Framework of IoT-based Shop Floor Material Management System for a Panelized Home Builder

By

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Abstract

Modular construction has been promoted and recognized globally as an advanced construction technology. Not only has this construction method been utilized in oil and gas industries etc., but it has also successfully been introduced into the residential building construction industry. In North America, as an even more tailored modular technology, panelized construction method has become popular particularly for wood-frame wall panels. However, although utilizing this advanced construction method can greatly improve the working environment and productivity, the conventional mentality in construction, which historically overlooks the value of an automated management system to support off-site prefabrication and on-site installation, hinders its application potential. An Internet of Things (IoT)-based shop floor material management system can capture all dynamic data in real-time and effectively synthesize it along the supply chain associated with various types of resources. Eventually, with the assistance of a feature-based modelling method, IoT-based information collection can be merged into an Enterprise Resource Planning (ERP) system. Although highly dynamic market demands result in continual changes in the production plan, schedule, and inventory levels, adopting an IoT-based shop floor material control system can be very useful to address the dynamic changes characteristic of this advanced construction method in order to maximize production. Therefore, in this thesis, a framework for an IoT-based floor shop material management system is proposed

in order to enhance the production and control along the supply chain in terms of inventory and production operations for a panelized construction facility. Real-time data acquisition technology is applied and the development of supportive software is described. Key parts of the proposed IoT-based shop floor material control system is implemented as a case study in a panelized construction manufacturing facility, ACQBUILT, Inc., based in Edmonton, Alberta, Canada.

Preface

This thesis is the original work by Meng Wang who completes the thesis work under the supervision of Dr. Mohamed Al-Hussein and Dr. Yongsheng Ma. The research related topics, proposed methodology and paper writing were finished by Meng Wang with guidance from both Dr. Al-Hussein and Dr. Ma. One journal paper and one conference paper related to this thesis have been submitted for publishing and they are listed as below.

List of proceedings:

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Chapter 1. Introduction

1.1 Research Motivation

Modular construction as an engineering approval has been utilized in many different type of construction in recent years, such as for oil and gas plants, pipeline construction, and residential construction. It is a term to describe the use of factory-produced pre-engineered building units that are delivered to the construction site and assembled as large volumetric components or substantial elements of a unit. Compared to traditional stick-built home construction, modular home construction has emerged as a sustainable and innovative construction method among homebuilders, improving the quality of the product because of better construction environment, increase in productivity, and reduction in waste and construction time. As a special application of modular construction approach, panelized home construction has been widely used as a modular home construction method which breaks down the entire work process into several elements including floor, wall, and roof. These elements are manufactured in a fabrication plant and shipped to the construction site for final installation. Garza-Reyes compared pre-manufactured home construction with conventional stick-built construction and identified several advantages i.e. controlled working environment, better inventory management, and ease of implementation of new technology into the process [1]. One of the most important factors is that monetary costs can be greatly reduced so that the construction company can truly benefit from it. Although the potential benefits of panelized construction have garnered increasing attention in recent years, the complexity of the material types and product variability are significant factors that affect the production process. In addition, time management can be negatively affected by these factors, such that the enormous potential of panelized construction cannot be realized.

In the present research, in order to help panelized manufacturers to gain maximum benefit, an Internet of Things (IoT)-based shop floor material management system is studied, with part of the system developed and implemented at a case company. Through the use of an IoT-based real-time data collection technology and a technical ERP system, production data for a panelized facility production line can be obtained in real-time through the processes of inventory control, production line, and on-site assembly. Further, how the continuously collected real-time data can be analyzed and utilized, as an input in optimizing the concurrent planning and controlling stage is studied. Finally, the IoT-based shop floor material management system prototype is introduced with software developed to support the partner's panelized construction facility.

1.2 Research Objectives

This research is built toward the following objective:

The proposed framework of an integrated management system with IoT-based real-time technologies will potentially control and manage the inventory and production operation for a panelized home builder in order to better satisfy the Just-in-Time (JIT) principle.

In order to verify this objective, this research encompasses the following activities:

i. Design a real-time data acquisition system (barcode technology) for a panelized fabrication inventory facility.

ii. Plan and develop an integrated shop floor material management system framework for a panelized home builder.

iii. Prototype the above technology (barcode technology) and analyze the costs and benefits of the future full implementation.

This research focuses on a real-time data collection and management system in panelized construction manufacture. The goal of the research presented in this thesis is to use an information technology management system for a panelized home-builder to enhance the production and control along the supply and production chain, including off-site facility inventory and production operation, and on-site installation production. Such an advanced information management system not only can systematically improve the internal production operation, but can also potentially improve the communication with its suppliers along the supply chain in a real-time manner. Potentially, with the aid of the IoT-based shop floor material management system, the panelized home builder can benefit and become increasingly competitive in today's housing market.

1.3 Thesis Organization

The thesis comprises six chapters.

Chapter 1 (Introduction) introduces the background of the current panelized home fabrication, research objectives, and overview of the thesis structure.

Chapter 2 (Literature Review) reviews current literature about modular and panelized home building industry as it pertains to real-time technology. This chapter includes modular/panelized construction, integration of CAx, ERP and Just-in-Time approach.

Chapter 3 (Commercial Solution of ERP and Review of IoT) reviews the commercial solution of ERP systems, industrial 4.0 and IoT associated with its applications.

Chapter 4 (Proposed Methodology) presents the conceptual framework of the approach for the proposed IoT-based shop floor material management system.

Chapter 5 (Implementation and Results) presents the implementation results of the proposed methodology at a panelized fabrication plant, focusing on a cost-benefit analysis.

Chapter 6 (Conclusion and future development) summarizes the research contributions, industry application, limitations, and future development for panelized construction manufacturers.

Chapter 2. Literature Review

The literature review in this chapter mainly focuses on the following research topics: (1) Concept of modular/panelized construction; (2) Integration of computer-aided (CAx); (3) Enterprise resource planning (ERP); (4) Just-in-Time approach; and (5) Literature summary

2.1 Modular/Panelized Home Construction

Modular construction methodology initially was defined as "*the process of manufacturing and pre-assembly of certain amounts of building components, modules and elements, prior to their shipment and installation on construction sites*" [2]. The definition of modular construction later was expanded more specifically in terms of planning, design, fabrication and assembly of building elements at a manufacturing environment other than final construction site location [3]. The earliest study of modular construction was evidenced in 1624, houses that were built in England and were shipped to US. 166 years after, timber-framed shelters were pre-fabricated and transported to Australia from UK due to the absence of local man-power [4]. Modularization has also been applied into oil and gas industry. Since the 1970s, engineering, procurement and construction (EPC) companies started applying modular construction methodology into designing simple preassemblies and transporting the module to an oil and gas plant [5]. The advantages of modular construction method compared with conventional stick-built construction are greatly documented from time to time [6]. Benefits include project costs reduction, project cycle time reduction, productivity improvement [7]. Moreover, modular construction can also bring soft benefits in terms of positive impacts on health and safety, better controlled and improved working environment, and reduction in the need for working environment space [8].

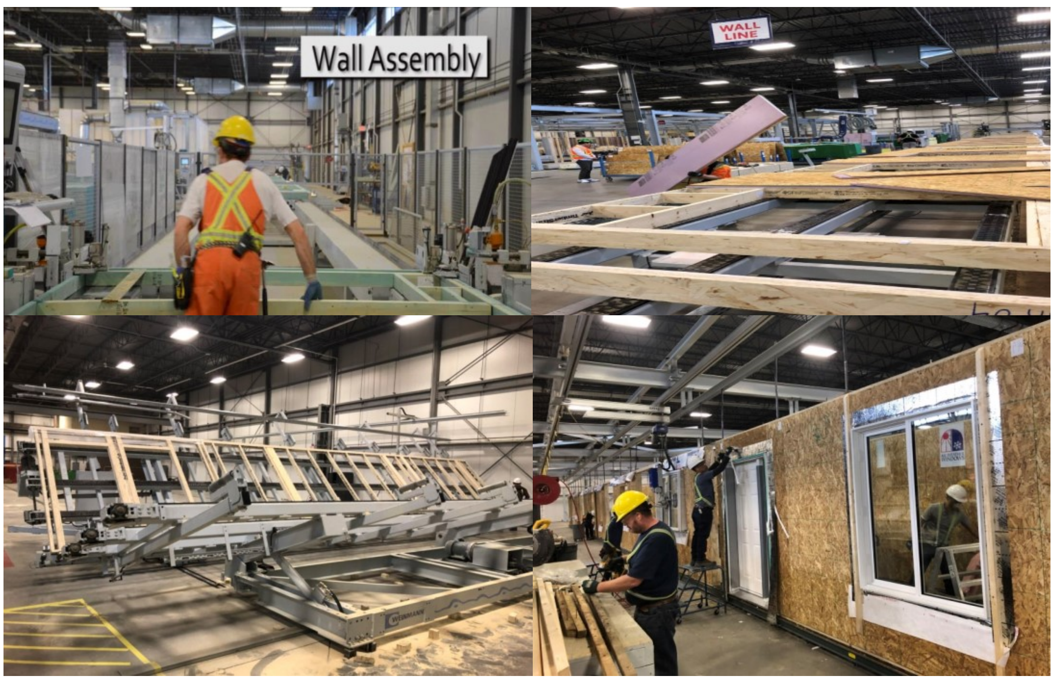

Figure 2-1. Panelized Construction (Courtesy of ACQBUILT, Inc.)

Panelized home construction, was defined as a form of modular construction with origins in manufacturing industry, is fast evolving as an effective alternative to traditional stick-built home construction [9]. The housing components are mainly in panels such as panels for walls, floors and roofs and prefabricated in an off-site manufacturing plant, shipped to a home construction site, and placed on a prepared foundation for final installation. Cranes are normally used to lift all panels into place in a specified order according to assembly requirement. Figure 2-1 shows a typical production line in a panelized home construction facility. Many benefits have been identified and evidenced over the past years. They include the equipment used, the nature of the transportation logistics, and insulation technology. In particular, panelized construction minimizes transportation requirements because panels are much lighter. Moreover, the machinery and equipment required on site are less for panelized construction [10]. Not only has the panelized construction method been applied in North America for wood-panels framework, it has also applied into precast concrete wall panels [11]. A specific case study was carried out on direct cost for 100 m2 of precast concrete walls and traditional Cast-in-Place walls. Their results show that prefabricated housing systems are highly recommended for large-scale housing in China. In addition, panelized home construction process can be automated with the assistance of building information modelling (BIM) and project schedule can be automatically generated in an Autodesk Revit environment based on the material and quantity takeoff that are extracted automatically [12].

Although panelized home construction is very welcomed particularly in design stage because prefabricated panels are unique and vary in product design features (e.g., length, different type of windows and doors, and associated joints, connections) [13], such an advanced construction approach is still facing numbers of challenges. They include that production capacity could be limited by product mass customization, material flow cannot be easily managed on the shop floor without being tracked properly, and inventory control cannot satisfy JIT principle with lack of real-time information.

Radio frequency identification (RFID) technology was utilized to automate a wall production line in a panelized home prefabrication facility, but the data collected from RFID system is considered as a mess and how to extract relevant data from raw data becomes crucial [14]. Another challenge from implementing RFID is privacy and security issue that companies will have to face due to the automatic data flowing [15]. RFID can potentially save costs for data collection compared to traditional manually tracking daily data and input into system, but the cost of purchasing hardware package and developing the software of barcode technology is more competitive in the market [16]. Thus, in this thesis, an IoT-based floor shop material management framework is proposed to enhance the production and supply chain. Barcode real-time data acquisition technology is applied to control the shop floor material flow and inventory.

2.2 Integration of Computer-Aided (CAx) /Feature-based Approach

From 1980s to early 2000, traditionally CAx researches still focused on geometric conversion and simplification [17]. CAD/CAE integration remains high demanding research topic in various industries, and even now the integration is still not fully achieved. In early 1990s, feature-based approach has been brought to researchers' attention and a lot of studies have been conducted [18]. In this approach, it is to develop a feature-based model to incorporate the information from both CAD and CAE, thus information from both views can be extracted and maintained consistent [19]. Moreover, in order to narrow the product domain and achieve a greater degree of specificity between stages, the concepts of unified and associative features have been established, each with its unique definition and functionality. Ma introduces a modelling associative engineering relations method in a unified feature modelling scheme and an algorithm for maintaining information consistency control among multiple applications through product lifecycle stages based on unified feature modelling [20]. Ma et al. present a new type of feature, called an associative assembly design feature, in the module design of assembly, (the application being a mould base library for injection mould design) [21]. Not only has this feature-based modelling been utilized in manufacturing, Li also introduce two CAD/CAE associative feature concepts that form a robust mechanism to ensure automatic CAD/CAE interactions with both semantic and geometric information [17]. They propose a CAE boundary feature to better assist with modelling and ensure effective and efficient collaboration in the design stage and capture sensitivity information for analysis so that evaluation and modification can be automatically performed for cyclic fluid control effect modelling. Li shows that feature-based modelling can also support simulation in terms of flow control product optimization, and they define two feature concepts include the fluid physics feature and the dynamic physics feature [22].

In addition, the feature concept has been applied to supply chain management and the ERP design stage. Wei propose a design framework of feature-based order acceptance and scheduling module in an ERP system [23]. A feature-based order acceptance system has the potential to associate product configuration features with manufacturing features in order to link the manufacturing production process for better control and more efficient operations. The conceptual framework proposed in the present research can enhance the ability of the ERP system to accommodate the variability of customer orders by applying the feature-based unification method. With the development of feature definition and utilization of the feature concept across various industries, in the present research feature-based modelling with its associated definitions and concepts is extended to panelized home construction industry, and associative inventory feature was defined for the purpose of designing an IoT-based shop floor material management system. This proposed mechanism will be introduced in chapter 4.

2.3 Enterprise Resource Planning (ERP)

2.3.1 Development of Material Resource Planning (MRP)

Material Resource Planning (MRP) is a technology, predating ERP, that mainly focuses on the material and inventory management associated with production. It has been deployed to greatly improve manufacturing inventory management. Jacobs & Weston summarize the history of MRP, describing it as a solution to manage and control industrial resources which was used widely prior to the introduction of the ERP system [24]. Hung assert that MRP technology can help to improve suppliers' scheduling accuracy, can quickly update the inventory quantity associated with production process planning so that the lead time can be shortened by the material planning accordingly [25]. MRP mainly comprises inventory management, bill of materials (BOM), as well as some scheduling functionalities. Li proposes the integration of MRP II and JIT using the basic resource of the BOM as a logistics management information system for optimizing the logistics management of the given enterprise [26]. Dynamic calculations can be automatically performed within the MRP system based on current inventory level and forecasted orders, unlike in traditional inventory management which can only perform simple orders in a linear sequence. Therefore, such a technology can be valuable in a construction manufacturing environment with dynamic inventory driven by customer demand. However, according to Jacobs & Weston, the limitation of the MRP system is that it is restricted to the material department and operations department and does not incorporate accounting and finance into the information sharing process [24].

