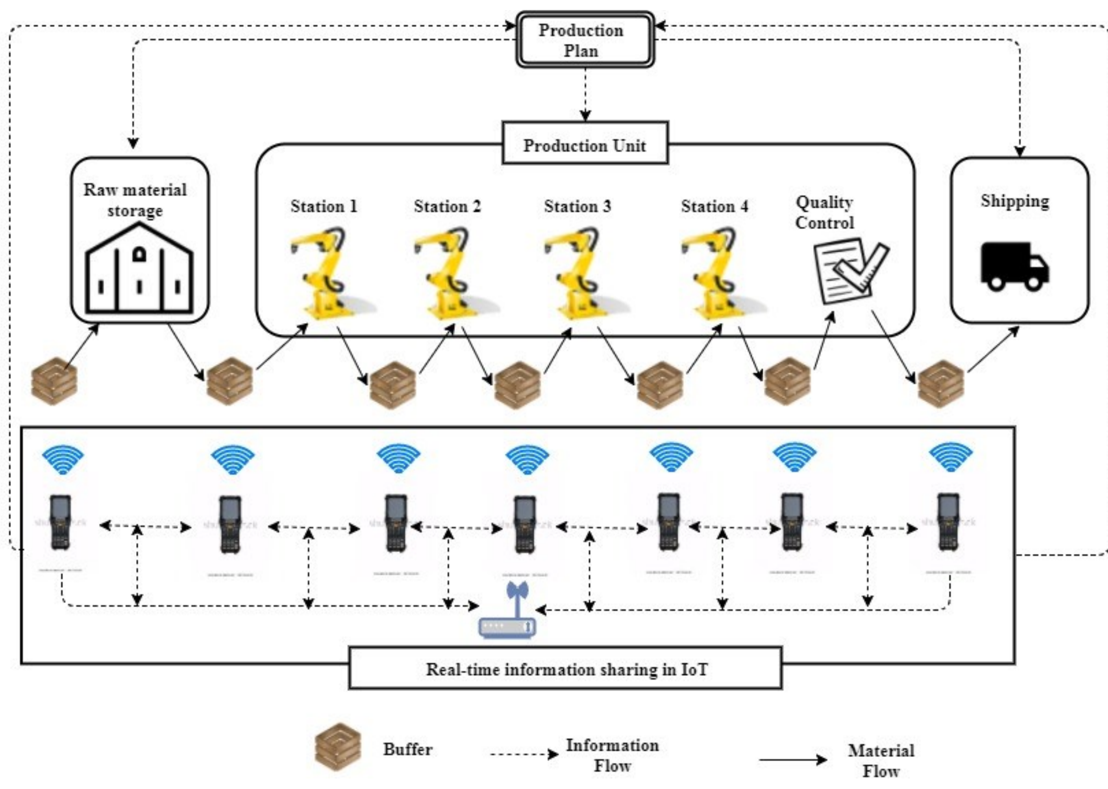


Figure 4-8 IoT-enabled manufacturing system

RFID is used in the system to locate the objects and obtain the movement of materials within the internal SC process. This real-time information is acquired automatically and shared between several other objects. This assists to abridge manual operation in recording, inspecting, counting, identifying and improves the accuracy of real-time information related to work-in-progress (WIP) inventory. The information sharing becomes a real-time system providing effective feedback between the production plan and the information flow.

4.3.2 Integration of ERP and IoT system

To create a model for integration, it is necessary to identify and define the parameters of the different objects present in the SC system. The following assumptions were made for the parameter identification.

1) A manufacturer has one or more customers.
2) A customer has one or more orders.
3) An order is composed of one or more items.
4) An item is made up of several parts.
5) Each part has one or more supplier(s).
6) A manufacturer has one or more suppliers.
7) An item has to undergo a sequence of processes to produce a new product.
8) Each process is associated with an assembly station.
9) A manufacturing unit has more assembly stations.

The principal goal of the model is to track the status of every order item in the internal SC or production unit using the real-time information obtained from IoT. A UML diagram representing the different object parameters and their relationship with other objects is illustrated in the Figure 4-9. RFID tags are used for automatic location tracking and are integrated with the ERP system to obtain the real-time status of every item. The ERP system consists of a production plan, which has the execution sequence of orders and the SC path that the item has to undergo within the manufacturing unit. The SC path of an item is identified by linking the item, process, and the station objects. Once the SC execution path of an item is identified, it is integrated with the real-time information obtained from the RFID system.

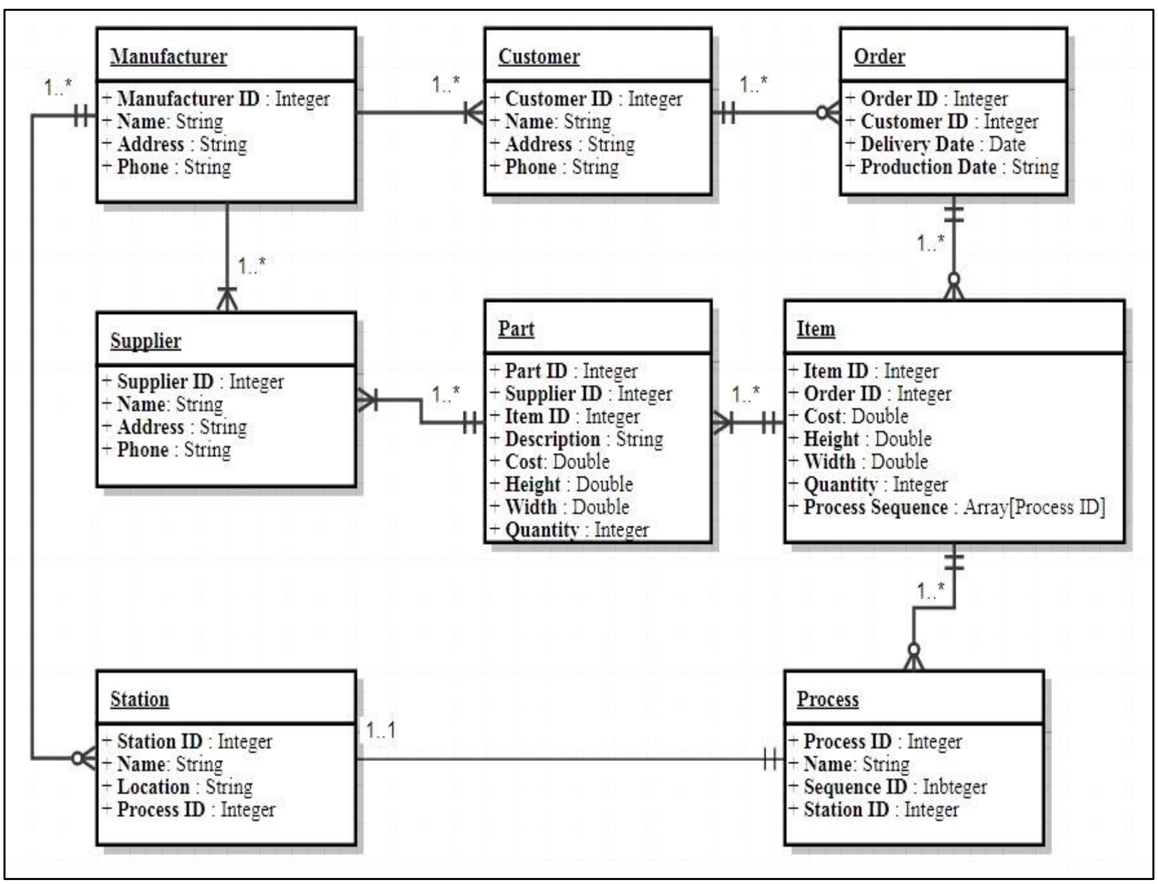


Figure 4-9 A UML diagram representing the parameters

A value map streaming of different product configurations and some labor hours required for the production day can be identified and integrated with the real-time data. Integrations help in achieving the synchronization among various stages along the SC path. For example, the real-time status and location information of an item obtained from RFID can be verified with the actual production plan and alert employees at different stations who are not following the sequence. A detailed implementation of the model is discussed in Chapter 6.

Moreover, automatic information collection is possible with the implementation of IoT. Since IoT can collect information automatically, the status of an item is displayed to the employee automatically in real time. For example, an item when transferred from one station to another, RFID can capture the transfer and automatically show the status and other process related information to the employee. This automatic display of information reduces the time that an item spends in the SC path. This time reduction not only facilitates in fastening the production process but also helps to increase the production capacity.

4.3.3 Production efficiency model

IoT has not changed the operation process of the traditional manufacturing system. The relationship between the production efficiency and the real-time information can be explained using a model. Hence, this paragraph describes the equations required for measuring production efficiency and defines the different relationship with the parameters.

Following equations were defined to measure the production efficiency. Table 5.1 describes the parameters used in the comparison.

$$CI_i = CR_i + CD_i + CL_i + CE_i \tag{1}$$

$$P_i = S_i - CI_i \tag{2}$$

$$T_i = \sum_{j=1}^{m} [AT_{i,j} + BT_{i,j}] \tag{3}$$

$$PE_i = \mathrm{k}\frac{P_i}{T_i} \tag{4}$$

Equation (1) is used to calculate the cost of investment for making a product or item and is obtained by the summation of raw material cost, delivery or logistics cost, labor cost, and the equipment cost. Here the delivery cost includes the cost of delivery of raw materials from the supplier and the cost of delivery of the finished products to the end customer. The manufacturer cannot obtain a profit until an item is being sold. Profit is a direct measure of the value added to an item. Profit can be measured by the reducing the investment cost from the selling price, hence Equation (2). Selling price includes all the discounts and other promotions applied to the product sold. Using Equation (3), the time required for manufacturing an item is calculated. Manufacturing time is measured by summing the time required to assemble an item at different assembly stations and the time an item spends in the buffer placed between two different stations. Once the manufacturing time and the profit of an item are calculated, the efficiency of producing an item can be obtained. Production efficiency is calculated by the profit over time and is defined using Equation (4).