2.3.2 Development of Enterprise Resource Planning (ERP)

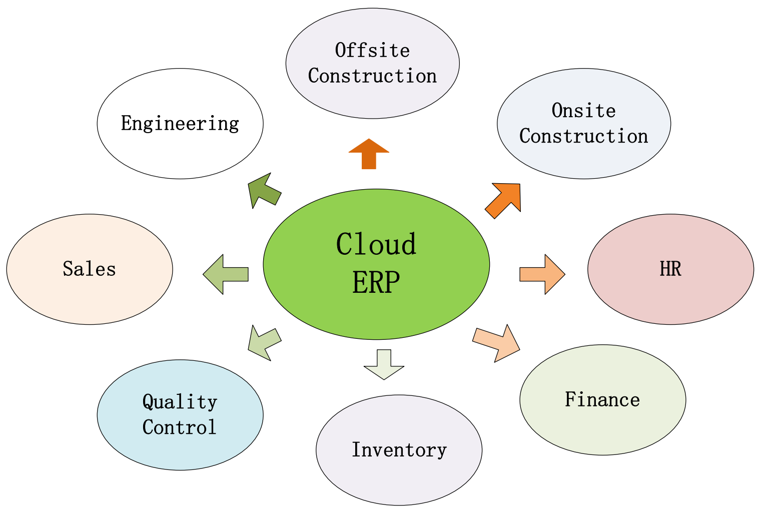

Figure 2-2. General Layout of an ERP System

Figure 2-2 was drawn and shows that an ERP system represents each component of the business and helps management and all departments to keep track of all historical and live data. In such a system, all data, report formats, and information are consistent and easy to utilize and can be shared across departments. General elements in an ERP system (shown above in Figure 2-2) include sales management, engineering, human resource management, accounting, shipping and delivery, production management, quality management, inventory management, purchasing management, production planning, and so on [27]. ERP systems were first developed to extend the functionality of MRP to the entire enterprise rather than only the material department and operations department [24]. ERP controls and manages the manufacturer's entire daily activities in real-time and helps to ensure that technical personnel comply with the established manufacturing processes and procedures in order to enhance production planning and accuracy. With the introduction of ERP, though, not only have the interactions between departments within an enterprise been improved, but also interactions between companies can be streamlined. Internal relationships are improved and consolidated based on the use of ERP in terms of inventory, accounting, finance, and operations and management. Yen discusses some of the basic characteristics of ERP systems [28]. For one, ERP offers standardized data definitions shared across all departments within a given enterprise in order to better manage and control data entry, whereas each department would have had its unique data definitions prior to the introduction of ERP. In ERP, common access to a single set of data enhances data accuracy and consistency from all departments, thereby establishing a normalized standard for better management [29]. ERP also offers system flexibility such that it can be simply modified and easily adapted to the needs of the enterprise. Open system architecture means that each department in the system is able to interface or be isolated any time when required without affecting the functionality of other departments or corrupting previous data input.

Previous research shows that number of cases have been studied on integration of ERP with other software packages, such as product data management [30], supply chain management [31] etc. Meanwhile, from academic perspective, product identification is the key component from the beginning of the supply chain to the end of the final product assembly, which should be tracked properly and managed consistently [32]. Most current ERP systems are developed for company internal use due to its unique complexity. Therefore, there is always a gap between manufacture and suppliers due to lack of information updating and information consistency. Thus, in this thesis, the IoT-enabled shop floor material management framework with the feature-based modelling approach can potentially address the existing issues. Associative inventory feature is the key relation along the supply chain.

2.4 Just-in-Time (JIT)

2.4.1 Lean Manufacturing

Lean principles have been discussed and utilized in many different industries over the years. Initially it was introduced and developed by Taiichi Ohno from Toyota [35], and the intent of these principles was to eliminate process waste in manufacturing. The term "Lean" was introduced by the research team working on international auto production in order to compare the waste reduction from the Toyota Production System to the original form of a mass and craft production system [33]. To put it another way, instead of the initial production focus of increasing craft productivity and mass production by means of machine, attention was shifted to the entire production system. The new production philosophy of "Lean" was discussed by Koskela, and two significant techniques of this new philosophy have been introduced in the literature: Just in Time (JIT) and Total Quality Control (TQC) [34]. Building on these two concepts, many other concepts have been elaborated on to better benefit and serve industry. These concepts include total productive maintenance (TPM), employee involvement, continuous improvement, benchmarking, time-based competition, concurrent engineering, value-based management, visual management, and re-engineering. Koskela also emphasizes that the core concept of this new philosophy is to reduce or eliminate the non-value-adding activities and increase the efficiency of value-added activities. For example, in the process of inventory transfer and management, transferring the needed material on time would be considered a value-adding activity because it directly affects the efficiency of the production line. However, waiting time and paper time would be considered non-value-adding activities, such that reducing or eliminating these elements can help to achieve the core value of this new philosophy. In addition, the core idea of the new production philosophy is illustrated in the following, according to Koskela [34]:

(1) Reduce the share of non-value-adding activities.

(2) Increase output value through systematic consideration of customer requirements.

(3) Reduce variability.

(4) Reduce the cycle time.

(5) Simplify by minimizing the number of steps, parts and linkages.

(6) Increase output flexibility.

(7) Increase process transparency.

(8) Focus control on the complete process.

(9) Build continuous improvement into the process.

(10) Balance flow improvement with conversion improvement.

(11) Benchmark.

Howell (1999) summarizes that designing a production system that helps to eliminate process wastes while at the same time maintaining just-in-time inventory as well as the fundamental basis of Lean principles in the following aspects:

(1) To deliver the product to customer and meet customers' expectation; to eliminate those portions of production that do not add value.

(2) To organize and operate the production in a continuous flow manner.

(3) To stop the production line, pulling inventory and distribution information in order to perfect the product and make the production flow in a reliable sense.

(4) To pursue perfection in meeting customer expectations while keeping no inventory and just in time material management approach.

The above-discussed principles introduced by Koskela constitute the fundamentals of Lean production, and in recent years they have been increasingly adopted by other industries. Although Lean was initially developed for the manufacturing environment, it has in recent years been adopted in the construction environment, hence the term "Lean construction". According to Howell (1999), a number of essential conditions have been introduced for lean construction:

(1) Having a clear set of objectives for the delivery process.

(2) Lean construction is aimed at maximizing performance for the customer at the project level.

(3) Designing product and process concurrently.

(4) Lean applies production control throughout the project lifecycle

Yu even further augment the lean methodology by implementing it in the home building industry in a study intended to focus on initiating a stable production flow rather than using traditional means of eliminating process wastes [36]. In their study, value stream mapping (VSM), a powerful lean technique, is used to analyze the production system and production process. However, applying conventional lean VSM to the home building construction poses some issues, so their study proposes a practical approach based upon which total lead time is reduced to 50 percent of the current-state process [42]. Moreover, although several such studies have focused on lean and its application to residential construction, JIT principle still can't be fully achieved. With the absence of real-time information and unique identification of each product, it is very difficult to track and manage the production and material flow. Thus, this present study develops IoT-based real-time technology to control material in order to realize the JIT goal for panelized home construction.

2.4.2 Inventory Management

Inventory management is an essential element of panelized home construction with a considerable associated cost. One may question why a panel manufacturer would hold a large inventory, since it is difficult and expensive to control and manage. There are many reasons why inventory might be kept, including unexpected change requests from customers, lead times, and economies of scale as it pertains to transportation aspects. Inventory management may comprise a number of elements, including controlling, overseeing ordering history, storage of inventory, and controlling of the product for sale. Controlling the amount of inventory can be very difficult, though, given that low inventory may result in a failure to meet customer demand, while high inventory can be costly to maintain. Another risk is that if stock is kept at full capacity then this may trigger a situation in which clearance sales are necessary. The task of defining the optimal level of inventory to meet customer demand with the lowest inventory holding costs has thus drawn the attention of researchers in recent years. Material management is a critical element in inventory management, and it is very important in achieving continuous work flow on site. Tsao discusses material management and identified two critical parameters for the planning stage for on-site construction as the space occupied by a material and the time when this space is needed [37]. As they define storage and staging, storage entails that materials cannot be delivered just-in-time and may be moved multiple times before the final installation. Staging from both offsite and traditional construction means that the materials will only be handled once for final installation and ideally the materials are delivered JIT. The project team should try to avoid the storage step as much as possible because work space can be limited by an abundance of materials, which can be difficult to manage and control. However, if storage is unavoidable, then the need to store the materials at the optimal location should be accounted for in the inventory management system. Current practice is such that panelized construction could help to improve the production quality and processing time.

Unlike in the traditional construction method, though, in panelized construction components are manufactured offsite and then shipped to the construction site for final assembly. In this way the panelization process can introduce irregularities in the procurement so that unexpected delays may sometimes occur, and the product may not be delivered on time. Maintaining a large inventory with sufficient materials in stock could help to eliminate these potential issues, but it is not an economical solution. Bu Hamdan thus proposes a framework to manage and control inventory in panelized construction based on simulation integrated with BIM [38]. The objective of the framework is to strengthen the inventory performance in panelized construction by reducing the inventory size. In an offsite panel fabrication facility, inventory can be described as high-product-variety with low-demand-volume because customers can design their own custom home based on their preferences combined with the designer's skills. As such, a small change in inventory level for one product could dramatically affect the other products for which the same types of resources are used. Srinivasan seek to define the optimal Work-In-Process (WIP) inventory level to meet the demand of each product [39]. The objective of the system is not only to minimize the total WIP inventory across all products, but also to minimize the total inventory value (including indirect) and to minimize production lifecycle times. They set out to find the lower and upper bounds of the optimal number of each product, and then to determine the batch size and value of the WIP inventory for each product so as to define the optimal inventory level for the whole system. Other studies have been published on the topic of inventory management, but this thesis is unique in that it presents an IoT-based shop floor material management system to collect live data so that managers can update and control the inventory in real-time and thereby realize the objective of JIT inventory principle.

In terms of inventory management, two types of management methods have been discussed in the scholarship in recent years. The traditional forecast-driven planning has been widely utilized across industries, and today is still a popular technique in project management and supply chain management for larger retailers and manufacturers. Forecast-driven planning is based on historical production data combined with management experience and predictions to predetermine the amount of product that needs to be produced in order to meet expected customer demand as well as to maximize business profits. The advantage of the forecast-driven method is that upper management can have a general idea of the current production and predicted orders and their financial impact. However, forecast-driven planning lacks accuracy in the presence of frequent changes in demand, and so associative scheduling and sequencing will be unfavorably affected. Zhang & Chen carried out an empirical analysis of the Chinese automotive industry, concluding that forecast-driven production may regularly lead to delivery delays and poor quality because of inaccuracy of forecasts of demand and dynamic changes in production scheduling and sequencing [40]. Forecast-driven planning, it should be noted, can be based on either sales forecasts or demand forecasts. However, in the offsite home construction industry in particular, the comparably high variety and low volume in panelized construction (due to the varying design requirements from customer to customer) become potential driving factors. Customizations based on customer preference, such as 9′ ceiling, larger windows, thicker windows, and additional bonus rooms, serve to alter the design requirements. In fact, engineering design modifications or even re-design of the entire product will have to be performed. Indeed, in the context of rapid housing development and high market demand, it is widely recognized that traditional forecast-driven inventory is not the best option in the prefabricated home industry, hence the gradual shift to a customer-driven model [41].

The customer-driven method is much more accurate in inventory management, but it is also more complex, subject to dynamic demand changes. In order to ensure the raw material arrives in time, the lead time of each product from each vendor needs to be accurately established so that the resulting production schedule can be simulated based on capacity availability and assembly timeline, among other factors. Due to technological advancements, human living conditions have been greatly improved, and customers have been gradually becoming more creative in designing their own housing such that the traditional forecast-driven and uniform housing styles may no longer be a suitable option to satisfy customer demand. In this way, it is beneficial for prefabricated housing companies to design their products according to customer requirements. Different customers may have different design requirements; even returning customers could require different customization of a given product. In order for a prefabricated construction company to be competitive in the market, not only is the post-sale customer service important, but meeting customer demand requirements at the design stage could remarkably help the business. When the traditional forecast-driven inventory and production methods are replaced by a customer-driven method, it can serve as an effective and efficient method of arranging and processing customized orders. Thus, an integrated IoT-based shop floor material management system can update the inventory level in real-time and aid on inventory forecasting based on dynamic demand.

2.5 Literature Summary

In this thesis, the history of modular construction and concept of panelized construction have been carefully reviewed. Computer-aided design and computer-aided engineering have been introduced into various industries including modular construction industry. ERP systems become one of the advanced management tools for almost each enterprise. Just in time principle can be a key driven factor to affect the productivity and efficiency of production and supply chain. All the reviewed knowledge exists in the case company and are playing important roles from management perspective. IoT-based shop floor material management system can enhance the production and supply chain process in real-time manner so that to chase the JIT principle. Feature – based modelling approach can link the system to existing ERP in a very quick and friendly manner.

Chapter 3. Technological Review of ERP and IoT

This chapter briefly reviews the technology underlying enterprise resource planning (ERP) system's current solutions, concept of Industry 4.0 and IoT technological approach.

3.1 Commercial Solutions of ERP

ERP systems were first developed to extend the functionality of MRP to the entire enterprise rather than only the material department and operations department [43]. ERP controls and manages the manufacturer's entire daily activities in real-time and helps to ensure that technical personnel comply with the established manufacturing processes and procedures in order to enhance production planning and accuracy. With the introduction of ERP, though, not only have the interactions between departments within an enterprise been improved, but also interactions between companies can be streamlined. Internal relationships are improved and consolidated based on the use of ERP in terms of inventory, accounting, finance, and operations and management.

According to Jacobs & Weston [24], ERP was introduced by the Gartner Group in the early-1990s. The significant contribution of the ERP system they introduced was that it included more interfaces between different departments within a given enterprise, particularly between operational activities and the corresponding accounting transactions. Following the introduction of ERP, a number of specialized ERP vendors such as Microsoft Dynamics, Infor, SAP, SQL, Epicor, and Eclipse have been leading the market [44]. With more recent developments of ERP, Vendors can also design special versions of ERP systems based on the customer requirements associated with special demand features. Considerable effort has been invested toward developing additional functions in terms of purchase management, accounting management, warehouse and fabrication shop, quality control, production and operation, and human resources. ERP can keep track of finance functions such as general ledger, account receivables, account payables, fixed assets and cost control, as well as logistics department functions such as production planning, new ordering, warehouse and shipping management, project management, and customer service management. Unique designs with special features such as supply chain management, order and shipping forecast, and sales department have been integrated into ERP in recent years.

Most of ERP vendors have reasonable compatibility with several of operating systems, for instance Linux, Mac and Windows. In particular, Epicor and Microsoft use the .NET framework that are really compatible with most of products from Microsoft, for example Word, Excel, and Outlook etc. Furthermore, all mentioned ERP systems are compatible with Microsoft SQL server management studio database from database management perspective. SAP is compatible with various data management server include DB2 and Oracle. Epicor, is also compatible with another database called progress databases.

One of the notable disadvantages of ERP is the high cost (both initial cost and the cost of implementation and maintenance), which prevents small and medium size businesses from purchasing ERP systems. Furthermore, technical personnel need to be hired for maintaining the system, and implementation is a time-consuming process. Initial implementation of ERP may complicate the existing process and thereby negatively affect the productivity of the company. Some companies may require customization of the ERP system to match their unique operations. However, customization of an ERP system can be even more costly and time-consuming [28]. Therefore, having a better plan and preparation for implementing the system, such as providing proper training before actual implementation, could potentially smooth the process. Failure of the system implementation in a given company could result from the lack of proper training and unrealistic expectations, lack of IT support, lack of management support, and lack of historical data from previous projects.

3.2 Industry 4.0 – Future of Industry

Industry 4.0 has become a popular and attractive topic over the past few years. The term "Industry 4.0" initially started from German and become publicly known in 2011, the initiative of industry 4.0 is to represent an association between business, politics and academia so that to enhance German manufacturing industry [45].

Meanwhile, some similar ideas have been brought to our attentions globally in terms of smart factory [46], smart production, networking manufacturing [47] and internet of things (IoT) [48]. In order to accomplish the highly promoted approach of industry 4.0, new information exchange and communication technologies, such as industrial cloud [49], big data [50], and wireless cloud networks [51], industrial IoT have been presented and introduced to meet expectations.

The main objective of Industry 4.0 is to integrate the traditional manufacturing, is to consolidate the efficiency, adaptability and flexibility by increasing effective communications between manufacturing, supplier and costumers [52]. Thus, networks, IoT and cyber physical systems enabled communications are the key factors in industry 4.0. As shown in Figure 3-1. Industry revolutions have been illustrated and industry 4.0 is just a common name that is promoting a trend and an approach towards a fully automated manufacturing system or smart factory. Eventually, all production decisions are optimized based on real-time information from a set of technologies or equipment.