Table 4.1 Parameter Description – Production efficiency modeling

Notation	Description
k	represents the constant of general application given by fatigue of the human personnel involved, wear and tear of machines and obsolescence of IoT
i	represents an order item, that is being manufactured
PE_i	represents the efficiency of production for the order item *i*
P_i	represents the profit obtained from the order item i
T_i	represents the time required to produce the order item i
CI_i	represents the cost of investment in making the product
S_i	represents the selling price of item i to the customer or the dealer
CR_i	represents the cost of raw materials required for manufacturing the order item i
CD_i	represents the cost of delivery of the order item i
CL_i	represents the cost of labor for manufacturing the order item i
CE_i	represents the cost of equipment(s) involved in manufacturing the order item i
j	represents an assembly station present on the production floor
m	represents the total number of assembly stations present on the production floor
$AT_{i,j}$	represents the time required to assemble an item i in the station j
$BT_{i,j}$	represents the waiting buffer time of item i before entering the station j

In the overall internal SC process, the time required to produce an item decreases due to the application of IoT. Synchronization of the entire internal SC process results in a reduction of buffer time for an item. Synchronization also increases the accuracy, effectiveness, and reliability of the SC system. Real-time status information of the WIP item helps employees to identify the parts easily in the buffer, thus reducing the time spent in locating the parts and defining the process that needs to be carried out to an assembly station.

IoT also helps to incorporate production quality control into the SC process. Quality checksheets can be introduced at the assembly stations, reducing the process errors and increasing the inspections. As a result, the overall quality is improved, reducing the number of quality rejections and backorders. More quality products enhance customer relationships and also increase the profit per product. Production efficiency is increased as the profit increases and the production time decreases.

4.3.4 System adaptiveness

A substantial number of benefits can be obtained once the IoT is integrated into the manufacturing process. An adaptation of the system is improved by identifying the root cause of any quality rejected item. This helps in improving the production process. Since the production plan is integrated with real-time information, the flexibility of the production plan to adapt to new changes is possible. With the traditional manufacturing system, any last minute changes in the production plan affect the entire production process. For example, rush order from a VIP customer, quality rejected items, and backorders from the customer alters the actual production plan. Such orders are given high priority over the other orders, to maintain the relationship with the customer. This directly affects the production sequence and indirectly affects the truck loading and delivery time and as a result delivery cost of an item (CD_i) increases, decreasing the production efficiency of an item (PE_i). Since access to real-time information is enabled, last minute changes are adapted smoothly into the production plan. Hence, maintaining the production efficiency of the manufacturing system.

4.4 External SC System

4.4.1 Operation Analysis

In a traditional external SC system, the information flows from the manufacturer to the supplier and then to supplier's supplier and so on. This information flow is illustrated in Figure 4-10 below. Here different colors represent different levels of suppliers. Here the information flows from top to bottom. However, the flow of materials is opposite to the information flow. Materials flow from the bottom to the top. Each supplier is itself a manufacturer and has their distinct supply chain.

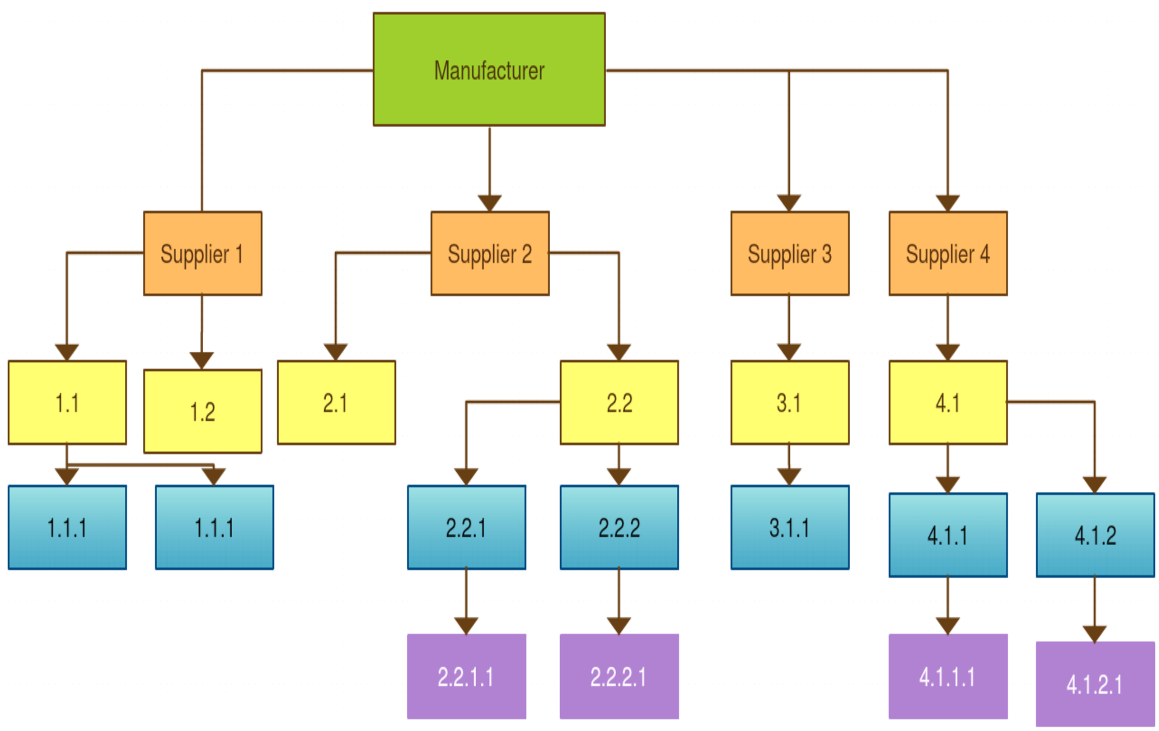


Figure 4-10 Information flow in a traditional external SC system

Unlike traditional external SC systems, in IoT enabled external SC system information does not flow through suppliers. Instead, all the information from the supplier is shared to a centralized cloud-based storage, and the information is accessed by the manufacturers from the centralized database. However, the flow materials in both the traditional and the IoT enabled external SC system remains the same, i.e., material flows from suppliers to the manufacturers. Figure 4-11 illustrates IoT enabled information sharing in an external SC system. Each object in the external SC system is itself an internal SC system discussed earlier in section 5.2.

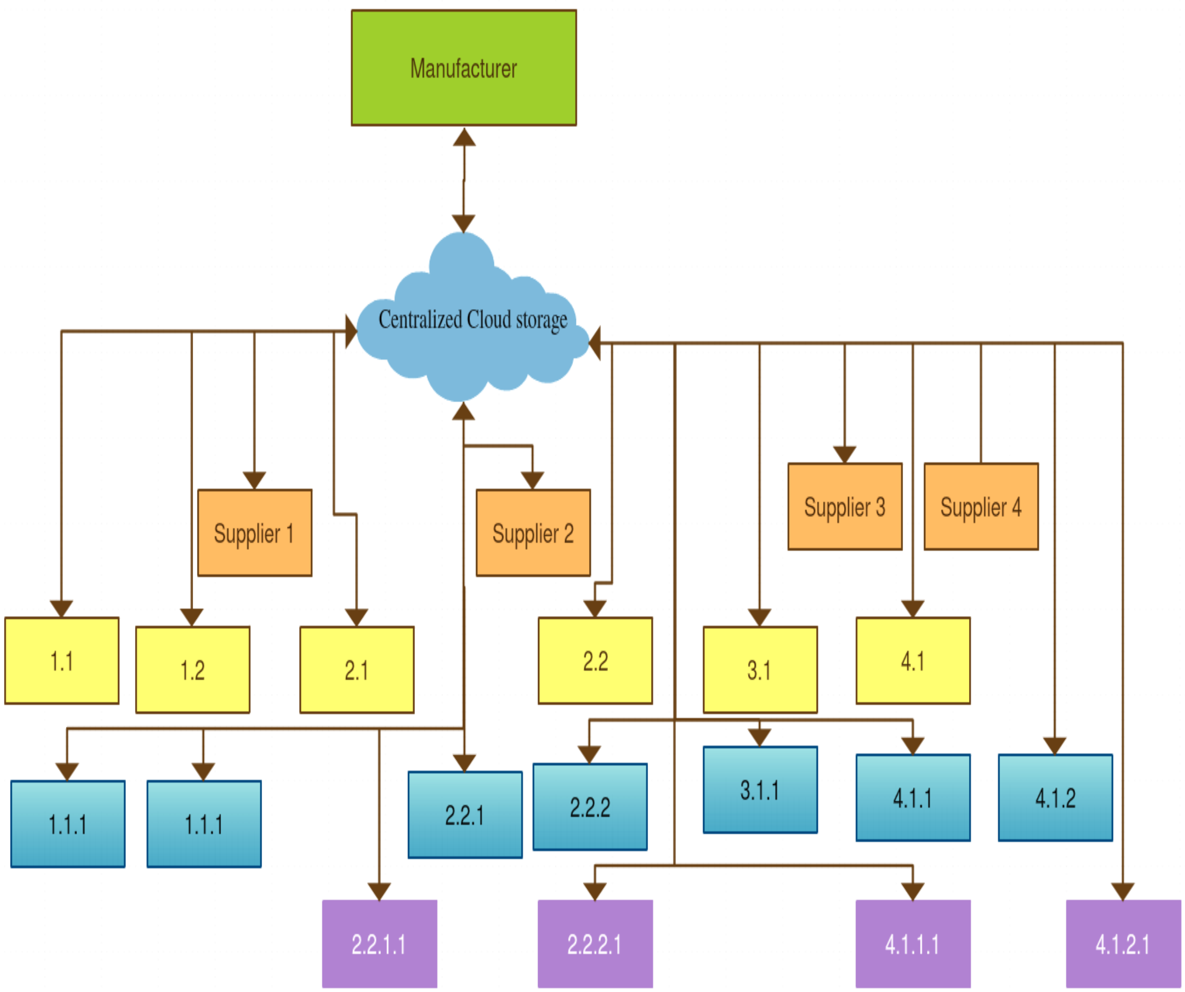


Figure 4-11 IoT enabled information sharing in the external SC system

Despite suppliers sharing the information, manufacturers also share the demand information with the centralized cloud system. Information shared by the manufacturers can be accessed by the suppliers at all levels and help in planning their production and execution processes. In an IoT enabled external supply chain system, information flows in both the directions, whereas in traditional systems information flow from top to bottom. Security becomes a major concern, when information is shared in the centralized cloud based system. Suppliers at the same level are competitors to each other and do not wish to share information with the supplier(s). In certain cases competition might exist at different levels for example, when suppliers produce same products or when suppliers produce products for different receivers that belong to the same industry. In order to protect information being accessed by competitors and other un-authorized players, identity and security mechanisms are in place that handles all the incoming requests to the cloud storage system. Figure 4.4 illustrates the presence of identity and security agents in the IoT enabled cloud storage system. Identity and security agents check whether the request is valid to accesses the authorized information. Requests that not valid or does not access for authorized information are rejected without further processing. Several security mechanisms are available that can provide security schemes for the rightful information sharing, but they are not the main focus of this research.

4.4.2 Mathematical model for optimization

Traditional external SC systems are less complex as it interacts with less single SC objects. The complexity of the external SC system increases with the introduction of IoT-based external SC system, as more suppliers across different tiers share their information with the centralized cloud storage. To resolve the complexity of the SC system, it is essential to have a mathematical model for optimization. Table 4.2 describes the parameters used for representing the model. The mathematical model explores all possible supply chains that could fulfill the request from the customer. Then the mathematical identifies the best applicable solution by eliminating the SC paths that could not lead to a best solution.

First, only objects present at one tier are considered, i.e., k is fixed and assumed that the customers demand is to reduce the cost of the product. The matrix C_{NxM} is a real matrix that consists of product costs between 'N' suppliers and 'M' manufacturers. The cost matrix is represented below.

$$C_{NxM} = \begin{bmatrix} C_{11} & C_{12} & . & C_{1M} \\ C_{21} & C_{22} & . & C_{2M} \\ . & . & . & . \\ C_{N1} & C_{N2} & . & C_{NM} \end{bmatrix}$$

The matrix L_{NxM} is a binary matrix that represents whether there is a link that exists between the supplier and the receiver. If there is no link exists between a supplier and a receiver, then the corresponding link has to be neglected from the modeling. Hence it is represented with a '0'. The link matrix helps to identify and eliminate if there is no relationship exists between the supplier and the receiver. The link matrix is represented below, where '0' represents the absence of relationship between the n^{th} supplier and m^{th} manufacturer and '1' represents the existence of relationship between the n^{th} supplier and m^{th} manufacturer.

$$L_{NxM} = \begin{bmatrix} 0 & 1 & . & 1 \\ 0 & 0 & . & 1 \\ . & . & . & . \\ 1 & 0 & . & 1 \end{bmatrix}$$

The matrix D_{MxL} is an integer matrix that consists of the demands from the manufacturer and the links. The demand matrix is represented below.

$$D_{MxL} = \begin{bmatrix} D_{11} & D_{12} & . & D_{1L} \\ D_{21} & D_{22} & . & D_{2L} \\ . & . & . & . \\ D_{N1} & D_{N2} & . & D_{NL} \end{bmatrix}$$

The matrix W_{NxL} is an integer matrix that consists of the capacity of the supplier in correspondence to the link and is represented as shown below.

$$W_{NxL} = \begin{bmatrix} W_{11} & W_{12} & . & W_{1L} \\ W_{21} & W_{22} & . & W_{2L} \\ . & . & . & . \\ W_{N1} & W_{N2} & . & W_{NL} \end{bmatrix}$$

The matrix U_{NxL} is an integer matrix that contains the units being supplied from the supplier into the link. The unit matrix is represented as below.

$$U_{NxL} = \begin{bmatrix} U_{11} & U_{12} & . & U_{1L} \\ U_{21} & U_{22} & . & U_{2L} \\ . & . & . & . \\ U_{N1} & U_{N2} & . & U_{NL} \end{bmatrix}$$

For multiple k tiers, the variables can be represented as below.

$$C_P^K \in R^{NxM};$$

$$D^K \in I^{MxL};$$

$$W^K \in I^{NxL};$$

$$U_P^K \in I^{NxM};$$

$$L^K \in B^{NxM};$$

Table 4.2 Parameter Description – Mathematical modeling for optimization

Notation	Description
k	represents the level of the supply chain. For example, k=1 represents the objects present at tier 1.
n	represents a supplier
m	represents a receiver or manufacturer
l	represents the link between the supplier and the receiver
p	represents a product or part
N	represents the set of suppliers
M	represents the set of receivers or manufacturers
P	represents the set of product or parts
C	represents the set of the cost required for producing the product
D	represents the set of demand
U	represents the set of being units supplied
L	represents the set of the link between the supplier and the receiver
W	represents the set of the capacity of the suppliers to produce

Here the goal is to find the part with the lowest cost. Hence the equation to optimize can be represented as shown in Equation (5), subject to the demand and supply constraints.

Goal: $$\text{Minimize } \sum_{k=1}^{K}\sum_{p=1}^{P}\sum_{n=1}^{N}\sum_{m=1}^{M} U_l^k(n,m)^* C_l^k(n,m) \tag{5}$$

Demand Constraint: $$U_p^k(:,m)^T L(:,m) \geq D^k(m,p) \quad \forall p,m,k$$

Supply Constraint: $$U_p^k(n,:)L(n,:)^T \leq W^k(n,p)^T \quad \forall n,p,k$$

The demand constraint present here is, the quantity of part received by the manufacturer should be at least equal to or greater than his actual demand, and the supply constraint is, the quantity of units shipped by a supplier cannot exceed his capacity to produce. The constraints also filter the supplier and receiver nodes that do not contain links between them. The optimized SC path and that contains the optimal cost can be obtained by solving the optimization problem discussed.

Matrix for delivery time and quality and other features can be formed that is similar to the cost matrix. The same model can be used by replacing cost matrix with delivery time matrix, and quality matrix can be obtained and the goals to find the optimal SC path with fastest delivery time or SC path that produces a quality product, etc. can be achieved.

4.4.3 System adaptiveness

Information sharing enables, easy and fast access to real-time information aiding in the better decision-making. Information gathering from individual suppliers is done internally and is shared with the cloud-based system via the internet. Information stored in the cloud storage is enormous and hence require data analytics and data mining software to analyze the data and respond to any request. Material flows through different suppliers, and the sequence of suppliers that the material undergoes in the flow is referred as the SC path.

System adaptiveness is achieved by allowing manufacturers to choose an optimal SC path for the materials to flow through in the entire SC, starting from the raw material supplier to the end customer. An efficient SC path is chosen considering the live information. For example, different customers have different demands or priorities. A customer may have faster delivery of the product as his top priority. For another customer, product with least cost is the priority. Some customers may have a combination of different features as a priority. By replacing the cost function in the mathematical model discussed in section 4.4.2, with the required functions (for example, fastest delivery date, quality product or supplier with good relationship), desired results can be obtained each satisfying different demands from the customer. With real-time information, manufacturers are given the flexibility to choose the SC path based on the demands or preferences from the customer.

Chapter 5 IoT Technologies considered for the implementation

5.1 Information gathering technologies

Information gathering technologies help in collecting information from various SC processes that are required by the system. Information gathering technologies include IoT devices such as RFID sensors, QR code readers, and barcode scanners. Usage of these IoT devices varies depending upon the environment of the supply chain. Each technology has its pros and cons. The following section, explains briefly how these techniques are used in the proposed system.

5.1.1 RFID, Barcodes & QR Codes

The RFID is an automated technology device which retrieves information using RFID tags. RFID is more advanced in comparison to the manual tracking systems as it collects, analyzes and stores information [70]. Therefore, it is more applicable to the supply chain system. The RFID device can automatically identify, retrieve, and store information. RFID is made up of two parts which are the reader and the tags. The tags store information about the product electronically and then the reader helps in reading this information. Figure 5-1illustrates, how information is gathered from the RFID tags and product information is stored in the database.