Therefore, with industry 4.0 approach, the inventory management can be potentially controlled because cloud-based system can update and share information between suppliers and manufactures in real-time. Lowering the inventory holding costs, obtaining accurate lead time help and achieve JIT principle.

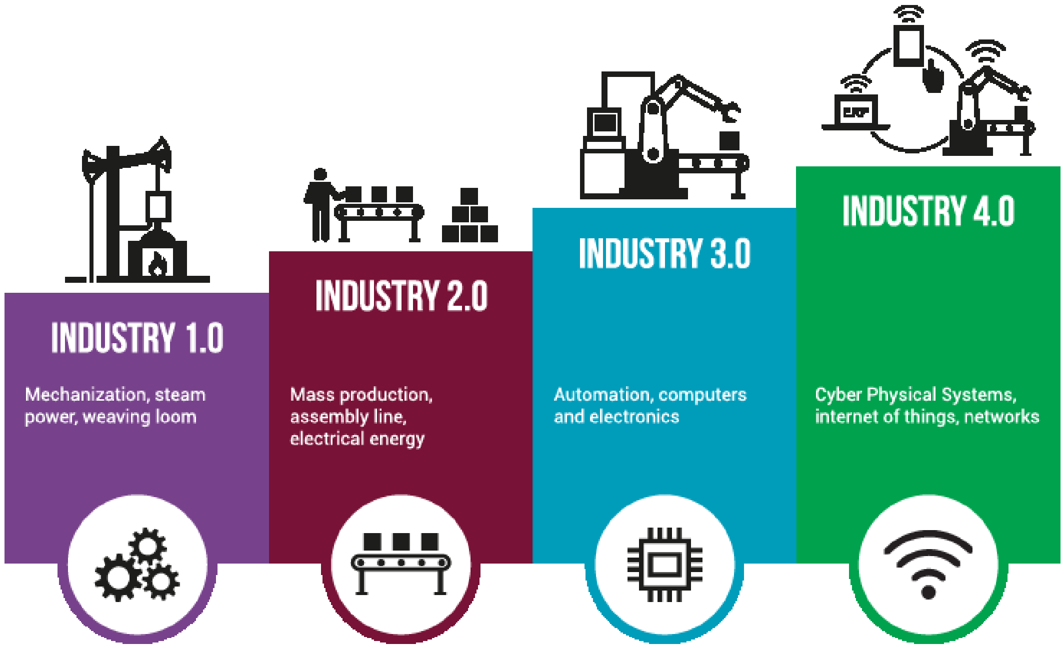

Figure 3-1. Industry Revolutions [65]

3.3 Review of IoT-Technological Approach

3.3.1 Internet of Things (IoT) and IoT Related Applications

Fleisch describes IoT as an extension of the internet to capture the physical world of things from an economic perspective [53]. The first word in the term focuses on network-oriented tools, whereas the second term emphasizes generic "objects" to be integrated into a system framework [54]. In IoT-based technology, a network of physical devices embedded with software, sensors, and actuators enables objects to connect and transmit real-time data [55]. Liu introduces the concept of an IoT-enabled intelligent assembly system for mechanical products and find that efficiency is greatly improved based on the developed system [56]. IoT also provides a solution for the management of additive manufacturing processes, where the existing technology in the manufacturing environment can communicate and extract data from machines through mobile device in real-time [64]. Qu proposes an IoT-enabled wireless manufacturing execution system that can be automatically controlled and managed [57]. RFID is used in their proposed system to automatically collect the location information associated with other required data. In contrast to traditional manufacturing, this system simplifies the human component in inspection and data recording and improves the accuracy of work-in-process inventory. The information collected is real-time-based and can provide effective feedback between production plan and in-flow. Altaf designed an automated data collection system for panelized construction, with RFID used as the IoT-based technology for implementation [14]. Pasquier introduces a case study of a truck enabled with IoT-based technology that can communicate with the operations manager when a delivery has been made, thus saving time and resources spent in tracking orders [58]. In addition to system monitoring of the production plan and tracking of objects, the proposed system from my research can potentially assist with risk analysis and prediction based on buffer times. Implementation of IoT-based real-time technology can further enhance computer-aided adaptive learning based on real life data collected from industry practice. Moreover, the computer-aided learning based on real life data collected by the proposed system from my research can improve the performance of the inventory operation. Thus, this research fills the gap and evaluates the potential benefits of IoT based real-time shop floor material management system in a panelized home construction facility and seeks to advance the development of smart construction management in Industrial 4.0 with big data environment in place of traditional manual practice.

3.3.2 IoT-based Technologies

Figure 3-2. IoT-based Technologies [66]

Real-time technology plays an important role in allowing the manufacturing environment to become fully automated. A real-time system can be a location system which is used to automatically identify and track the location of objects or personnel associated with other requirements or features (in terms of identification, quality and quantity, etc.) in a real-time manner. Figure 3-2 represents a framework of Internet of Things (IoT). The figure shows all different things in modern society can connect with internet so that forming the structure of smart world. Other real-time devices such as GPS, RFID, and locator devices. The smart device system can potentially benefit industry in many aspects, such as forecasting, remote monitoring, real-time visibility, alerts and notifications and scheduling adherence. Such a system is usually designed within a wireless-covered environment because WiFi can assist in immediately transmitting the data collected [59]. Common real-time systems in the market and industry include GPS, RFID, barcode, and mobile phone tracking [60]. Each system brings numerous potential benefits to different industries. Not only can live data be automatically collected, Zhong also describes how an RFID-enabled real-time system can be utilized for advanced production planning and scheduling to support decision making by management [62]. Zhong proposes integrating RFID with BIM technologies in order to mitigate risk and improving schedule performance for prefabricated house construction [61]. Islam & Shuva study and analyze barcode technology and its application in a case of selected libraries in Bangladesh [63]. A number of merits are identified based on the study, such as increasing the accuracy of service, saving money and time for library management, ensuring high speed and high quality of service, ensuring data integrity, and creating positive user attitudes. Song propose the use of a combination of barcode and GPS for material identification and location and describe the related software development [16]. Cost-benefit analysis shows that the initial cost of the software development and implementation are low, pointing to a strong potential to significantly improve material tracking efficiency.

3.4 Review Summary

In summary, the IoT-based leading technologies such as barcode, RFID, GPS, QR mobile etc. are all briefly summarized and reviewed. Current existing ERP vendors and ERP systems have been introduced associated with its pros and cons. Moreover, industry 4.0 is a trend of future manufacturing development. There have been extensively researches that are focusing on BIM, CAD, RFID and barcode technologies in multi-industries. In this case company of panelization, many of the advanced technologies have been implemented. Barcode technology can keep track of product ID associated with detailed product information, which further enhance the supply chain. The detailed software development is introduced in Appendix. The implementation of the technology is introduced in chapter 5.

Chapter 4. Methodology

4.1 Overview

Chapter 4 introduces IoT-based shop floor material management system that can effectively assist management staff to obtain real-time information in both internal and external along the supply chain. This IoT-based approach can potential improve the uncertainties of lead time and high inventory holding costs due to overstocked material. Figure 4-1 provides an overview of the proposed integrated IoT-based real-time shop floor material management system framework, including production line control and a newly developed inventory control system for a panelized home building facility as well as potential future on-site construction control. The chart shows the input parameters, central designed database, and data analysis models to support management with decision making.

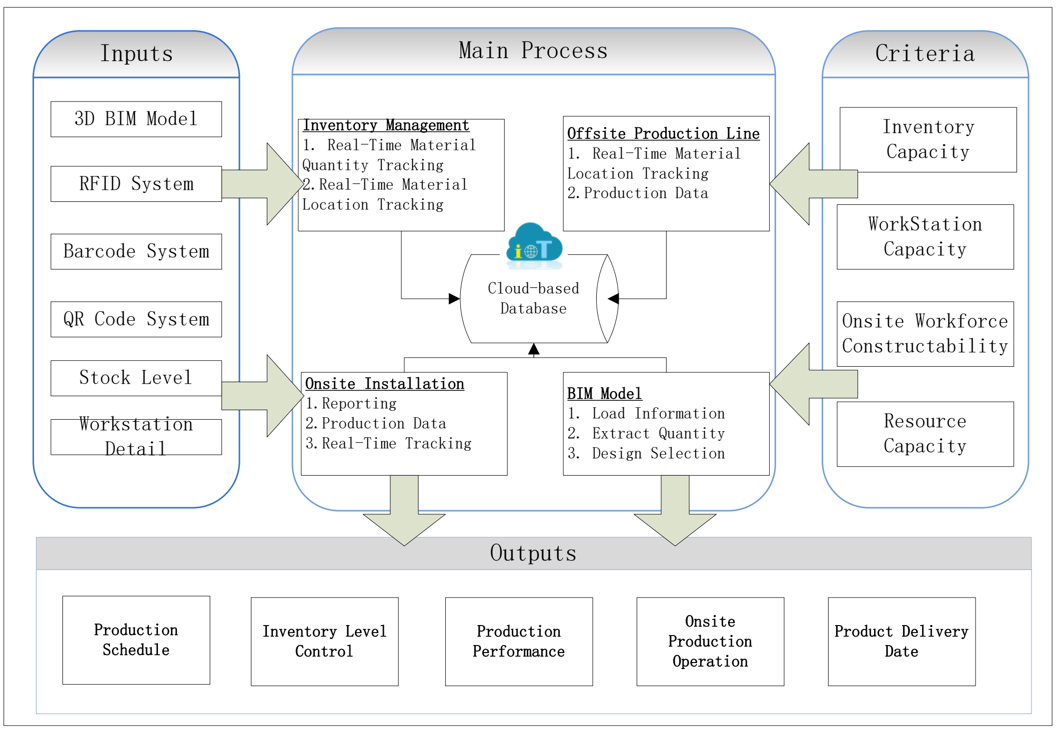

Figure 4-1. Overview of Proposed Integrated IoT-based System

4.2 Material and Information Flow in Supply Chain

The offsite construction technique is unique but has become increasingly productive in various construction sectors, including oil & gas and residential, in recent years. To better serve the needs of so-called High Variety High Volume

(HVHW) home construction, many enterprise management systems have been developed to improve productivity and profitability. Figure 4-2 illustrates traditional production process and supply chain system in a typical panelized home construction industry.

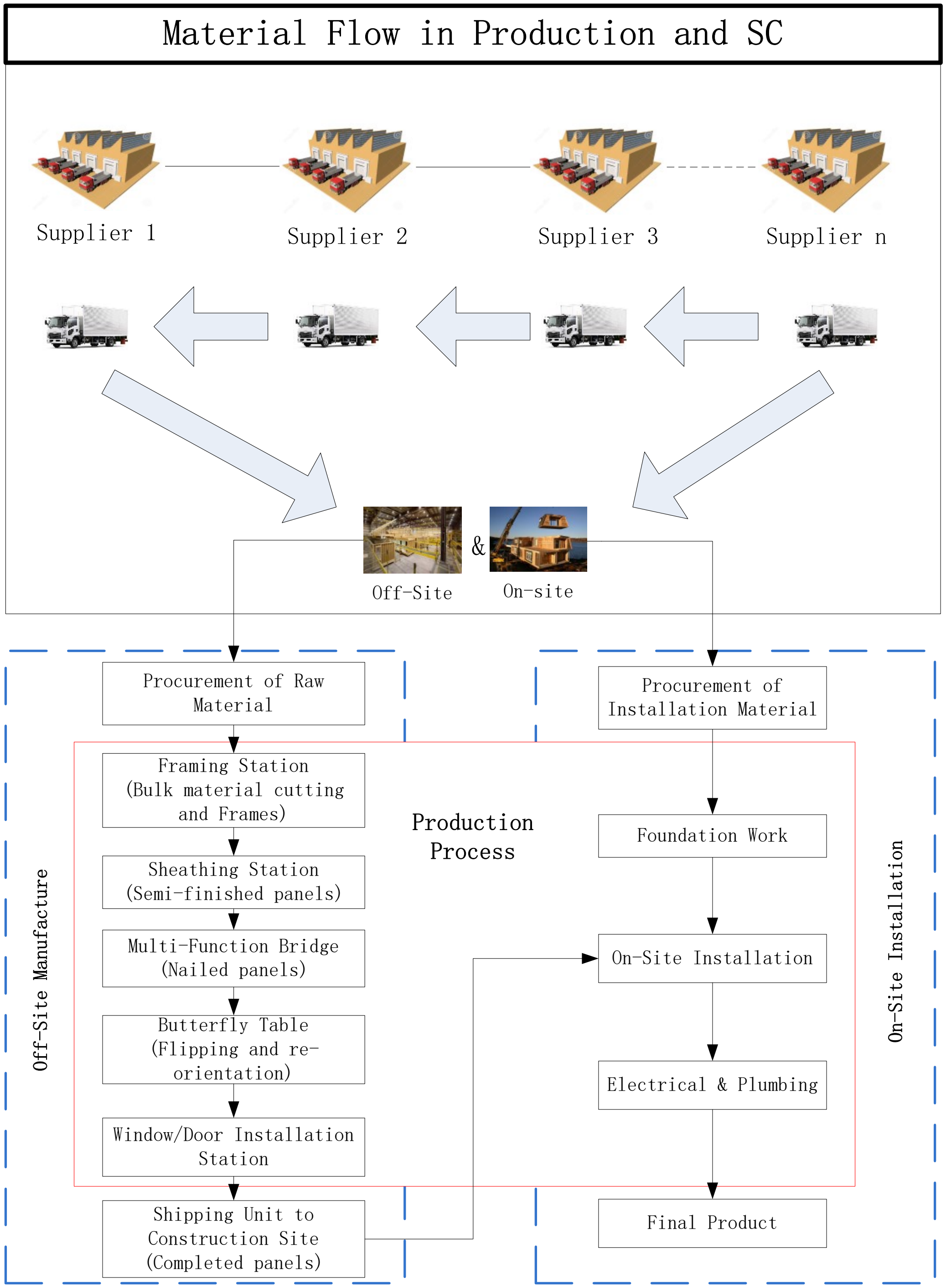

Figure 4-2. Production and SC Material Flows in a Panelized Home Builder

The upper section of Figure 4-2 is the external supply chain process in which material will be shipped to either an off-site prefabrication facility or a construction site for final assembly. The lower section shows the internal supply chain system and production processes for both off-site and on-site construction. Both material and information flow in a single direction, such as suppliers can only provide quotation for the material when manufactures ask. Moreover, all material purchasing is based on forecast-driven production planning. As discussed in the previous chapter, though, forecast-driven planning fails to satisfy the expectations of customers and stakeholders due to its uncertainties. Dynamic changes in the production process and customized orders are perhaps the primary constraints that inhibit its effectualness. Internal dynamics include unique designs for customized orders, insufficient materials, equipment breakdown, and workforce shortage. All of these identified issues can be potentially improved using real-time information sharing. Not only can real-time information technology improve productivity and efficiency, it can also potentially enhance the efficiency and effectiveness in very early convenient between panelized home business and suppliers. Thus, shop floor material management system, which is part of smart factory, can better support and enhance the mass-customization production.