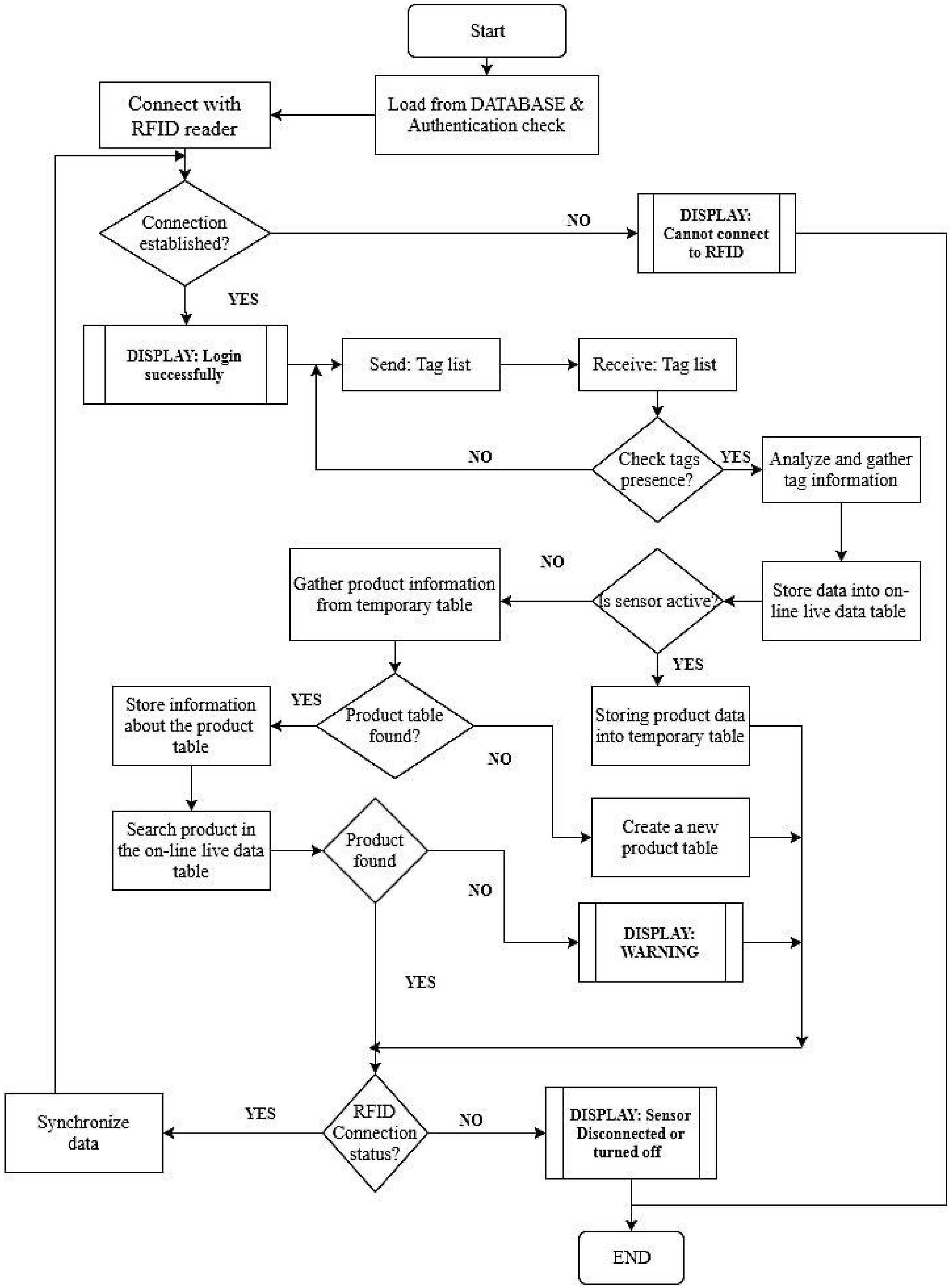


Figure 5-1 Flowchart - RFID information gathering

The device has a significant advantage of being wireless. The RFID device located in a warehouse can identify the details of the product and report to the manufacturer before the products are entered into storage when found at the appropriate place. This ensures efficient inventory management and also information on the physical condition of the products can also be obtained. The RFID can even counter check the inbound goods to the warehouse against relevant receipts and the outgoing assets as per the delivery, therefore minimizing instances of loss of merchandise along the supply chain. Also, the transporting products will also require being fitted with the tracking device which such as the GPS. This provides information on the location of the cargo relative to its origin and destination. At the receiving end, a RFIDs are used to check the received goods if they tally with the information of the dispensed product from the warehouse. Therefore, users can access information on the product from the supplier to the warehouse during transportation and when the client receives it.

Barcodes have gained significant attention across the supply chain systems, especially in the logistics. The barcode can be one dimensional or multidimensional which stores data regarding a specific product. The barcode applies optical technology to extract information stored in the barcode tag, therefore, very applicable using smart devices such smartphone applications. The barcode has an advantage of being useful in constraining environment where the RFID cannot operate such as the retail environment. Also, they are also relatively cheap. However, it is also a disadvantage that the bar code reader must be in the line of sight with the barcode reader, hence requires a person to direct the barcode reader to the barcode, which is strenuous and technically expensive where large volumes of inventories are involved. Secondly, barcode tags are vulnerable in damp environments and may be ineffective thus providing misleading information when damaged and must be reprinted under such cases. The information carried by the barcodes can include the name, the model, the quantity and quality of the products as well details of the producer. The technical capability of these devices is attributed to the progress in the micro-electro-mechanical systems, which have advanced communication capabilities to visualize data.

5.2 Network, Data Storage, and Processing Technologies

The network plays a significant role in the proposed system. It facilitates the transmission of the collected data for analysis in the integrated information management system. The interface enables communication between the information gathering devices in the supply chain processes and the centralized cloud storage system. The interface is also responsible for information being updated accurately in real time. The type and technology of the network depend on nature and the kind of information being transferred. The type of information shared by the proposed framework is vehicle location, details of the products and the manufacturer and the condition of the product, which therefore require reliable and high-speed network if the information is to be relayed in real time. One of the significant network types applied to the proposed framework is the internet. Also, other types of networks such as the Wi-Fi, ZigBee, and GPRS may also be used to relay information on the integrated information management system. However, the amount data transmitted on this network require big-data technology, to avoid the challenges associated with the traditional data transmission process. This is because it integrates information from the four aspects of the supply chain discussed earlier into one system. Also, the processing power required for real-time processing and gathering of information needs big data analytics technology.

The data streams generated by the sensors can be utilized using dedicated software or platform. However, the current major challenge is the lack of standardized platforms which hinders many developers from coming up with innovative applications and process that can analyze and present that data to users. This is one the significant challenges that the proposed framework aims to address. It will create a standardized platform that allows developers to participate in innovation that is essential for the growth of the supply chain management. A standardized platform will reduce data processing costs, server load and the delay that is experienced by having fewer applications and services that analyze this data for the end user. Modern IoT data stream processing techniques have also been proposed for real-time processing with several platforms already created for streaming real-time data. This information, therefore, demonstrates that the proposed framework is indeed achievable, despite the amount of data that is involved and the data processing capabilities that are required.

Data transmission and processing are the most critical aspects of the proposed framework. Modern data processing and storage applications are required to ensure a high data processing and analysis capability so as users can access information with real-time information collected from various supply chain processes and transmitted to the system. Currently, there are some high tech data processing and storage applications applied in IoT. Some of the modern demands of IoT include the ultra-realistic broadcasts in sports and tracking the pedestrian flow in a city in real time. These applications use streams of data and demonstrate the capability of the IoT technology as applied in the proposed framework, providing live streams of the information collected in various supply chain processes for analyzing.

Chapter 6 Case Study and prototype implementation

6.1 Live status screen project

A case study has been done in one of the leading window and door manufacturing company in Northern America. The company has clients all over Northern America. The company is more known for building custom doors and windows. The company had synchronization issues in building products, according to the truck delivery route. Building products not according to the truck route is a problem because the company has to block the required trucks more than the time required. Also, the company needs to allocate buffer space for finished products since no one had the visibility of product flow. The shipping department spends a lot of time in identifying each of the finished products that have to be loaded into the truck. Lack of visibility among the production employees was another major problem; no one knew if a product had been neglected from the production process until shipping identifies during the loading and notifies the corresponding production employees. Once production department has been told, they have to do a rush order leading to quality problems and more waiting time for the product. All of these issues resulted in the colossal waste of resources and are related to the cost and the time that the management spends to solve this problem. The shipping department has estimated that the company could save $1 million/year if the products can be built in order of truck loading and optimizing the delivery routes. A tool to optimize the truck routes was developed to address the problem and provided to the scheduling department for their use. The truck route optimizer was built using the Google API, which takes a list of customer addresses as input and gives an optimized path. The truck route optimizer application is shown in the Figure 6-1. After finding the optimized smooth route(s), the scheduling department batches the orders in the sequence that the products have to enter into the truck (i.e., the first item loaded into the truck will be delivered last).

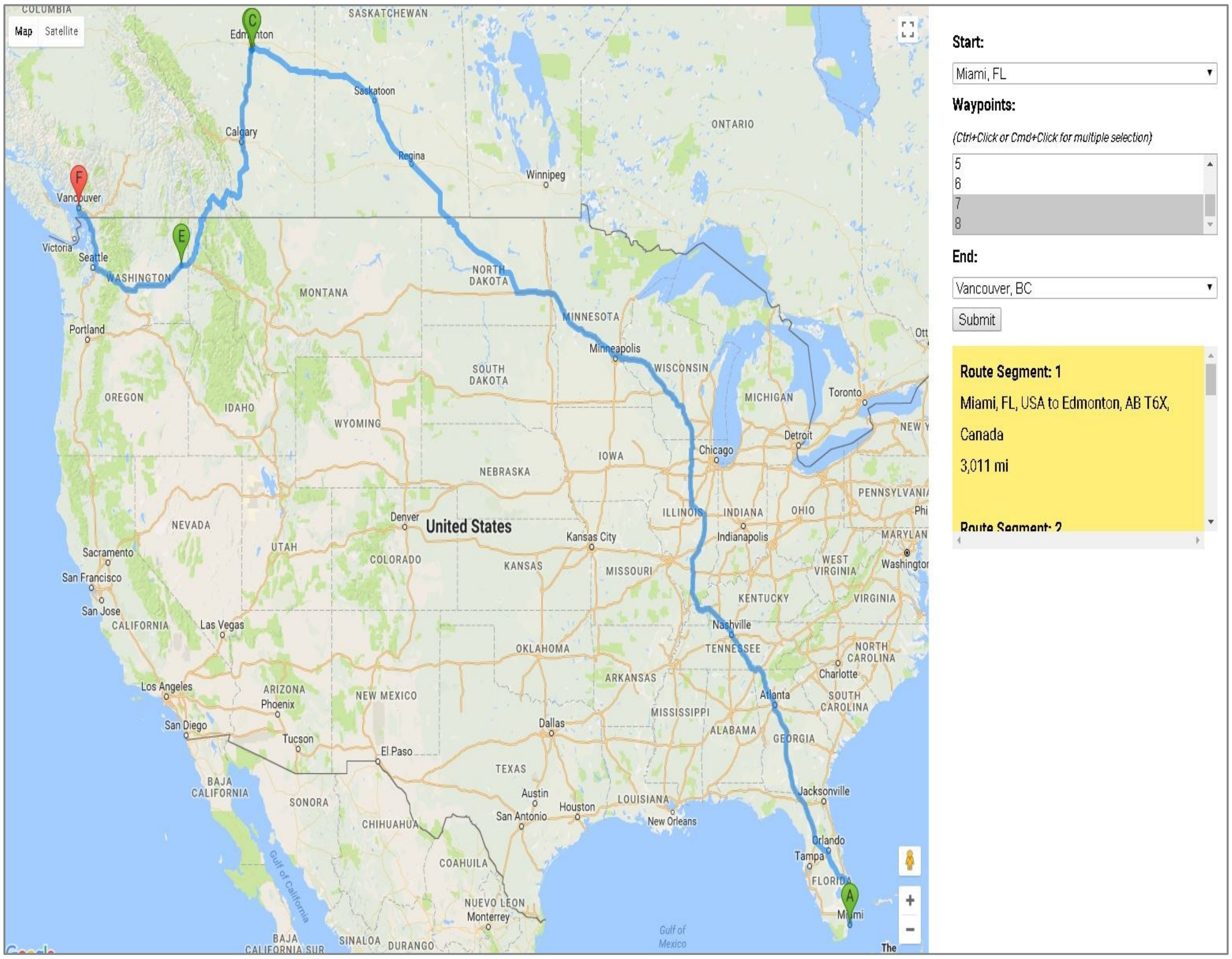
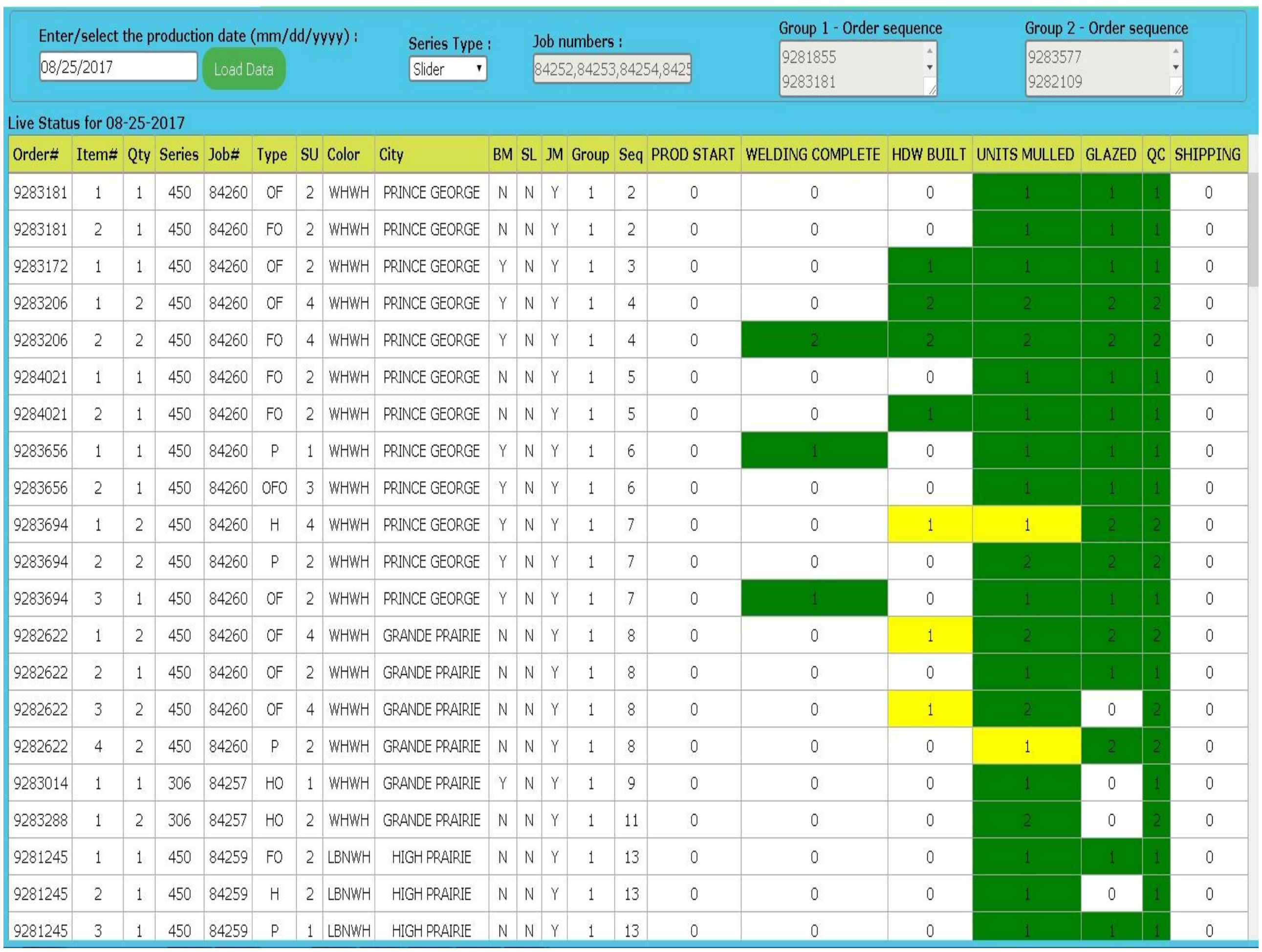


Figure 6-1 Truck route optimizer

It was noted that the production employees have to scan the items to know what parts and configurations regarding the product. With the help of sequencing and the scanning technology a visibility tool called ‘Production Live Status’ has been built to track the sequence of the product flow. This production live status screen is displayed on a big monitor on the production floor, where all the production employees can see the flow of the products. Sample production live status screen is displayed Figure 6-2. This tool will highlight any orders that are not in sequence, forcing the production employees to work in synchronous with the chain. Every product is given the address (cart number and bin number) so that the shipping team and or the production team can identify the right product.



Order#	Item#	Qty	Series	Job#	Type	SU	Color	City	BM	SL	JM	Group	Seq	PROD START	WELDING COMPLETE	HDW BUILT	UNITS MULLED	GLAZED	QC	SHIPPING
9283181	1	1	450	84260	OF	2	WHWH	PRINCE GEORGE	N	N	Y	1	2	0	0	0	1	1	1	0
9283181	2	1	450	84260	FO	2	WHWH	PRINCE GEORGE	N	N	Y	1	2	0	0	0	1	1	1	0
9283172	1	1	450	84260	OF	2	WHWH	PRINCE GEORGE	Y	N	Y	1	3	0	0	1	1	1	1	0
9283206	1	2	450	84260	OF	4	WHWH	PRINCE GEORGE	Y	N	Y	1	4	0	0	2	2	2	2	0
9283206	2	2	450	84260	FO	4	WHWH	PRINCE GEORGE	Y	N	Y	1	4	0	2	2	2	2	2	0
9284021	1	1	450	84260	FO	2	WHWH	PRINCE GEORGE	N	N	Y	1	5	0	0	0	1	1	1	0
9284021	2	1	450	84260	FO	2	WHWH	PRINCE GEORGE	N	N	Y	1	5	0	0	1	1	1	1	0
9283656	1	1	450	84260	P	1	WHWH	PRINCE GEORGE	Y	N	Y	1	6	0	1	0	1	1	1	0
9283656	2	1	450	84260	OFO	3	WHWH	PRINCE GEORGE	Y	N	Y	1	6	0	0	0	1	1	1	0
9283694	1	2	450	84260	H	4	WHWH	PRINCE GEORGE	Y	N	Y	1	7	0	0	1	1	2	2	0
9283694	2	2	450	84260	P	2	WHWH	PRINCE GEORGE	Y	N	Y	1	7	0	0	0	2	2	2	0
9283694	3	1	450	84260	OF	2	WHWH	PRINCE GEORGE	Y	N	Y	1	7	0	1	0	1	1	1	0
9282622	1	2	450	84260	OF	4	WHWH	GRANDE PRAIRIE	N	N	Y	1	8	0	0	1	2	2	2	0
9282622	2	1	450	84260	OF	2	WHWH	GRANDE PRAIRIE	N	N	Y	1	8	0	0	0	1	1	1	0
9282622	3	2	450	84260	OF	4	WHWH	GRANDE PRAIRIE	N	N	Y	1	8	0	0	1	2	0	2	0
9282622	4	2	450	84260	P	2	WHWH	GRANDE PRAIRIE	N	N	Y	1	8	0	0	0	1	2	2	0
9283014	1	1	306	84257	HO	1	WHWH	GRANDE PRAIRIE	Y	N	Y	1	9	0	0	0	1	0	1	0
9283288	1	2	306	84257	HO	2	WHWH	GRANDE PRAIRIE	N	N	Y	1	11	0	0	0	2	0	2	0
9281245	1	1	450	84259	FO	2	LBNWH	HIGH PRAIRIE	N	N	Y	1	13	0	0	0	1	1	1	0
9281245	2	1	450	84259	H	2	LBNWH	HIGH PRAIRIE	N	N	Y	1	13	0	0	0	1	0	1	0
9281245	3	1	450	84259	P	1	LBNWH	HIGH PRAIRIE	N	N	Y	1	13	0	0	0	1	1	1	0

Figure 6-2 Production Live status screen

The barcode scanning details at various stages for the WIP items are captured and stored in the database. Each assembly station is assigned a letter as shown in Table 6.1 below. The WIP details are linked with other information such as orders, corresponding batches, and the delivery sequence. A SQL query shown in the Appendix-B Query-1 is used to fetch the data from the database then rendered into a human-readable format using visual studio asp.net server and I-frame browser plugin helps in the integration of the "Production live status screen" into the ERP software. The entire set up is illustrated in the Figure 6-3.