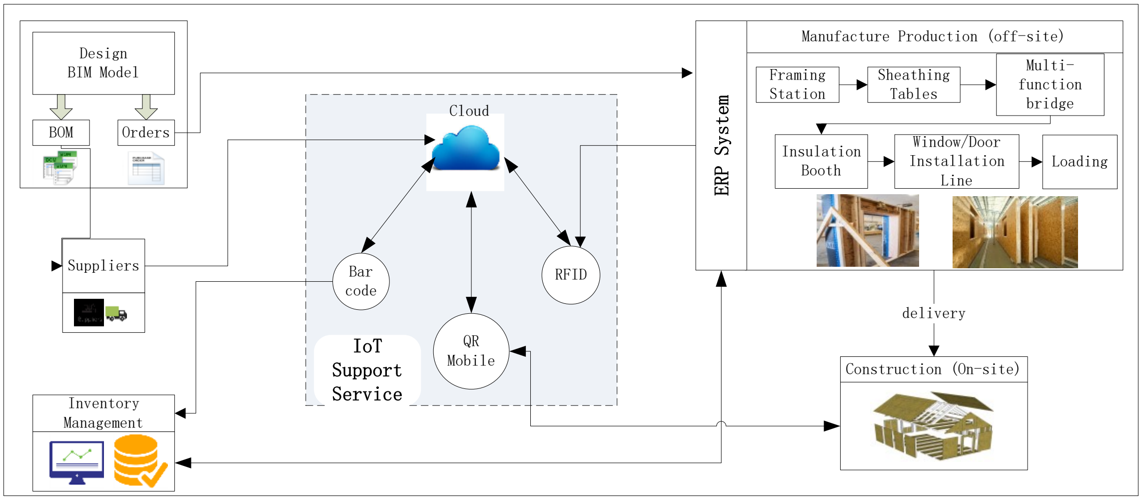

Figure 4-3. IoT-enabled Information Flow in the Material Management System

Figure 4-3 presents an overview IoT-enabled information flow in material management system. A BIM model is used at the design stage to aid the homebuyer in selecting and designing their custom home. BIM can be used to generate the preliminary construction schedule based on dynamic real-time information obtained from inventory, off-site production, on-site production, and suppliers. Bill of material (BOM) can also be extracted from BIM model so that the detailed relation between raw material and design product can be shared with supplies through cloud-based network. Additionally, suppliers can share their material availability on the cloud server. The BIM model can assist in preparing the construction schedule based on shared material information on the cloud, such as lead time and material availability in stock; barcode technology is used in the IoT-enabled management system to track the internal movement of materials, including stock, material receiving and transferring, as well as off-site production operations. Meanwhile, the BIM model will generate the bill of materials (BOM) and a purchase list for additional required materials based on existing material in stock. Thus, the project orders will become the input of preparation for the off-site manufacturing production schedule. The overall wall panel production process at the case company involves framing, sheathing, insulation, window/door installation, and loading, where RFID is the IoT-based technology that monitors the production operation inside the plant, collects data in real-time, and transmits it to a cloud-based database. RFID technology is utilized to automatically capture the panel location and processing time at each workstation in the prefabrication facility. Material locations on the production line and daily productivity can be identified through the proposed integrated system with real-time information obtained through IoT-based technologies. After processing all wall panels on the wall production line, the wall panels are moved to a loading cart and are then attached to an overhead crane to be transferred onto the trailer for transportation. Once the panelized products are transported to the site, QR mobile is the IoT-based technology used to aid in the control and management of on-site material movement and production productivity. All real-time information can be acquired for multiple objectives and synchronized to a cloud-based central database for the proposed integrated system. This system increases the level of automation of the construction process in both the off-site and on-site environments, such that traditionally manual operations such as recording, data entry, inspection, and counting can be eliminated, thereby improving the accuracy of the collected data based on real-time information and further improving productivity and work-in-process inventory in a real-time manner.

4.3 Real-time Data Management

4.3.1 Data Acquisition System

The real-time data acquisition system is designed for data collection for material tracking purposes, i.e., location tracking, allowing for the locations of different types of materials to be monitored and recorded in a database (as well as the quantity of materials in and out of the stock pile). Time stamps allow the inventory level to be monitored and recorded in real-time by tracking the materials transferred into and out of stock. However, identification number (ID) for product and product related raw material are the very important and significant in the real-time tracking process. Without unified ID, raw material and product have no direct relationship. Moreover, assigning unique ID to each type of material, all information include location, quantity etc. related to the material can be extracted by unique ID instead of other detailed inputs.

From management perspective, not only the ID is a unique identification key representing each type of material, the ID is also a relational key to link product and raw material. Such as producing one product A maybe need four material B. With all the relationship defined and pre-entered into the database, the calculations and unit conversation process can be eliminated by SQL query language. Moreover, product ID can also play the key role in identifying bill of material (BOM), schedule, production plan, and current stock status and so on. Without ID, the relation between management systems can be hardly linked. IoT-based technologies can collect ID and related data in real-time. However, barcode technology is more strengthened on collecting ID because it is easily under human's control. Thus, in this research, barcode technology has been selected for the case company.

4.3.2 Barcode Technology

Figure 4-4 provides the technology overview, including the barcode mobile scanner, existing wireless in the facility, and newly designed database in Microsoft SQL Server 2017.

Figure 4-4. Overview of Proposed Hardware and Other Technology

The barcode mobile computer device is selected rather than RFID because the case panelized facility stores most of its inventory stock in a yard outside the warehouse that does not have WiFi coverage. Barcode mobile computer devices can be either online or offline, unlike RFID which requires continuous WiFi support. In offline mode barcode technology can automatically store the collected data in the device itself until reaching a WiFi area, at which point all the stored data is transmitted to a central database. The programming code is illustrated in an example later in chapter 5. In addition, the initial cost of developing the software and purchasing barcode mobile devices can be lower than for other technologies such as RFID.

Specifications of Barcode Mobile Computer of Motorola MC55A0

- Data Wedge software types barcodes automatically
- Wireless capability: 802.11a/b/g and Bluetooth
- 1 GB internal storage, up to 32 GB storage on Micro SD
- Runs Windows CE 6.5 (CE OS 5.2)
- Software is developed using Visual Studio 2008

Figure 4-5 shows the required tools and existing programming language to build this proposed program to track the material movement. C# programming language is used in a Visual Studio 2008 environment, along with a .NET Compact Framework 3.5 to build the interface of the mobile device. Microsoft SQL Server

CE is used to build the internal local database in the device itself. Local databases are built in Microsoft SQL Server Management 2017 to receive and track all the real-time data collected. The details of implementation are introduced in chapter 5.

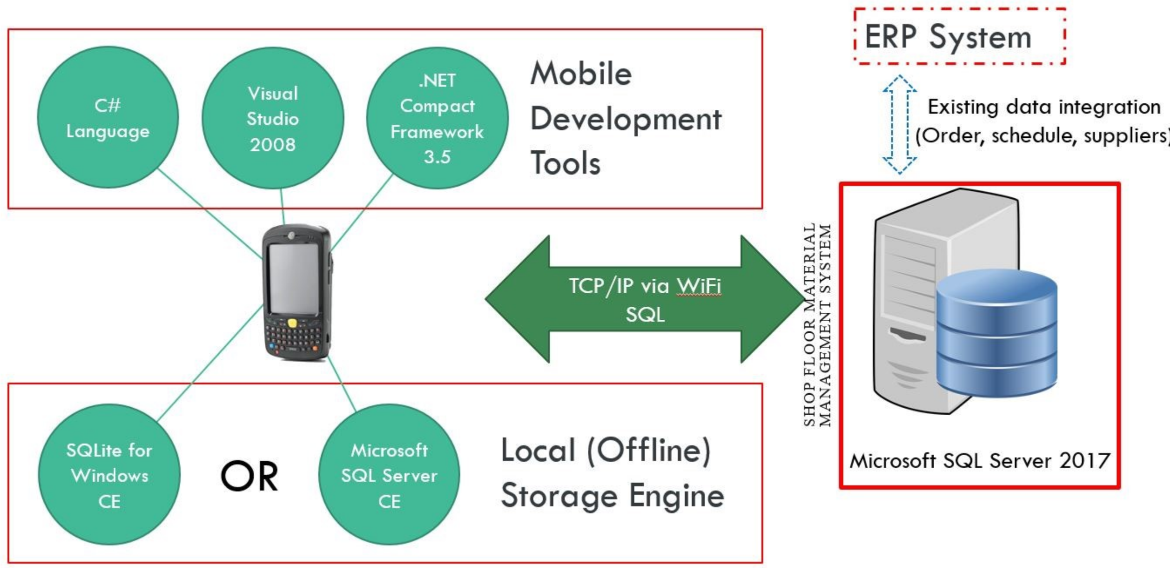

Figure 4-5. Overview of Program Development

4.4 IoT/ERP Integration

4.4.1 IoT-based Network

The following section provides an overview of the basic architecture and elements of an IoT-based production and supply chain network including both internal system and external system. Understanding the structural layers associated with the functions in Figure 4-6 is crucial in implementing the network and potential integrated system. The basic architecture of the IoT system and its functions is illustrated in Figure 4-6.

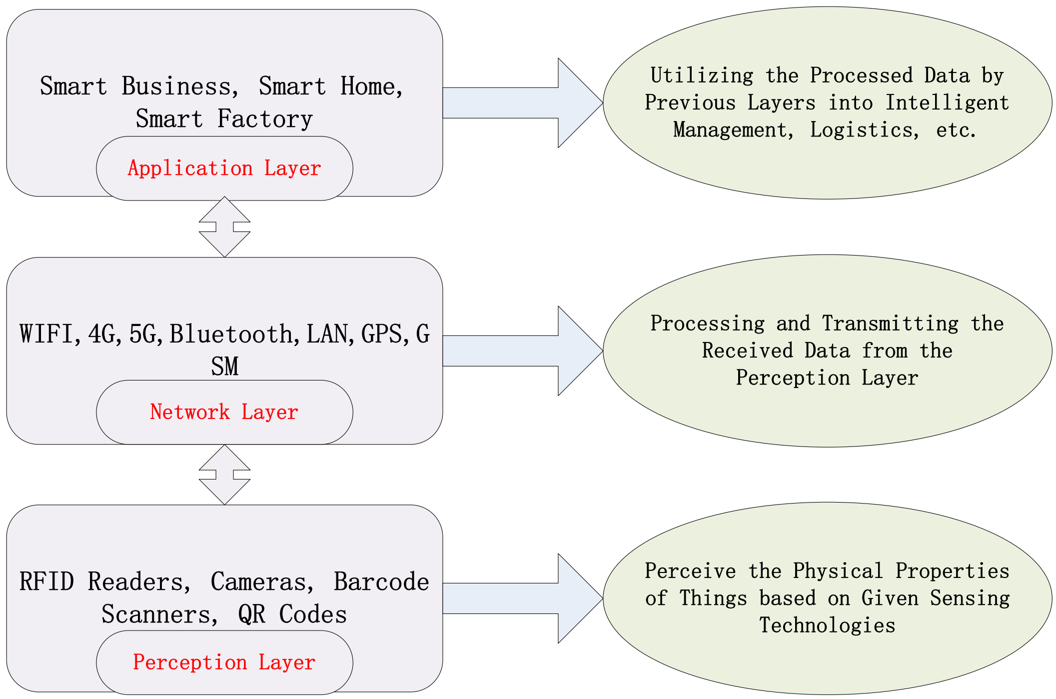

Figure 4-6. Three Basic Layers of IoT and Functions

As shown in the figure, the basic architecture of IoT comprises three layers—the application user layer, the network support layer, and the perception layer. The perception layer is also called the object or sensing layer, and the main function of the perception layer is to collect the physical properties of things based on listed sensing technologies. The network layer enables communication between the perception layer and the application layer. The network layer contains numbers of network supportive technologies including 4G, 5G, WiFi, wired, Bluetooth, GPS, LAN, and so on. The main function of the network layer is to process and transmit physical properties of things from perception layer to databases. The application layer is that the end user can interact with collected real-time data or utilize the collected data to perform data analysis within the IoT framework.

Based on the basic architecture of the IoT, the proposed cloud-based system can provide great assistance internally between the on-site and off-site construction operations; it can also connect the suppliers and the prefabrication facility via the cloud-based system in order to better control and manage both the on-site and off-site activities. IoT-based technologies such as RFID, QR code scan, and barcode scanner can track locations and collect real-time information internally. Moreover, the end user from the prefabrication facility can also obtain real-time information of the particular product in terms of quantity availability, lead time, and related costs through the cloud-based system and IoT-based technologies from suppliers.

4.4.2 Internal IoT-based Technologies

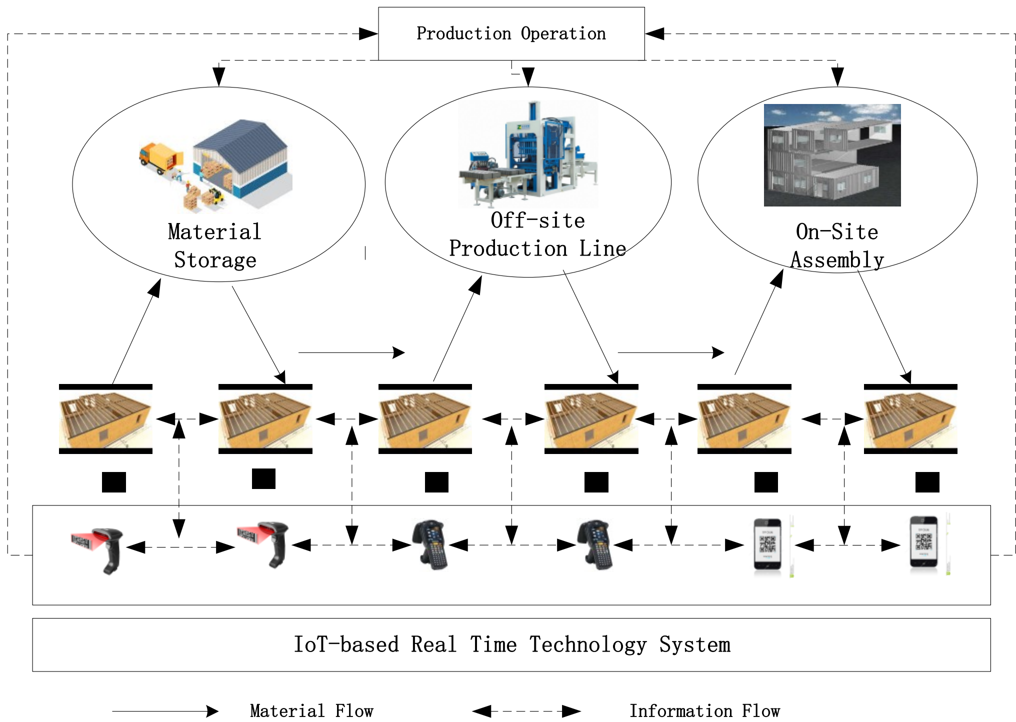

Figure 4-7. Internal IoT-based Technolgies

The following section presents an overview of internal IoT-based real-time technologies in a panelized construction company. Real-time technologies can advance a traditional prefabrication facility to an automated and intelligent production process. Without the introduction and implementation of real-time technologies, a traditional facility is hard-pressed to reach maximum productivity, and such operations entail a considerable amount of highly repetitive and time-consuming work, rendering them detrimental to productivity and profitability. Even if real-time information could be obtained through complex means, analysis, management, and utilization of the obtained data is tedious and error-prone. However, proper training can be very helpful in this regard and can improve the productivity and efficiently stabilize the production process. Figure 4-7 illustrates the proposed and implemented real-time technologies in the case company.

With implementation of the real-time technology, all dynamic information flow can be shared and transmitted in both directions, unlike in the traditional prefabrication environment where production details are generated at the production plan stage in the same direction as the material flow. Traditional prefabrication facilities struggle to satisfy dynamic demand from customers due to either shortages of material or cash flow problems resulting from overstock inventory. Moreover, buffer time and real-time effective feedback can be obtained through an IoT-based shop floor material management system between the production operation plan and information flow. In addition to production monitoring, analyses such as risk analysis and prediction can be performed using the real-time information collected automatically.

4.4.3 Semantic Model of Integrated System

Figure 4-8 shows relationships between IoT and ERP system. Associative inventory feature and associative manufacturing feature, an integration mechanism, are defined and developed as keys factor in the process of IoT and ERP integration.