Table 6.1 Assignment of different stations

Assignment	Assembly station
A	Production start
W	Welding station
H	Station for hardware installation
C	Station for cladding installation
S	Station for installing the screens
U	Station for sealing the units
M	Station where units are mulled together
G	Station where sealed units are glazed
Q	Station for inspection and quality control
E	Production complete
L	Area where the finished product gets loaded into the trucks

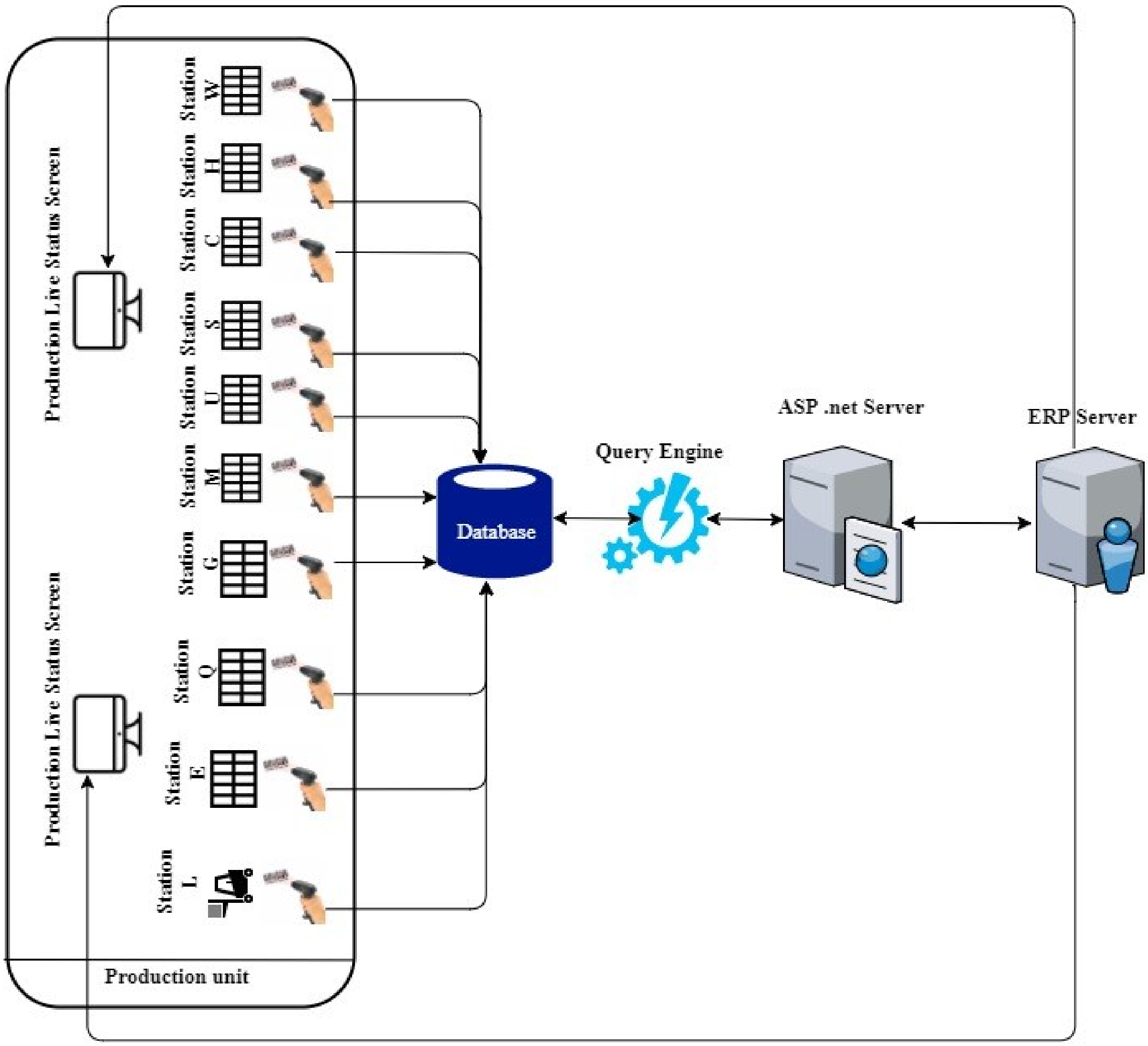


Figure 6-3 Implementation of Production live status screen

One disadvantage of this system is the application relies on manual scanning. There are chances that the employee does not scan items to know its details. Some employees are experienced and do not need to scan the items to identify the parts associated with it. Some orders have repeated items and employees, does not scan every item.

6.2 Material requirement project

One of the critical stakeholders in supply chain management includes the purchasing department. The ultimate goal of the purchasing department is to maintain up-to-date inventory and stock level. The window and door manufacturing company were unable to continue updated inventory information for several reasons such as lack of access to real-time data, more manual paper works involved in material handling process, and the inability of the current ERP system for efficient material handling. Hence, the company faced problems in projecting the raw material requirements for the orders that are scheduled.

The orders are batched and scheduled two weeks ahead of production time. With the order information and their corresponding Bill of Materials (BOM), it is possible to identify the quantity of raw material required. Every order is composed of several items (either different or same), and each item consists of different profiles or parts. All these information was available in the ERP database and required data-mining techniques to be applied to find the right information. A data mining query was generated; see Appendix-B Query-2 and a small an exe tool was developed using Visual Studio 2015, for the use of the purchasing department. A screenshot of the material requirement tools is shown in the Figure 6-4.

As shown in the Figure 6-4, the user can select a date range, for which the user wishes to see the material requirements. The data mining query identifies the complete list of profiles and their corresponding length that is required for the selected dates.

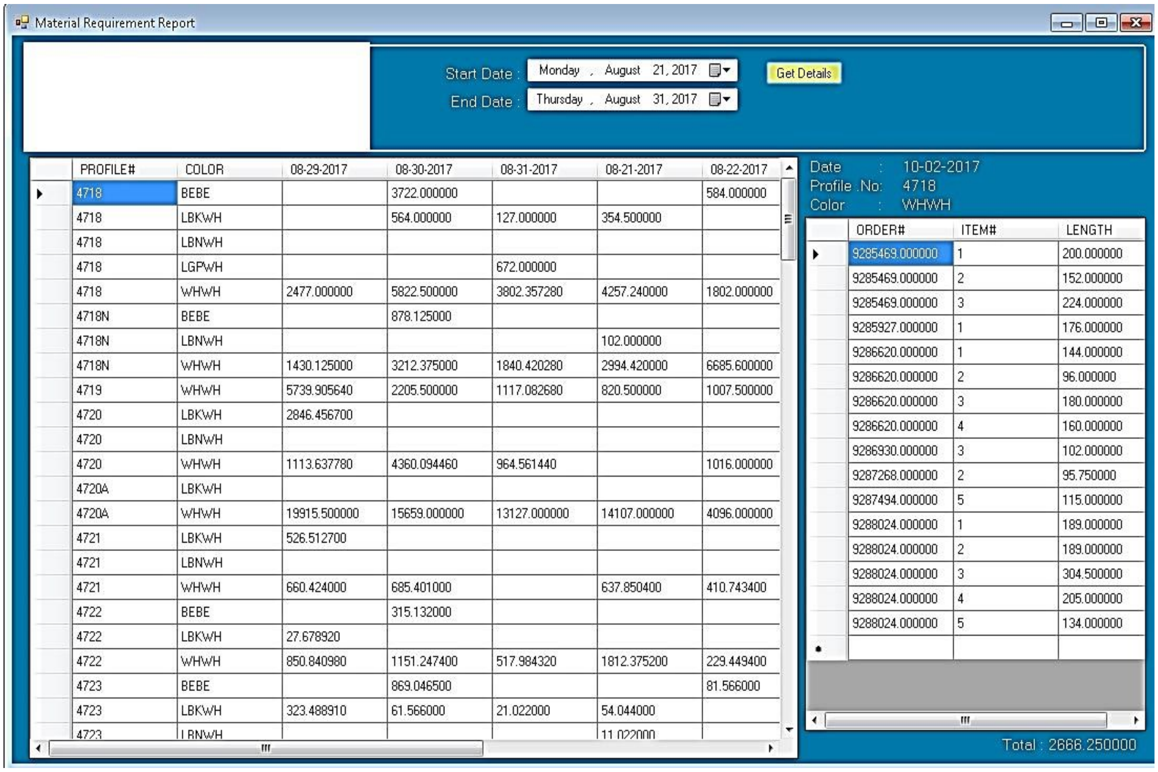


Figure 6-4 Material requirement tool - screenshot

Presently, the material requirements tool is used by the purchasing department on a daily basis and finds it very useful for forecasting the raw materials required.

Chapter 7 Conclusions and Future Work

7.1 Conclusions

As I conclude, the conceptual framework also proposes two mathematical models that indicate the change in performance. This is also a good foundation for empirical research. The variables can be investigated in a controlled environment where they are tested for the applicability. The results prove that IoT has the applicable significance to solve the real world problems. This experiment in the supply chain has identified that the real-world issues such as, reduced rework, lowering downtime, increasing efficiency, and lowering throughput time can be handled with the adoption of IoT technologies that are discussed earlier.

One of the most potential areas that have benefited from the innovation of the internet of things is the SCM through new technologies such as sensor devices, data storage, intelligent analytics and decision making tools. These tools have the potential to create a resource efficient supply system, enabling the users to share information across the supply chain. Hence this research project has developed a research framework that links the four aspects of the supply chain, i.e., manufacturers, suppliers, logistics, and clients, and provided a real-time solution to track the movement of the product along the supply chain. This framework demonstrates how IoT could enhance SCM, which helps the members of the supply chain to improve their overall performance through enhanced information sharing, efficient resources utilization and reduced loss of merchandise along the supply chain. Lack of information sharing is a significant challenge which has hindered the growth and innovation of supply chain systems. Also, it has led to the inefficient utilization of the scarce resources as companies set up individual monitoring systems for products along the supply chain substantially reducing the efficiency in the Supply chain. In addition, it has hindered innovation due to lack of standardized methods which allow developers to come up with innovative applications and solutions to improve SCM practices. These are some of the challenges which the proposed framework aims to address.

7.2 Challenges expected and proposed solutions in the implementation

Given the considerable amount of data that is associated with the technology and IoT devices, the creation of the relevant technology to facilitate data streams for IoT was a significant challenge in implementation. Data collected from the IoT devices contained irrelevant data that are not required for further processing. Firstly, data received from the sensor devices are stored in the SQL database, and filtering techniques were to obtain the necessary. Data filtering is achieved with the help of SQL Data Query Language (DQL) such as table queries and joins. The company's existing ERP database was implemented in the German language, for defining all the table semantics and structures. This was one of the significant challenges faced during the implementation. All the table semantics and structures were translated into English using Google translate, and the SQL queries were created using the translation as a reference. Figure A-1 shows a translated version of the order table. It was a tedious process to refer to the interpretation every time I need to work on the query.

Initially, it was tough to understand the internal supply chain process that hindered the development of the framework. Hence, Value Stream Mapping (VSM) of different procedures was obtained from the Continuous Improvement team, and database table structures were implemented accordingly. Figure A-2 depicts the value stream mapping for a PVC slider production process. The other challenge is to understand how the system works for the different members of the supply chain. People have to follow the flow and function of the framework. Lastly, information security and privacy may also be a significant issue. People do not feel secure when they provide information about their products to be accessed by other users. Different scholars studied many security-related types of research for implementing IoT and can be applied to prevent an infringement in the shared data.

Other challenges that may face the proposed SCM framework are willingness and the collaboration of the different supply chain on how the modern IoT technology can be used to promote information sharing, efficient sharing of resources and real-time information to improve decision making. Also, this proposed framework also depends on the availability of the modern data processing technologies to function optimally. This implies that a significant amount of resources may be required to set up the framework to achieve its total efficiency.

However, all the challenges can be quickly resolved through the choice of appropriate technology and create a system which has different privileges for different users. Awareness to create an efficient supply chain management consisting of proper utilization of resources promotes information and resource sharing among the various members of the supply chain system.

7.3 Recommendations and plans for future research and enhancements

This study is a trailblazer to the focus of future research in gathering information on the IoT. Firsts it shows the usefulness of the IoT, especially in the industrial setting. The illustration that the IoT enables the integration of various operations in a factory setting or the distribution channels shows that the technology has positive ramifications. This will inspire the dedication of research to investigate the continued utility of this technology in the future. Also, this conceptual framework identifies the various methods used to collect data by the IoT.

Future researchers can use this framework as the foundation of their analysis of the impact of the IoT. This can be achieved by leveraging on essential points developed in this framework like benefits of the IoT, data collection methods, and efficacy of supply chain. Research on the best approach to deploying them or the most optimum way to gather the same data from the same parameters can significantly aid the integration of the IoT in our daily lives. This is paved for by this conceptual framework that uses a less specialized approach where various methods are collectively discussed. Also, future research can extend the focus to see how the analytical tools can be streamlined to avoid the barrage of data that can be collected from the environment some of which is irrelevant to the users. Therefore, this conceptual framework lays the groundwork for a better look at the great success that can be achieved with IoT.

Currently, I had access only to the internal supply chain data, and thus the framework was tested in implementing internal supply chain alone. In future, I wish to gather data from the external supplier chain to implement and test the framework for its efficiency. Presently the truck route optimizer is capable of giving only the optimized routes. In future, I have plans to gather delivery truck's location data with the help of GPS tracking devices and linking the data to the truck route optimizer for monitoring the live location status of the delivery trucks. Also, there is a plan to integrate the material requirement tool discussed earlier in section 6.2, into the ERP software, enabling organization-wide access.

At this time, research is being carried to find, how RFIDs can be implemented for automatic detection of product flow along the shop floor. In the future, a tool was planned to develop that would display all the queue of orders, that looks similar to order status screens in the restaurant kitchens Figure 7-1. This would eliminate the need for employees to scan the products manually. Also, a process for embedding, back orders, quality rejected items and checklist for quality into the production live status screen is under construction.

Figure 7-1 Future - Order status screen [117]

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Appendix-A

Table field	Table field description	References	Reference Description	Foreign key	Foreign key description	Seq. #	Data Type	Code
ALTERNATIVE	Alternative item (J/N)					39	VARCHAR	
ARTIKELKLASSE	E: units, M: material or article class code	ART.ARTKLCODE, ARTKL.ARTKLCODE	ART: Accessory part ARTKLCODE: Code (product class) ------------------ ARTKL: Accessory - product classes ARTKLCODE: Code (product class)			67	VARCHAR	×
ARTIKELTYPANZEIGE	Displayed article type (e.g. M for mulled unit)					114	VARCHAR	×
ARTNR	Product code	ARTIKEL.ARTNR, MWMAT.MATNUMMER, ART.ARTNR	ARTIKEL: Units ARTNR: Product code ------------------ MWMAT: Material MATNUMMER: Material # ------------------ ART: Accessory part ARTNR: Product code	EXPORT.ARTNR, RECHPOS.ARTNR	EXPORT: Transfer option table ARTNR: Product code ------------------ RECHPOS: Invoice items ARTNR: Product code	6	VARCHAR	×
ARTNREXTERN	Depending on the item type stock product # (for stock products) or external materials #					69	VARCHAR	×
ARTTYP	E: units, M: material, Z: accessory					7	VARCHAR	×
ASL	Obsolete					102	NUMBER [	×
AUFNR	Order #	AUFKOPF.AUFNR	AUFKOPF: Order headers AUFNR: Order #	AH_AUFWK.AUFNR, AH_FIBU.AUFTRAGSNUMMER, AUF_HIST.AUFNR, AUFART.AUFNR, AUFARTIK.AUFNR ...	AH_AUFWK: Customer table for special cost interface AUFNR: Order # ------------------ AH_FIBU: Customer table for special financial accounting interface AUFTRAGSNUMMER: Order # ------------------ AUF_HIST: Order history AUFNR: Order # ------------------ AUFART: Fields to an order item (unit) AUFNR: Order # ------------------ AUFARTIK: Accessory to an order/an order item AUFNR: Order # ...	1	NUMBER [	