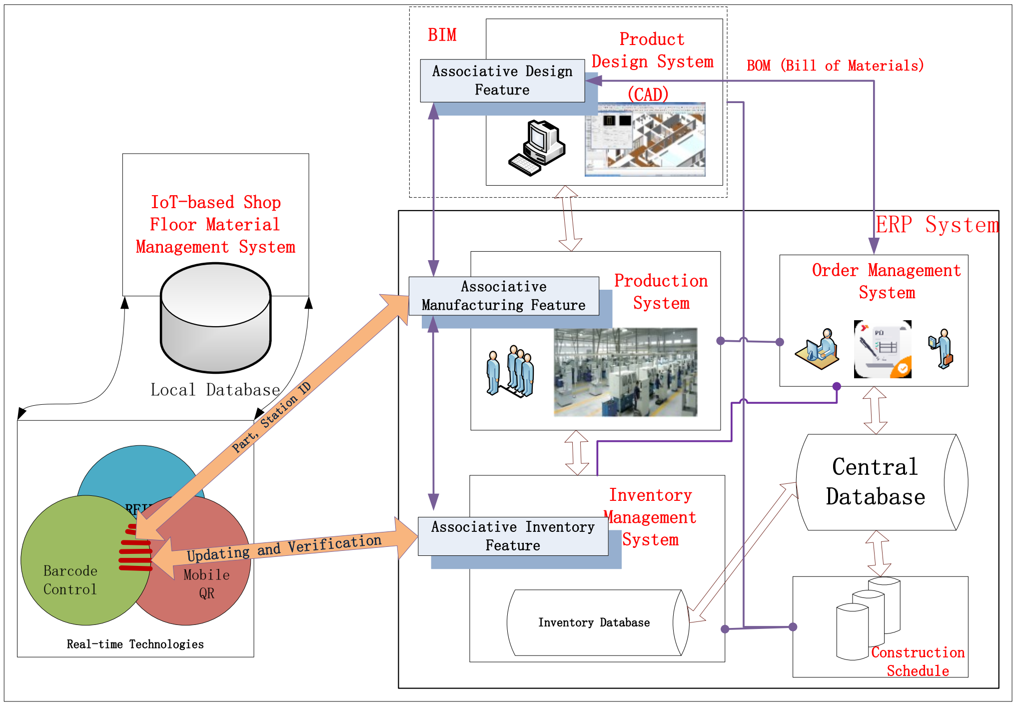

Figure 4-8. Relationships Between IoT Support System and ERP System

An associative feature is a set of semantic relationship expressions which can function as either geometric or non-geometric in the product and system modelling process. Associative feature is a relatively new concept that constitutes another advancement from traditional expressions of features. A new associative feature concept is identified as part of the present research to assist in modelling and to facilitate the IoT-based shop floor material management system's development, and it is introduced in the following section. To satisfy the JIT principle, it should be noted, material availability and production capacity are the driving factors. Without knowing the accurate stock level and the material lead time, the production will never reach the JIT standard. As a result, the Associative Inventory feature and associative manufacturing feature are proposed and defined to manage the relationships among the designing, production capacity, inventory level, and detailed material ordering information from suppliers. A UML diagram representing the different object parameters and relationships with others is illustrated in Figure 4-9.

(1) A panelized home builder has a number of customers.

(2) Customers have one or more customized home product.

(3) Customers utilize BIM to design the product and to project the estimated product delivery date.

(4) The BIM model utilizes production capacity and the associative inventory feature to schedule the project and order material.

(5) Each production process is associated with a panelized production line.

(6) A panelized production facility has multiple workstations.

(7) Associative inventory feature and manufacturing feature can obtain real-time information pertaining to on-site production, off-site production, inventory level, and suppliers from the IoT-based shop floor material management system.

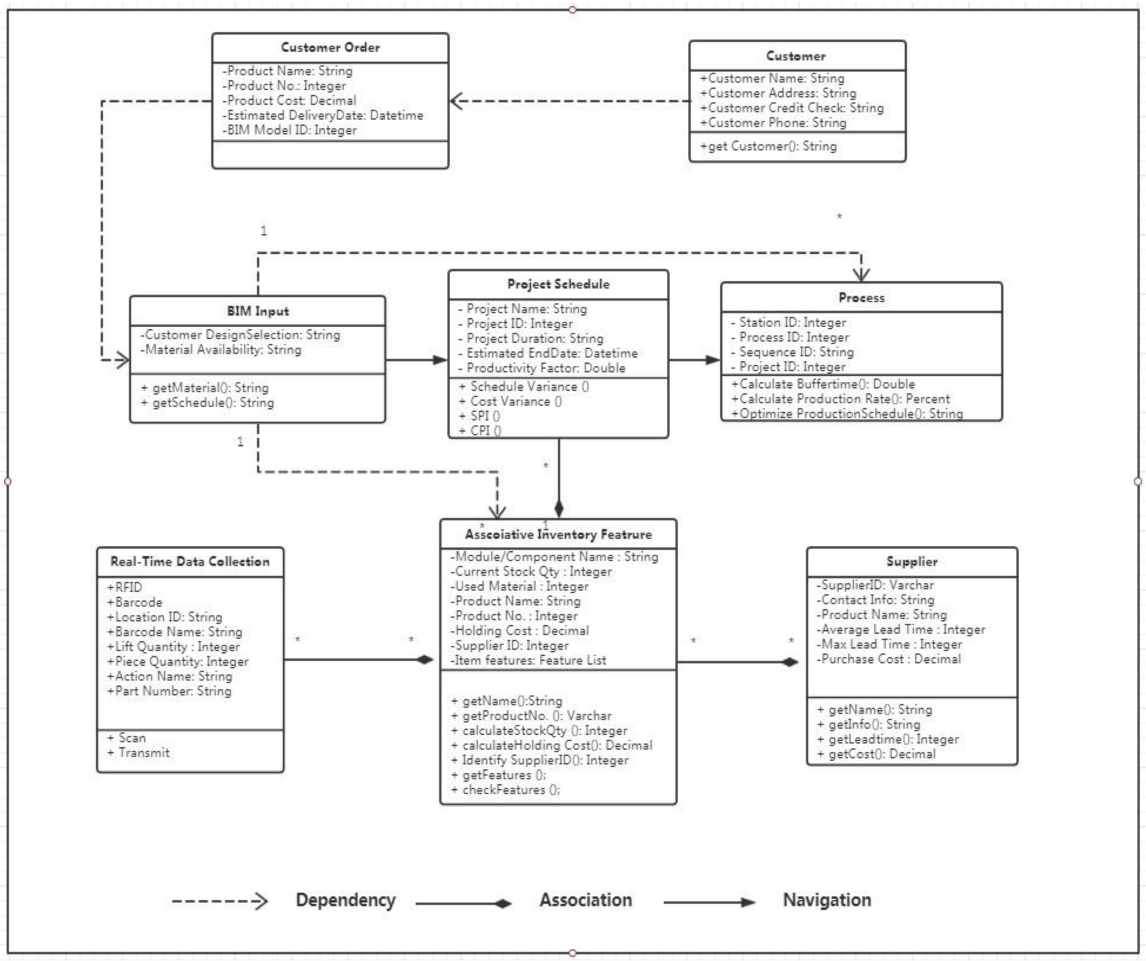

Figure 4-9. UML Diagram Representing the Parameters and Semantic Associations

The associative inventory feature can be defined as a class of features that contains material component name, current stock quantity, used material, product name, holding cost, and supplier ID. For example, the traditional approach is to accept the purchase order from the customer with the estimated product delivery schedule and to check the material availability. Further material orders can then be placed, and the corresponding lead time given. However, factors such as material lead time and current material availability can be expected to influence the product delivery schedule because uncertainties and discrepancies often existed in the first place. With the associative inventory feature concept being involved in the management system modelling, though, a more accurate schedule can be given at the design stage because all suppliers' detailed information—such as the quantity of materials to be purchased and related lead times, type of material available from each supplier—can be extracted from the system. As a result, the feature-based modelling approach can achieve higher accuracy and repetitive steps can be eliminated to improve productivity. The matter of accuracy is particularly important because it not only increases the productivity by improving the buffer time, but it also enables the panelized construction company to better meet customer expectations and thereby boost its reputation in the competitive construction market.

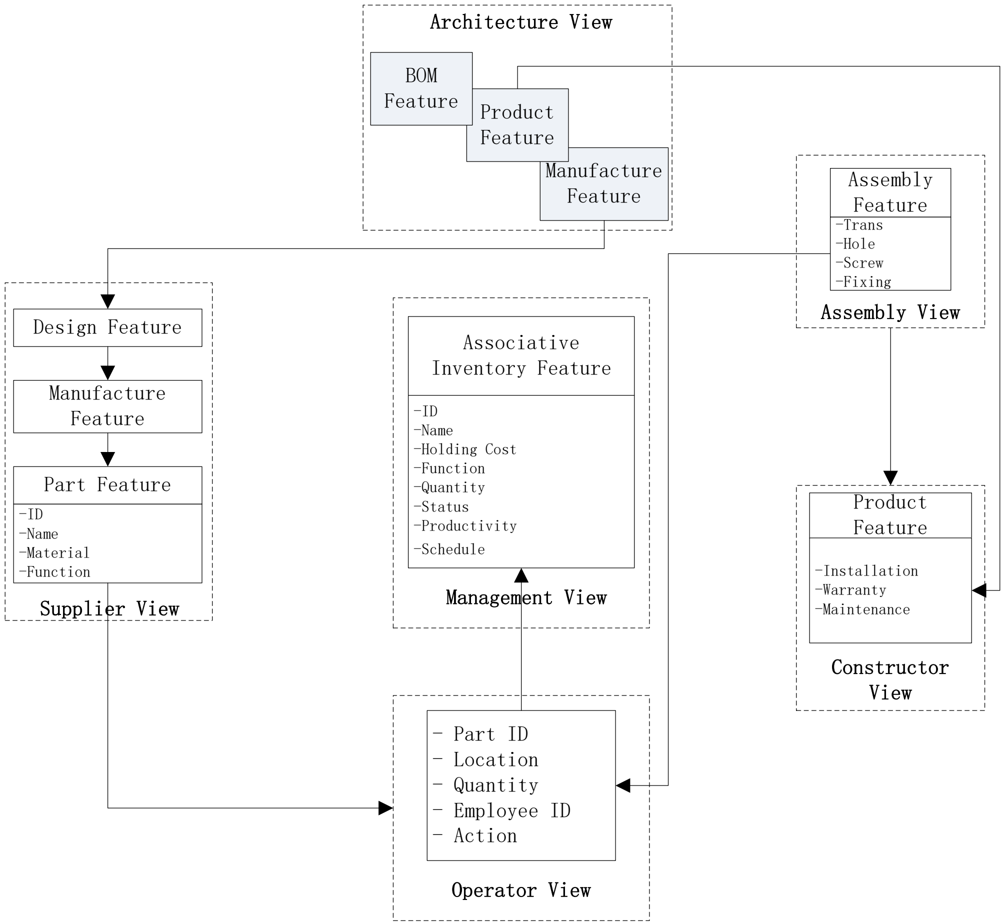

Figure 4-10. Semantic Model with Multi-view Representation

Figure 4-10 presents the sematic model with its multi-view approach. The multi-view feature modelling approach extends the basic feature-based modelling technique, providing a specific view for each phase of the product lifecycle and production process. From the perspective of engineering informatics, the information consistency can be maintained through view updating. Figure 4-10 illustrates the relationships among the different views. The conceptual architecture view consists of the bill of materials feature, the product feature, and the manufacture feature. The supplier view consists of the design feature, manufacture feature, and part feature. The associative inventory feature is the key element to associate the assembly feature and the part feature. For example, in the assembly view, once material parts have been used and assembled, the assembly feature can update the material status in terms of quantity and material holding cost automatically in the associative inventory feature. Moreover, material status and material availability information (from the supplier view), such as lead time, material type and its functions, can be obtained based on the associative inventory feature. Operator view is a key section of this process, operator collects and tracks all real-time data when transferring and receiving material. The productivity and schedule can be automatically updated accordingly once the status has been updated.

4.4.4 External Cloud-based Structure

The purchasing department is a very important and necessary entity within any construction enterprise, as they serve the function of inventory management. Keeping a higher material quantity in stock can be very costly due to expensive material holding cost and depreciation. Keeping a lower material quantity, on the other hand, may limit productivity due to insufficient supply of material. As such, decisions about procurement of material are critical. However, efforts to minimize lead time and cost using the traditional method of procurement, can be highly time consuming. In this approach information flow is one-directional, from prefabrication facility to supplier. The material flow, in turn, is in the opposite direction to the information flow in the traditional prefabrication facility. However, the proposed shop floor material management system via external cloud-based network enables information flow in both directions in real-time, and all material-related information between the prefabrication facility and its suppliers is shared in cloud (with agreed-upon terms of confidentiality in place). Material flow remains the same as suppliers provide material based on orders and purchases in a single direction. In the upper part of the figure 4.11 is the internal ERP structure, while in the lower part of the framework is the external network structure via cloud. A cloud-based management system can help a construction enterprise to manage its business more efficiently, and it provides windows in which to view other demands related to core activities. In this system, advanced IoT technologies are utilized within the cloud to update the cloud solution in real-time. Applications within the cloud function in an open environment, which increases accessibility, including external accessibility. In this case, suppliers share the material information and stock availability, while the panelized home builder shares the dynamic demand information. Information shared from suppliers (and, in turn, their suppliers) can be obtained by the panelized home builder in order to estimate the production schedule and material arrival time. Information shared by the panelized home builder can be accessed by suppliers from all different levels in order to plan accordingly to meet the dynamic demand.

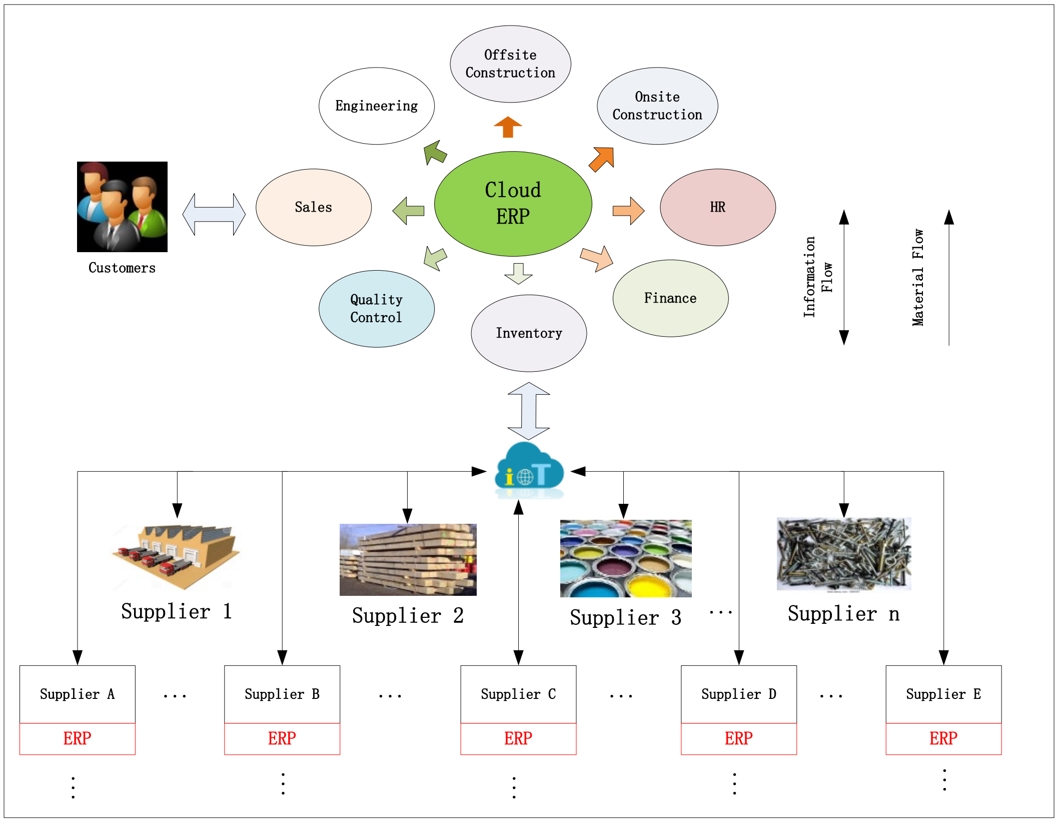

Figure 4-11. External Cloud-based Structure

Overall, the integrated IoT-based shop floor material management system utilizes barcode/RFID tag generated from BIM to represent the unique type of material. A preliminary schedule can be generated from the BIM model based on material availability from current stock and production capacity with the proposed system internally. If additional materials need to be purchased, the external cloud-based system can obtain required information from suppliers with detailed information, such as lead time, arrival time, and quotation of the product price. In the developed system there is also the potential for the mobile QR scan technology to keep track of the on-site production once the panelized products have been shipped to the construction site for final assembly.