Figure A-1 Sample translation of database semantics from German to English

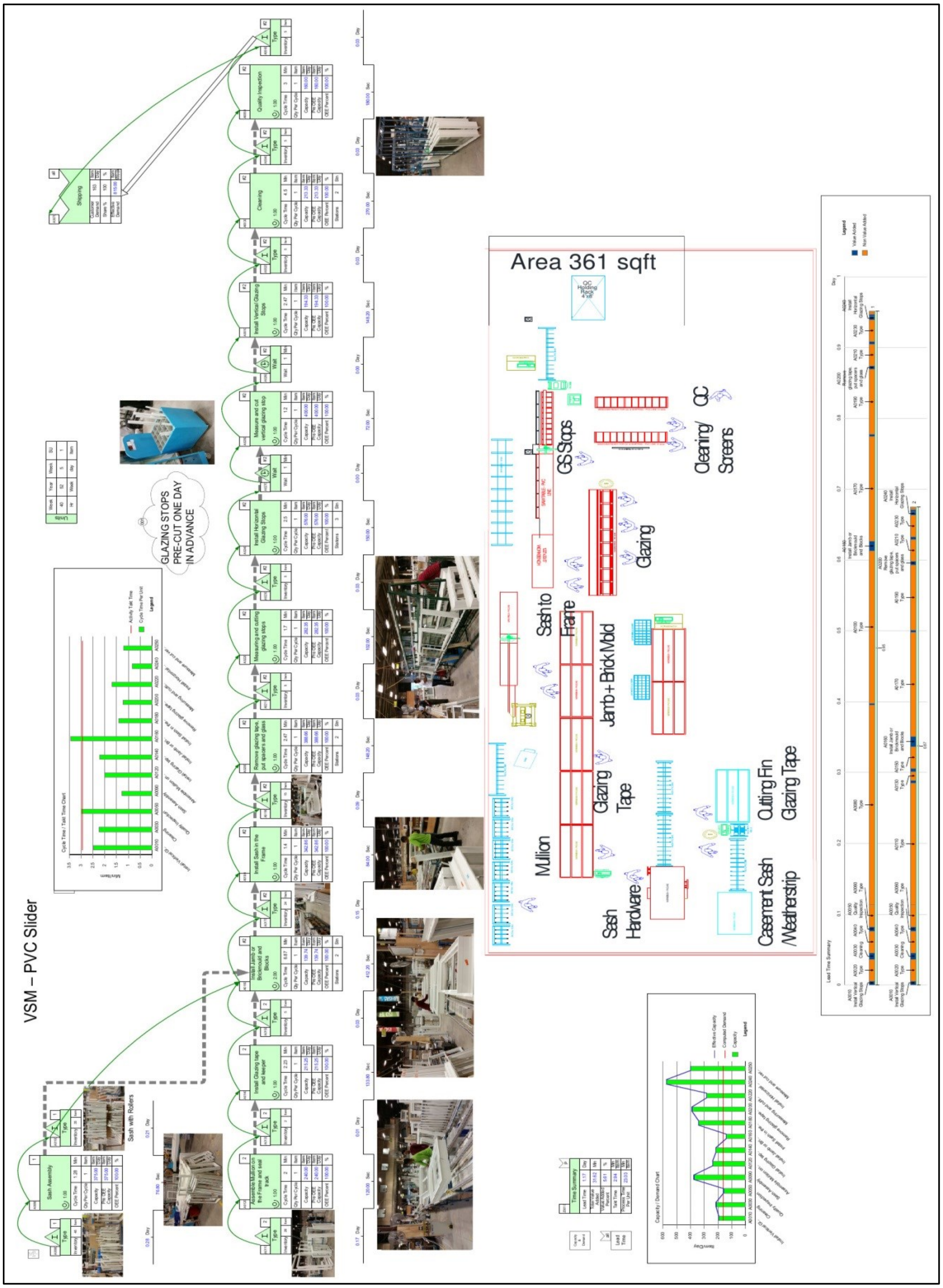

Figure A-2 Value stream mapping for PVC slider production process

Appendix- B

Query 1 - SQL stored procedure for obtaining the production live status screen.

```
/***********************************************************************
****
SP Name       :       SP_GET_DAILY_PROD_STATUS_BY_ITEMS
Purpose       :       Gets the live production status details
Used By       :       Production Live Status screen
Input   :
        @JOBNBR - List of job numbers (',' separated)
---------------------------Modification History---------------------------
Date            Modified By             Purpose
15-JUN-2017  Partha                     Initial Creation
---------------------------Modification History---------------------------
************************************************************************
***/
CREATE PROC [dbo].[SP_GET_DAILY_PROD_STATUS_BY_ITEMS]
        @JOBNBR NVARCHAR(MAX) = NULL,
        @SERIESTYPE VARCHAR(4) = NULL
AS
IF NOT (@JOBNBR IS NULL OR @JOBNBR='')
        DECLARE @strSeries VARCHAR(50);
        DECLARE @strQuery NVARCHAR(MAX);

        SET @strSeries=
        CASE @SERIESTYPE
                WHEN 'SLDR' THEN '325,450,306'
                WHEN 'CSMT' THEN '800,801,750,700,1200'
                ELSE '325,450,306,800,801,750,700,1200'
        END;

        SET @strQuery ='
SELECT
        CAST(dbo.AUFPOS.AUFNR AS INT)                   AS OrderNo,
        CAST(dbo.AUFPOS.SUBPOSNR AS FLOAT)      AS ItemNo,
        CAST(dbo.AUFPOS.MENGE AS INT)                   AS Quantity,
        dbo.AUFPOS.PRODUKTTYP                           AS Series,
        CAST(dbo.GRP.JOBNR AS INT)                      AS JobNo,
        dbo.AUFPOS.ARTNR                                AS ItemType,
        dbo.AUFPOS.FELDANZAHL                           AS SU,
        dbo.AUFPOS.PROFILFARBE                          AS Colour,
        dbo.AUFKOPF.INTERNEAUFNR                        AS RouteCode,
        dbo.AUFKOPF.ORT                         AS City,
```

```
	CASE WHEN CHARINDEX("810:J", dbo.AUFARTIK.ESFELD) > 0 THEN "Y" ELSE "N" END AS Brickmould,
	CASE WHEN CHARINDEX("840:J", dbo.AUFARTIK.ESFELD) > 0 THEN "Y" ELSE "N" END  AS SlopeSill,
	CASE WHEN CHARINDEX("1425=", dbo.AUFARTIK.ESFELD) > 0 THEN "Y" ELSE "N" END AS Jamb,
	SCAN_TBL.[ELEMENTBARCODE]				AS BARCODE,
dbo.fn_GETPRODDATE("A", SCAN_TBL.[PRODSTATUSINFO]) AS [PRODUCTION STARTED],
dbo.fn_GETPRODDATE("W", SCAN_TBL.[PRODSTATUSINFO]) AS [WELDING COMPLETE],
dbo.fn_GETPRODDATE("H", SCAN_TBL.[PRODSTATUSINFO]) AS [HARDWARE INSTALLED],
dbo.fn_GETPRODDATE("C", SCAN_TBL.[PRODSTATUSINFO]) AS [CLADDING INSTALLED],
dbo.fn_GETPRODDATE("S", SCAN_TBL.[PRODSTATUSINFO]) AS [SCREEN DONE],
dbo.fn_GETPRODDATE("U", SCAN_TBL.[PRODSTATUSINFO]) AS [SEALED UNIT DONE],
dbo.fn_GETPRODDATE("M", SCAN_TBL.[PRODSTATUSINFO]) AS [ASSEMBLED/ UNITS MULLED],
dbo.fn_GETPRODDATE("G", SCAN_TBL.[PRODSTATUSINFO]) AS [GLAZED],
dbo.fn_GETPRODDATE("Q", SCAN_TBL.[PRODSTATUSINFO]) AS [QC COMPLETE],
dbo.fn_GETPRODDATE("E", SCAN_TBL.[PRODSTATUSINFO]) AS [PRODUCTION COMPLETE],
dbo.fn_GETPRODDATE("L", SCAN_TBL.[PRODSTATUSINFO]) AS [SHIPPING COMPLETE]
FROM
	dbo.AUFPOS WITH (NOLOCK)
	INNER JOIN
	[CANTORPROD].[dbo].[CPB_PPOS] AS SCAN_TBL WITH (NOLOCK)
		ON  dbo.AUFPOS.AUFNR = SCAN_TBL.AUFNR
		AND  dbo.AUFPOS.SUBPOSNR = SCAN_TBL.SUBPOSNR
	INNER JOIN
	dbo.AUFKOPF WITH (NOLOCK)
		ON dbo.AUFPOS.AUFNR = dbo.AUFKOPF.AUFNR
	INNER JOIN
	dbo.GRP  WITH (NOLOCK)
		ON dbo.AUFPOS.GRPNR = dbo.GRP.GRPNR
		AND dbo.AUFPOS.AUFNR = dbo.GRP.AUFNR
	INNER JOIN
	dbo.AUFARTIK
		ON dbo.AUFARTIK.AUFNR = dbo.AUFPOS.AUFNR
		AND dbo.AUFARTIK.REFPOSNR = dbo.AUFPOS.REFPOSNR
GROUP BY
```

```
	OrderNo,ItemNo,Quantity,Series,JobNo,ItemType,SU,Colour,City,Brickmould,
Slopesill,Jamb
ORDER BY
	OrderNo, ItemNo ASC;'
```

Query 2 -Data mining query for material requirement

```
/*********************************************************************
****
SP Name		:	SP_GET_MATERIAL_REQUIREMENT
Purpose		:	Get the Get material requirements
Used By		:	Continuous Improvement - Standalone - Material Requirements
Report
Inpput	:
	@dteStartDate - Start Date
	@dteEndDate - End Date
---------------------------Modification History---------------------------
Date		Modified By		Purpose
10-Jul-2017	Partha			Initial Creation
---------------------------Modification History---------------------------
*********************************************************************
***/
SELECT * FROM(
		SELECT
			GRP.PRODDATUM			AS PROD_DATE,
			PROFTAB.PROFILNR		AS PROFILE#,
			PROFTAB.FARBE			AS COLOR,
			TA_PROF.WERT			AS [TOTAL_LENGTH]
		FROM
			GRP		WITH(NOLOCK)
			INNER JOIN
			AUFPOS		WITH(NOLOCK)
				ON	GRP.AUFNR	= AUFPOS.AUFNR
				AND	GRP.GRPNR	= AUFPOS.GRPNR
			INNER JOIN
			PROFTAB WITH(NOLOCK)
				ON	AUFPOS.AUFNR		= PROFTAB.AUFNR
				AND	AUFPOS.REFPOSNR	= PROFTAB.REFPOSNR
			INNER JOIN
			TA_PROF WITH(NOLOCK)
				ON	PROFTAB.REFPOSNR= TA_PROF.REFPOSNR
				AND	PROFTAB.IND		= TA_PROF.IND
				AND	PROFTAB.AUFNR		= TA_PROF.AUFNR
		WHERE
			GRP.PRODDATUM IN ('+@Dates1+')
			AND			GRP.LINIE			IN
("DS","HO","PC","PC8","PCM","PCM8","SH","SHM","SL","SLM","SSH","SU")
			AND GRP.JOBNR <> 0
```

```
                AND TA_PROF.VARNAME    ="ZL"
        ) AS PIVOTTABLE
        PIVOT(SUM([TOTAL_LENGTH])  for  PROD_DATE  IN  ('+@Dates+'))  AS
SUMLENGTH
    ORDER BY
        PROFILE#,COLOR'
```