Chapter 5. Technology Implementation and Results

The proposed methodology has been partially implemented in a home builder based in Edmonton, Canada. ACQBUILT, a panelized construction manufacturer, fabricates construction components, primarily in the form of open wall panels, floor panels, and roof panels, at its off-site prefabrication plant. The panels are then transported to the construction site for final assembly. The prefabrication facility is equipped with state-of-the-art computer numerical control machinery on the production line, such that all the panels required for up to three homes can be produced in one day. Real-time technology described in this thesis has been designed and implemented on the case company's production line. In spite of the high level of automation at the case production facility, it should be noted, the company still employs a traditional approach to managing inventory. For instance, operators manually populate the relevant paperwork with material information when receiving and transferring material, then the office staff manually enter all paperwork into a database. Such an antiquated procedure lowers productivity and prevents the production line from maximizing its potential. In this chapter, an overview of the case company's inventory management system and production line operation is provided, and the partial implementation of the proposed IoT-based material management system is described, along with a cost-benefit analysis.

5.1 IoT-based Information Technologies Implemented

According to the proposed IoT-based manufacturing system three real-time information technologies are required to form the system: barcode scanners for inventory receiving and transferring, RFID for off-site wall production line control, and mobile QR scanner for on-site installation. All technologies' development and implementation vary with supportive hardware and related surrounding environment. Every technology has its own advantages/disadvantages and cost, so technology selection prior to physically implementing the system is a significant step.

5.2 Shop Floor Material Management System

5.2.1 RFID Technology

The existing RFID system was developed and implemented in the case facility to enable automated production monitoring and reporting and historical data collection. At the framing station, an RFID tag is attached to each wall panel. The antenna receives the tag signal as the wall panel passes the RFID-covered read-zone. RFID antennas are installed at each workstation in order to capture the movement of the material along the production line. All antennas are connected to the RFID reader that captures all timestamp data in the designed database. The existing RFID system at the case facility's wall production line consists of five Motorola FX9500 RFID readers, 12 Motorola AN440 antennas, and one label printer. Figure 5-1 shows the existing wall production line.

Figure 5-1. RFID System on Wall Production Line (Courtesy of ACQBUILT, Inc.)

The upper-left frame of the figure shows the RFID technology on the framing station. The upper-right frame shows the RFID technology on the transfer cart, where wall panels and sheathing frames that have been nailed automatically at the multi-function station are transferred to the window installation line by means of the transfer cart. The lower-left frame shows the window/door installation line. Following window and door installation, the wall panel is transferred by another transfer cart (lower-right frame) furnished with RFID to the wall magazine line at the end of the production line for temporary storage. In addition, not only does the RFID system track the timestamp on the production line, it also identifies the locations of the panels in real-time. One disadvantage is that the devices need continuous support from wireless so that all real-time timestamp data can be captured in the prefabrication facility. Otherwise, whenever the power of the facility shuts down or the wireless connection is lost, the RFID system will stop working. For example, at the case company, wireless only covers the main office building and fabrication facility, while the main gate and stock yard are not covered by wireless. Therefore, real-time data collection from RFID cannot remain active continuously to support inventory management and on-site installation.

5.2.2 Barcode Technology

5.2.2.1 Software Development

With respect to the absence of RFID for material receiving and transferring from the stock, barcode technology can serve an ancillary function in combination with

RFID on the production line to keep the real-time data consistent. In particular, barcode scanning has gained extraordinary attention in both inventory and logistics management. A barcode, it should be noted, is a machine-readable and optical representation of data. Barcode can be one-dimensional or two-dimensional and defines a specific product with respect to a unique barcode. Such one- or two-dimensional pre-defined barcode technology not only can be applied in logistics and inventory management, but also has high potential for use in on-site installation construction since it does not require continuous wireless support. Furthermore, the implementation of barcode technology is comparably cheaper than RFID. This is also an important reason why barcode development and implementation has been prioritized despite some disadvantages of barcode technology, such as that the barcode scanner has to be carried in person and has to be manually aligned with the pre-defined barcode in order for the device to recognize the code. In order to avoid human error related to this, proper training on the correct use of the device is provided to the operators at the case company. Meanwhile, a barcode system is maintained and occasionally modified based on user experience. Figure 5-2 illustrates the flowchart of the barcode technology implemented at the case company.

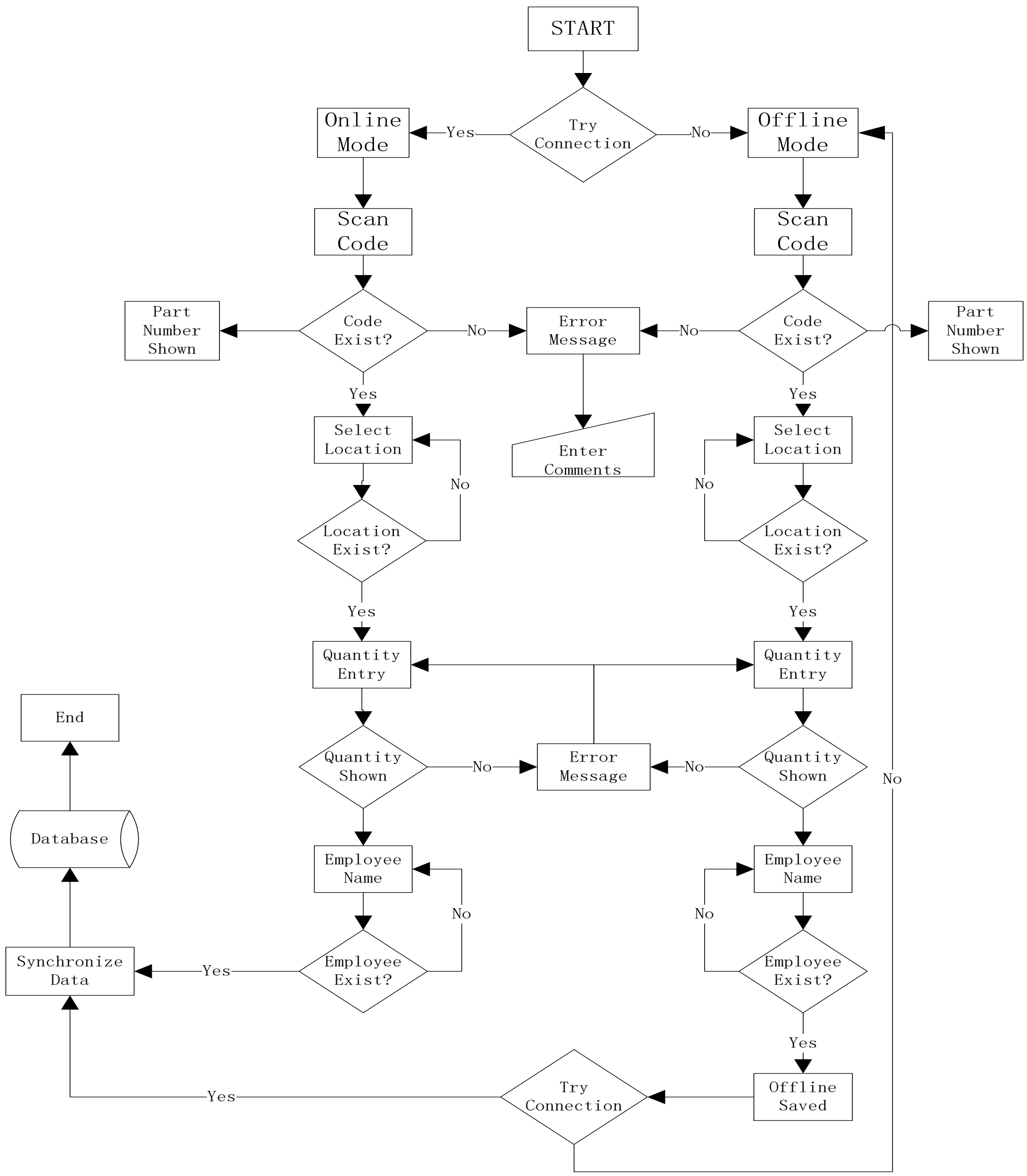

Figure 5-2. Flowchart–Barcode Technology

Figure 5-2 illustrates the information flow for barcode technology implementation at the case facility, designed for two different conditions—online mode and offline mode. The left side of the flowchart (online mode) shows how information need to be populated and data transmitted to the database. As seen on the right side of the figure, when it is identified that there is in no wireless network available, offline mode will take effect and store the data to the device. When the device returns to a wireless-covered area, the "submit" function from the online mode is initiated and synchronizes the device-stored data with the database.

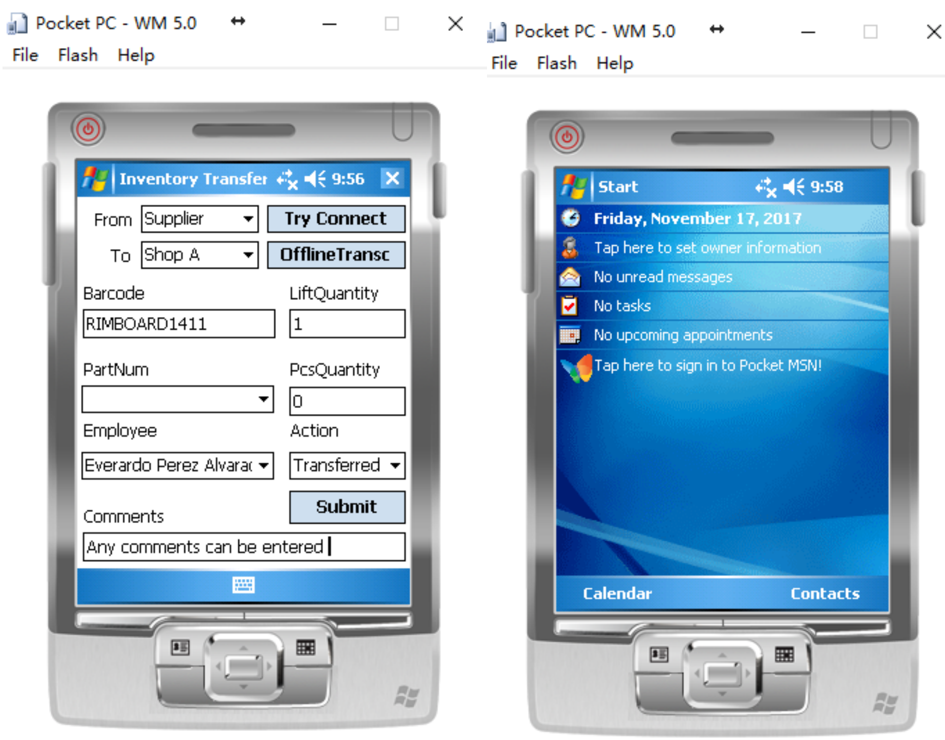

Figure 5-3. Overview of Designed Mobile Device Interface (Operator View)

Figure 5-3 provides a more detailed view of the designed interface for this data collection system. Each button or box has a unique function designed based on the specific requirement from the case panelized home facility's needs. All programming codes are attached in the appendix for reference.

Table 5 - 1. Interpretation of Designed Interface

Item Box	Functionality	Example of Selection
From	Track the location of material received from or transferred from	Supplier, Yard, Shop A, Shop B
To	Track the location of material received at or transferred to	Supplier, Reception, Yard, Shop A, Shop B
Barcode	Each unique barcode represents specific type of material	RIMBOARD1411
Lift Quantity	The lift quantity of material received or transferred using forklift	1 lift, 2 lifts
Part Number	Each type of material has a shorten name designed for operator	LSL
Piece Quantity	The piece quantity of material received or transferred	1,2,3,5,10, etc.
Employee	Name of Employee who receive or transfer the material	Ever ado Perez
Action	Receive, Transfer	Transferred
Comments	Any additional information that operator wants to report via the system	Any comments can be entered

Table 5 - 2. Interpretation of Buttons on Interface

Button	Functionality	Message Shows
Try Connect	Verifying device is connected to the network when return to network covered area	• Connection Success • Connection Failed
Submit	Transmit all data collected under network area to central database	• Transaction Successes • Failed to update DB. Transaction Stored.
OfflineTransc	Transmit all data collected and stored in device to central database under network	• Number of Quantity Transactions complete • Transactions failed

Two important functions of the barcode technology associated with its partial coding are illustrated in Appendix. The function of the partial programming codes below is to transmit the collected real-time data into the database of dbo.barcodedemo under WiFi condition. If the WiFi is connected, a message of "Transaction Successes" appears after clicking the "submit" button. Otherwise, the submitted transactions are saved in the device and a message of "Failed to update database, Transaction stored" displays. This is the basic function of the online mode to track the real-time material being received or transferred, along with the associated locations and quantities. When the operator receives or transfer materials at a WiFi-excluded area, the programming function below will take effect. The transactions submitted while in offline mode are saved in device; when the operator returns to a WiFi-covered area and clicks the offline transaction button, the saved transactions will be immediately synchronized into the central database.

Figure 5-4. Screenshot of VS 2008 and Interface Built with C#

Figure 5-4 is a screenshot of the interface uniquely designed for the case panelized home construction facility in C# programming language within a Visual Studio 2008 environment. The functions are classified into different classes including offline mode class, submission class, default data verification class, and so on. All the detailed coding are introduced later in appendix.

5.2.2.2 Barcode Design and Development

In addition to program design and development, pre-defined and pre-generated barcodes also play important roles in the process of inventory tracking and control. Pre-defined and pre-generated codes are unique identifications for each type of material used at the facility, and they are designed to assist the office controller and management staff to recognize the material in a simple way within a big data environment for inventory optimization and inventory forecast purposes. Moreover, pre-defined codes for each material should be imported into the database at the beginning so that the database can recognize the codes when the operator or receiver scans the codes using the device. For instance, the barcode "GOLD78410", (where the code stands for "Tongue-and-Groove Edge Gold 4×10×7/8″ oriented strand board floor panels only"), is pre-defined and entered in the database. An example of the barcode and description sheet should be pre-defined and printed out for operators' use. A screenshot of the imported barcodes associated with the names of materials from the central database for use by engineers and controllers is shown in Figure 5-5.

1	3.5X9BEAM	3.5X9BEAM
2	3/84X12REGSHT	3/8 4X12REGSHT
3	3/84X8REGSHT	3/8 4X8REGSHT
4	3/84X8S101SHT	3/8 4X8S101SHT
5	3/84X9REGSHT	3/8 4X9REGSHT
6	3/84X9S101SHT	3/8 4X9S101SHT
7	DOUBLELSL2640	LSL26DOUBLE40
8	DOUBLELSLSTD2491	LSLSTD2491DOUBLE
9	DOUBLELSLSTD2492	LSLSTD2492DOUBLE
10	DOUBLELSLSTD2691	LSLSTD2691DOUBLE
11	DOUBLELSLSTD2692	LSLSTD2692DOUBLE
12	GOLD78404	7/8 4X4GOLDT&G
13	GOLD78406	7/8 4X6GOLDT&G
14	GOLD78408	7/8 4X8GOLDT&G
15	GOLD78410	7/8 4X10GOLDT&G
16	GOLD78412	7/8 4X12GOLDT&G
17	LBR20410	LBR20410
18	LBR20412	LBR20412
19	LBR20416	LBR20416

Figure 5-5. Screenshot of Barcode Sample and Material Information in Database

5.2.3 The Database Design and Development

Table 5 - 3. Design of Main Inventory Table in Database

Field Name	Field Type	Remark
Uid	Int	Primary key of the record, uniqueness queues
date	datetime	Real-time tracked
from	Varchar(50)	Location Selection
to	Varchar(50)	Location Selection
barcode	Varchar(100)	Materials' Representation
Action	Varchar(50)	How material being moved
EmployeeId	Varchar(50)	Working Employee Name
LiftQuantity	Int	Material Quantity
PcsQuantity	Int	Material Quantity

The real-time technology stores and transmits the timestamp data into the above designed system database in real-time. The technology has five main tables: (1) Action table comprises the required actions when the operator identifies and updates the type of material as well as its quantity; (2) Material Part table provides the simplified material name automatically for operators once the unique barcode identification has been scanned into the device; (3) Employee Name table keeps track of the name of the employee who operators the device and submits the transactions; (4) Location table contains detailed location information for identifying where the material is being transferred to and where it is currently located; and (5) Main Barcode table receives all information submitted by means of the IoT-based technology in real-time. SQL is used to extract all necessary information from the database in terms of material quantity, material location, etc.

5.3 Case Study

5.3.2 Implementation of Proposed System

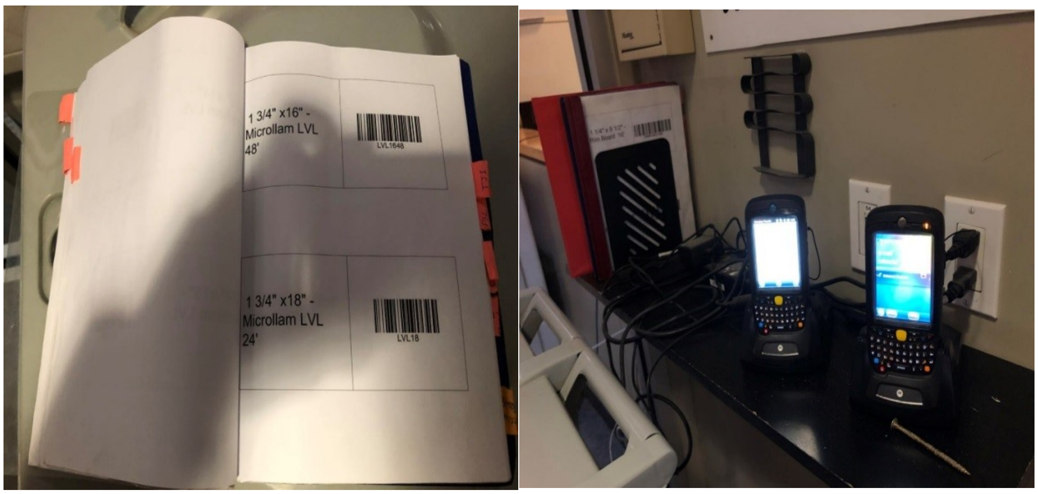

Figure 5-6. Barcode Scanner Devices and Pre-defined Barcode Library (Courtesy of ACQBUILT, Inc.)

Figure 5-6 shows the actual charging station at the case company where devices are charged during breaks and non-working hours. The detailed barcode information in the book is all pre-defined, and each unique code is associated with one unique type of material. They are assigned and arranged in alphabetical order in the book.

	LocationId	Location
1	1	Yard
2	5	A01
3	6	A02
4	7	B01
5	8	B02
6	10	Main

Figure 5-7. Screenshot of Location Table in Designed Database (Courtesy of ACQBUILT, Inc.)

Figure 5-7 is a screenshot of the location table in the case company's database with identification numbers. On the device interface, all indicated location information appears when the user clicks the location dropdown list. The action table and employee table function in the same manner.

PartNum	EpicorPartNum	Length	LiftSize	Description
PSL71418	PSL714	18	3	Parallam PSL 7 x 14 x 18 ft
PSL71420	PSL714	20	3	7" x 14" Parallam PSL - 2.2E Beam 20'
PSL716	PSL716	22	3	7" x 16" Parallam PSL - 2.2E Beam 22'
PT10DECKBOARD	PT10DECKBOARD	1	200	5/4" x 6" x 10' - ACQ Deck Board
PT12DECKBOARD	PT12DECKBOARD	1	200	5/4" x 6" x 12' - ACQ Deck Board
PT21010	PT21010	1	60	2 X 10 X 10' ACQ Treated
PT22SPINDLE	PT22SPINDLE	1	450	2 x 2 - 42" ACQ Spindle
PT2408	PT2408	1	234	2 X 4 X 8' ACQ Treated
PT2410	PT2410	1	234	2 X 4 X 10' ACQ Treated
PT2416	PT2416	1	234	2 X 4 X 16' ACQ Treated
PT2610	PT2610	1	144	2 X 6 X 10' ACQ Treated
PT2612	PT2612	1	144	2 X 6 X 12' ACQ Treated
PT2616	PT2616	1	144	2 X 6 X 16' ACQ Treated
PT2810	PT2810	1	84	2 X 8 X 10' ACQ Treated
PT2812	PT2812	1	84	2 X 8 X 12' ACQ Treated
PT2816	PT2816	1	84	2 X 8 X 16' ACQ Treated
PT4410	PT4410	1	78	4 X 4 X 10' ACQ Treated
RIM1409	RIM1409	16	90	1 1/4" x 9 1/2" - Rim Board 16'
RIM1411	RIM1411	32	32	1 1/4" x 11 7/8" - Rim Board 32'
RIM1414	RIM1414	32	24	1 1/4" x 14" - Rim Board 32'
RIM1416	RIM1416	32	24	1 1/4" x 16" - Rim Board 32'
TJI21009	TJI21009	22	37	TJI 210 – 9 ½" Joists – 22'
TJI21011	TJI21011	44	37	TJI 210 - 11 7/8" Joists - 44'
TJI21014	TJI21014	44	37	TJI 210 - 14" Joists - 44'
TJI2301627	TJI23016	27	35	TJI 230- 16" Joists - 27'

barcode	PartNum
ACQ20180067	7/8 4X8GOLDT&G
ACQ20180068	7/8 4X10GOLDT&G
ACQ20180069	7/8 4X12GOLDT&G
ACQ20180070	3/8 4X8REGSHT
ACQ20180071	3/8 4X8S101SHT
ACQ20180072	3/8 4X9REGSHT
ACQ20180073	3/8 4X9S101SHT
ACQ20180074	3/8 4X12REGSHT
ACQ20180075	PSL716
ACQ20180076	PSL711
ACQ20180077	PSL71420
ACQ20180078	PT10DECKBOARD
ACQ20180079	PT12DECKBOARD
ACQ20180080	PT21010
ACQ20180081	PT22SPINDLE
ACQ20180082	PT2408
ACQ20180083	PT2410
ACQ20180084	PT2416
ACQ20180085	PT2610
ACQ20180086	PT2612
ACQ20180087	PT2616
ACQ20180088	PT2810

Figure 5-8. Screenshot of Material Table (Courtesy of ACQBUIIT, Inc.)

Figure 5-8 shows that PartNum is the key association between two tables. From operator's view, operators only recognize the PartNum. EpicorPartNum is the only identification that ERP system would recognize. Therefore, part number is one of the associative inventory features that help both operators and estimators in the same system.

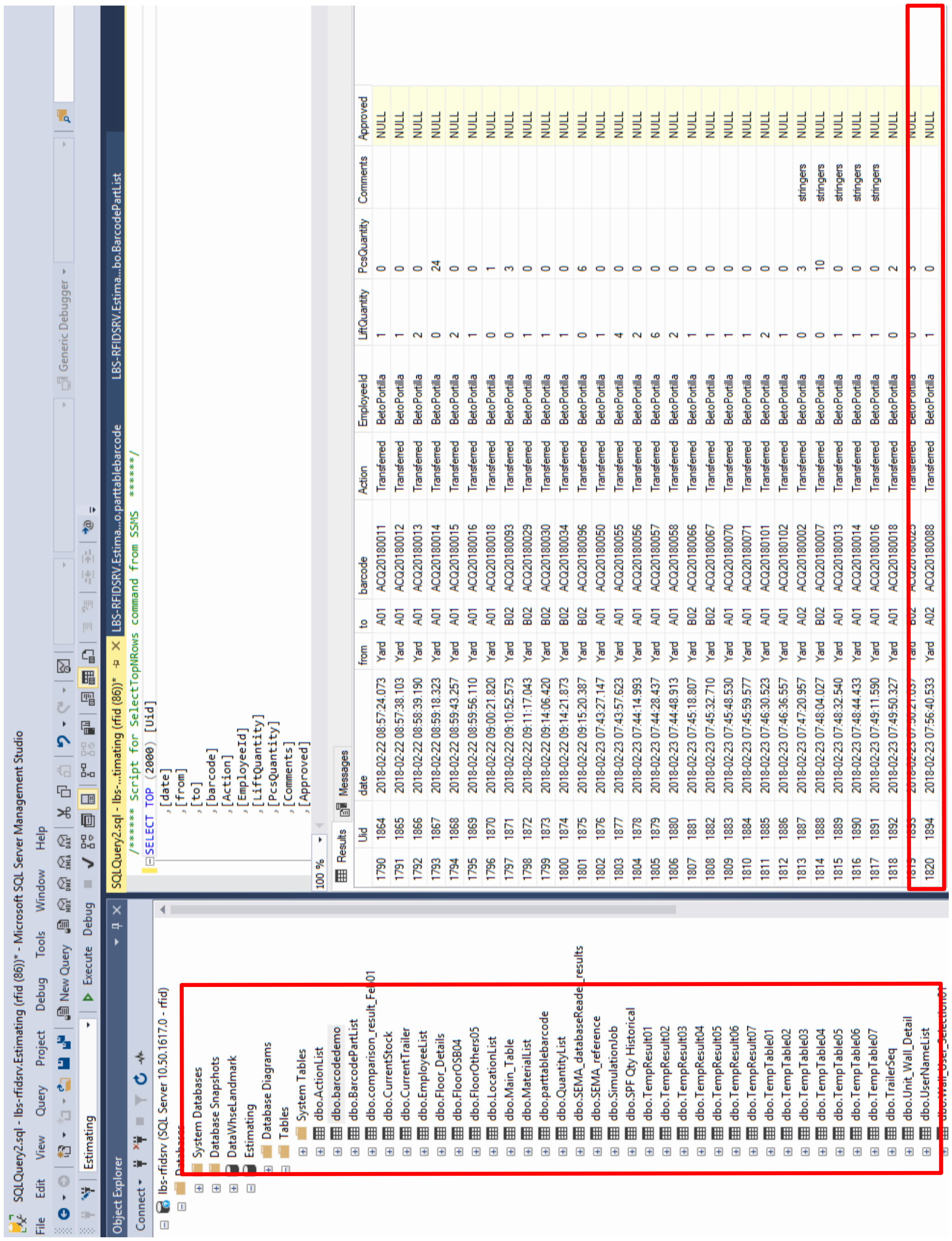

Figure 5-9. Screenshot of Query Table of Main Inventory Management

The above figure 5-8 shows the material table in the designed database, where PartNum is the unique identification name for the user to recognize, EpicorPartNum is the vendor's material identification name that was generated from ERP system, and detailed description of the type of material is under the description column. When users scan the barcode, the PartNum pre-assigned to the given type of material with unique code will automatically pop up in the interface. For example, for 2×4×12 lumber, the operator only recognizes the code LBR20412, whereas the vendor's EpicorPartNum is LBR204. In this regard, when control personnel conduct data mining and optimization with collected data, an entity relationship diagram or SQL query language can help with identifying and sorting the required information.

The barcode system is utilized to track the all material being received and transferred in real-time throughout the supply chain, excluding the wall production line and on-site installation. Figure 5-9 presents the actual query table of the real-time technology implemented at the industry partner's production plant from management view. It also tracks the start- and end-locations of the material being transferred. In contrast to traditional inventory management, where there is a lag due to operators filling up the reports and office personnel entering the data manually into the database the next day, using the inventory management table combined with the wall production RFID system with the assistance of SQL the remaining quantity of a material can be calculated in order to provide real-time decision support for material purchasing. Also, the production schedule can be optimized based on the IoT-based manufacturing system because the inventory management system can be combined with the existing simulation module and financial module. The production data generated from the RFID system can also be combined with the inventory level and existing stock data to calculate the idle time, buffer time, and daily production volume and material transfer quantity. In supporting the proposed IoT-based manufacturing system in functioning without any interruption, the quality of the network plays a significant role, where a high-speed network can expedite the transmission of the collected data to the cloud-based management system for further analysis and data mining. The interface enables communication between users and management personnel, and also allows the IoT-based device to interact with the cloud-based management system. More importantly, the designed interface based on user experience is able to collect the required data from one end to another without a time-consuming process.

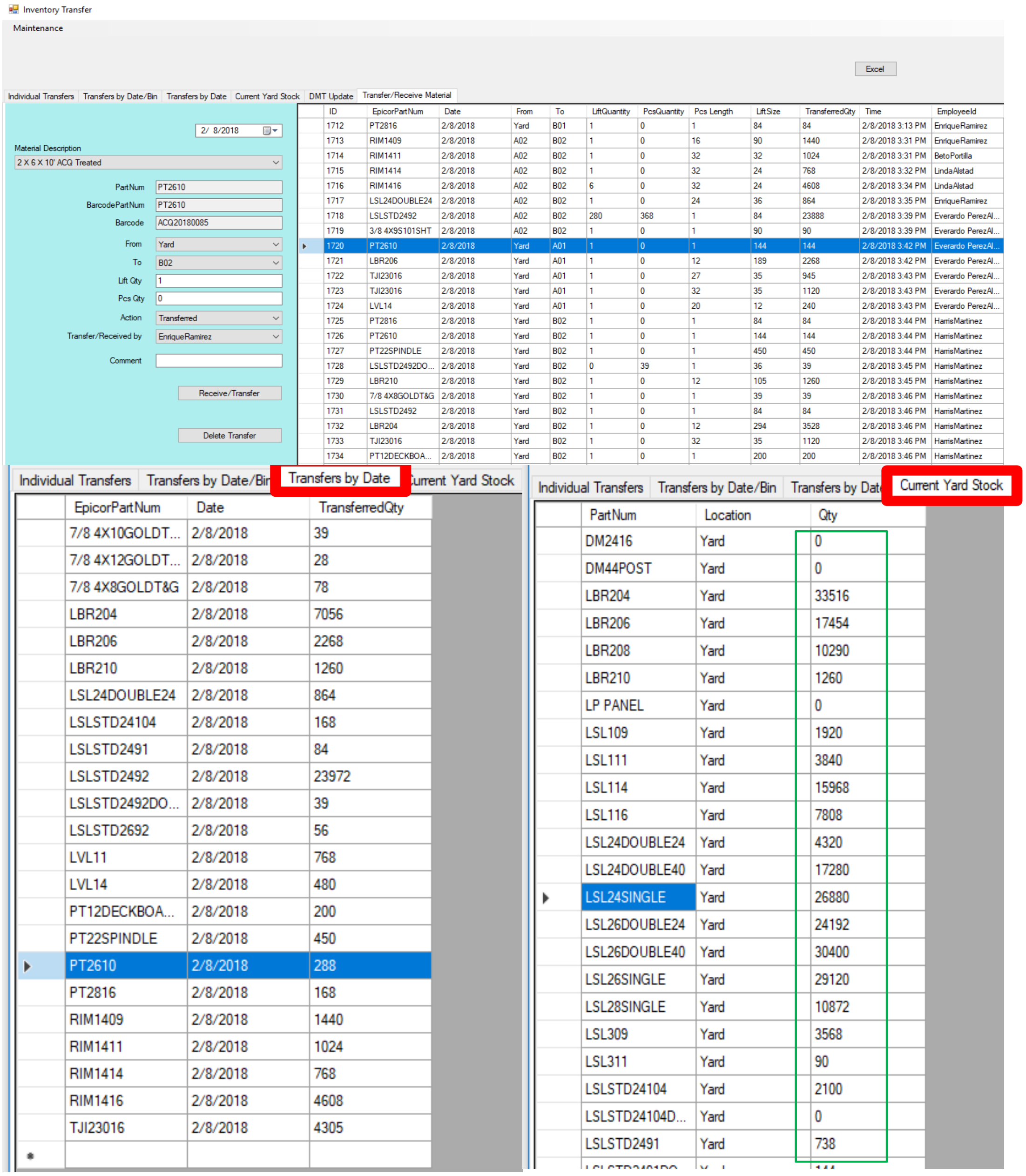

Figure 5-10. Screenshot of Inventory Module from Management View

Figure 5-10 presents the estimators/management view in inventory module. The module was developed and in-use in estimating department. Real-time data collected from the developed technology can be obtained for estimator view and it helps update the current stock quantity automatically.

Figure 5-11. Implementation of Real-time Technology at ACQBUILT Plant

Figure 5-11 shows a photograph of the operator transferring material from stock in the yard to the fabrication shop with the scanner in hand.

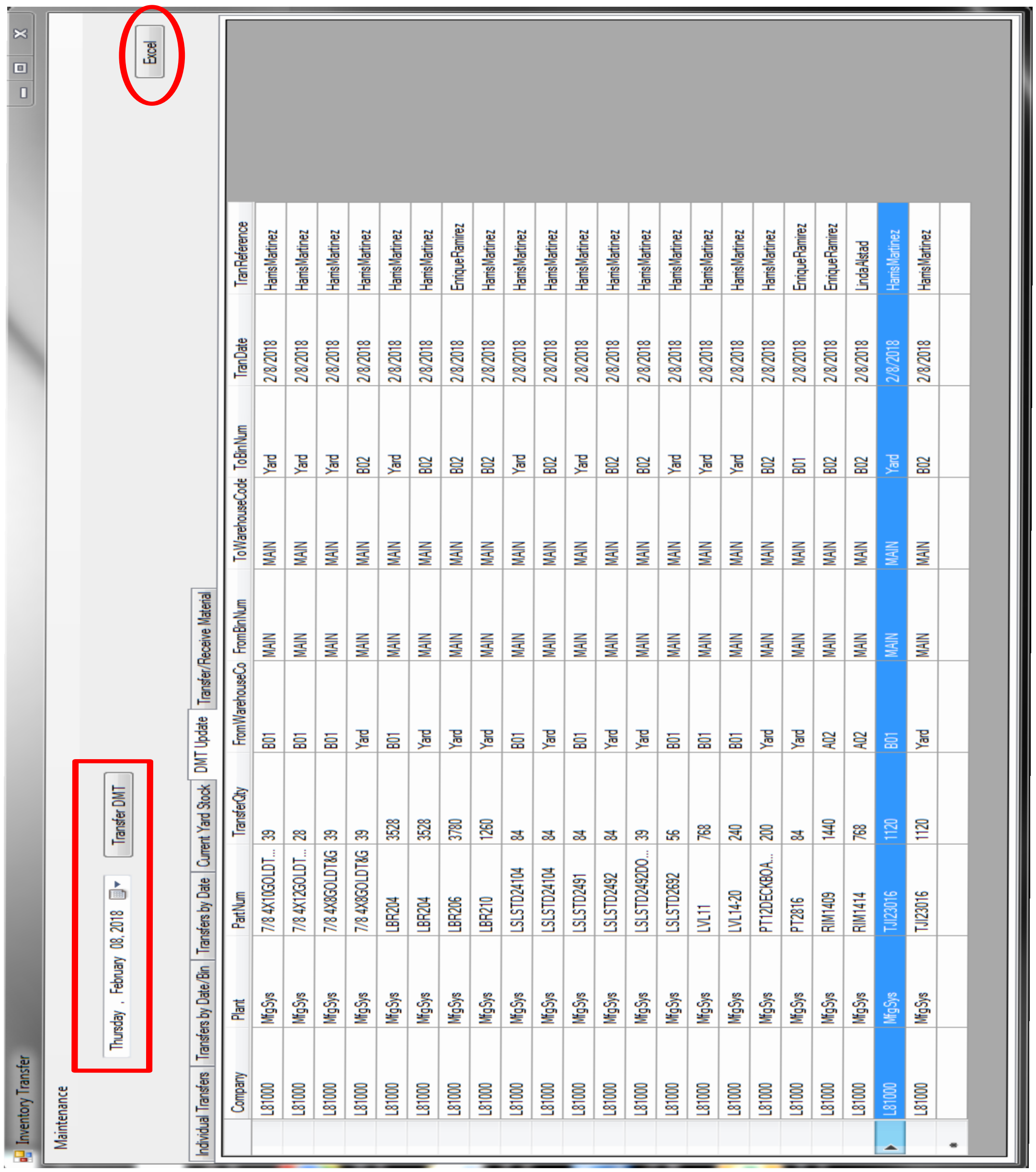

Figure 5-12. Interface of DMT in Proposed System

Figure 5-12 shows one DMT function tap in the proposed system. All real-time data collected will be re-arranged to the specific format that can be compatible with ERP system. Extracting the real-time data collection only take few seconds rather than traditional way of entering all data back in to ERP line by line in order to update inventory module in ERP system.

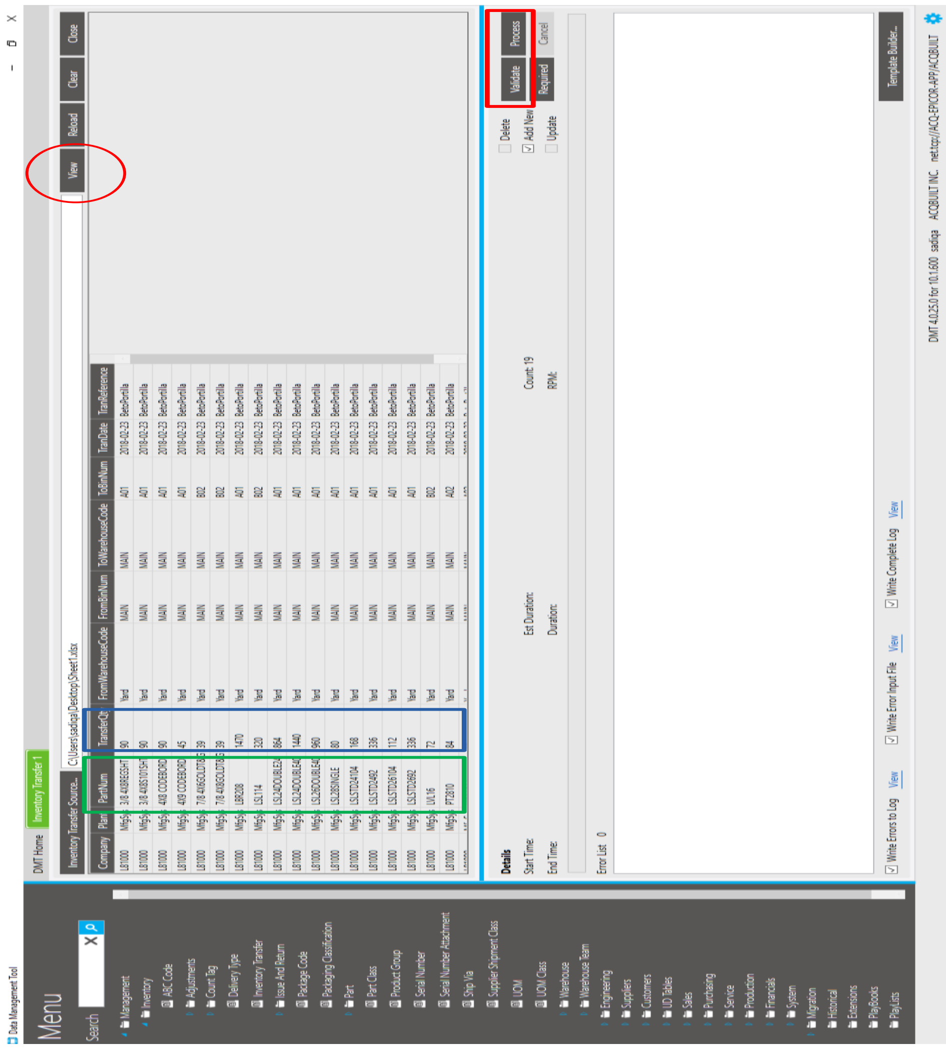

Figure 5-13. Interface of DMT in ERP System

Figure 5-13 shows the interface in the data management tool that assist to update the Epicor ERP system. Data collected from the proposed system have processed the unit conversion and format unification in both geometric and non-geometric manner. Clicking processing function button once validate the data uploaded. The inventory will be updated in ERP system in few seconds instead of 3 hours a day. Thus, with the proposed system to assist ERP, there are significant savings from this approach.

5.3.2Cost-benefit Analysis

To verify the cost effectiveness of the partially implemented IoT-based shop floor material management system, Table 5-4 shows a cost-benefit analysis that is performed for barcode technology and the system. The analysis is based on current market conditions in Alberta, Canada (at the time of writing), in terms of working hours, salary rate, and initial setup costs. As determined in the analysis, in the existing practice one office employee spends three hours per day entering production data from the previous day collected in paper form. Based on an hourly rate of $25 (Canadian dollars) and 260 days of production data (five days per week × 52 weeks in a year), the cost to the case company of carrying out this simple data entry task is approximately $19,500 per year. We can assume that the associated general & administrative expenses and office supply costs related to this particular task amount to approximately $300 per year. Meanwhile, assuming that each operator spends half an hour per day filling out the paper data forms, that there are three operators working a given shift, and that the hourly rate of pay for operators is $27, the cost of operators filling out the data forms manually is $10,530 per year. One senior estimator spends half an hour per day to manually enter all summarized data into estimating software to perform inventory forecasting. Assuming that senior estimator hourly rate is $50 and the cost to it is roughly $6500 per year. In summary, in the existing approach without real-time based RFID/barcode technology the simple activities of filling out the data forms and entering data into the system manually cost the company approximately $36,830 per year.

The initial setup cost for two barcode devices and a wireless network is estimated to be approximately $2,000. Thus, implementing the barcode technology results in a savings of $32,100 per year. This savings is expected to be even more significant in cases where housing demand is high, as well as for projects with longer durations. With the implementation of the proposed system, additional savings for the case company due to the IoT-based shop floor material management system can be expected. Similar benefits can be expected for other panelized construction companies.

Table 5 - 4. Cost-benefit Analysis

Scenario	3 Operators	1 Data Clerk	1 Estimator	Initial Cost	Related Office SG&A
Without Barcode Technology	$10,530	$19,500	$6,500	$0	$300
With Barcode Technology	$1,755	$325	$650	$2,000	$0
Percentage of Savings	83.3%	98.3%	90.0%	----	100%

Chapter 6. Conclusion and Future Research

6.1 Summary

This thesis presents a conceptual framework of an IoT-based shop floor material management system for a panelized construction builder. The lack of an efficient system for information sharing has been a challenge in construction for many years that inhibits the development, implementation, and operational efficiency of advanced construction methods. Real-time technologies can be used to obtain real-time information about the objectives along the supply chain and eliminates the need for traditional data collection methods for decision making and historical data storage. Real-time technologies, including GPS, sensors, data storage, and machine learning and decision support tools, form the IoT-based shop floor material management system. Such a system not only can effectively improve efficiency, but it also can establish communication linkages throughout the supply chain both internally and externally. With the adoption of IoT-based technologies, buffer time, inventory level, productivity, and re-work can all be easily identified and addressed accordingly. The proposed framework comprises an internal system and an external system. The internal IoT-based system includes barcode-controlled inventory, RFID-controlled production line and mobile QR code-controlled production. Real-time based barcode and RFID have been developed and implemented in the case panelized home prefabrication facility. The proposed external system of the framework is cloud-based in order to provide information sharing between the case company and its suppliers (and, in turn, their suppliers). In addition, to better facilitate the integration of the potential management system in the case company's operations, the feature-based modelling concept is introduced. A new category of feature, the associative inventory feature, is defined as a class structure. With the given definition, the new feature class can be incorporated with product features using semantic modelling. With the computer-aid designed system, required information pertaining to product and process can be obtained intelligently for the purpose of decision making in later stages of construction.

Training was provided to the case company's employees on how to properly use the real-time technology. The implementation results of the proposed system demonstrate that the IoT-based shop floor material management system can greatly improve the efficiency and ensure the accuracy of the collected data. Cost-benefit analysis was conducted, and it was found that more than $30,000/year could be saved by implementing only one of the real-time technologies. It can thus be expected that the case company will further benefit from the proposed system once it has been fully implemented.

6.2 Research Contributions

6.2.1 Academic Contributions

There have been number of studies on ERP system and IoT-based manufacturing system's design and development in various industries. However, to date no study has focused specifically on the design and development of an IoT-based shop floor material management system for a panelized construction manufacturer. In panelized construction manufacturing, unlike traditional manufacturing, special care must be taken due to the dynamic variability of the production process and the high level of customization of products. With such a high mix and high-volume production, a prefabrication facility could easily lose control of its operations in the absence of substantive management experience. Furthermore, even when management personnel are highly experienced and skilled the management approach is still error-prone. Thus, an IoT-based shop floor material management system has been developed and partially implemented in the case facility to enhance the control of the production line, inventory, and across the supply chain.

The academic contributions of this thesis are summarized below:

i. A real-time data acquisition system for panelized fabrication inventory management to track location and quantity of material movement along the supply chain has been developed.

ii. A framework of an integrated IoT-based shop floor material management system for a panelized home builder has been proposed.

iii. A real-time technology (barcode) has been implemented in a panelized builder, and the results after implementation have been analyzed based on the real-time data collected. It was integrated with the existing system to advance the production and inventory management and fulfill the JIT principle in both inventory management and production aspects.

iv. An associative inventory feature has been defined for the first time and expressed in UML to integrate the ERP system.

6.2.2 Industrial Contributions

The industrial contributions of this thesis are summarized as follows:

i. Management personnel can obtain and view real-time information about material movement along the chain without delay due to manually filling the paperwork and entering data into the system.

ii. It has been demonstrated that operator productivity can be improved by utilizing the real-time technology, thereby eliminating the time-consuming and error-prone traditional process.

iii. Cost-benefit analysis has been conducted which shows that the implemented system and barcode can achieve significant cost savings compared with traditional method.

iv. The proposed framework of an IoT-based shop floor material management system has been realized and partially implemented, and the integration with existing real-time technologies has already been shown to improve the inventory management. The case company can be expected to see further benefits once the whole system has been implemented.

6.3 Limitations and Future Research

6.3.1 Research Limitations

Real-time technologies are capable of automatically receiving and transmitting data into the database. However, the multiple real-time technologies that form the system receive a large amount of data from the production floor and even future at construction site; the enormous amount of data flowing into the ERP system can create a challenge for office management employees in terms of data processing and management. Furthermore, data noise may be obtained by the system which must be filtered and removed. The ERP system and lean production methodology also require the management team's support, and the cost of implementing the entire process can be quite significant.

Another challenge is that the proposed framework necessitate the execution of confidentiality agreements among the parties linked by the external component of the system. Moreover, the design, implementation, and maintenance of technologies for the IoT-based management system can be very costly.

6.3.2 Future Research and Improvement

Based on the research presented herein, the following is proposed as future work:

i. Real-time technology implementation for on-site installation: In panelized construction, once products have been fabricated in an off-site manufacturing environment, they are shipped to the construction site for final assembly. An IoT-based mobile technology can be developed for this special use in order to better manage and control the on-site construction in the internal IoT system.

ii. Integration of ERP with feature-based modelling technology: The associative manufacturing feature has been introduced in the present research. In the future the manufacturing system in ERP will be integrated with shop floor material management system based on associative manufacturing feature-based modelling approach.

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Appendix

Excerpt from the C#.Net Codes for IoT-based Technology Design Algorithm:

```
using System;
using System.Linq;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Text;
using System.Windows.Forms;
using System.Data.SqlClient;
using System.Data.SqlServerCe;
using System.IO;
using System.Reflection;

namespace SmartDeviceProject1
{
    public partial class Form1 : Form
    {

        bool connected;

        List<SqlCommand> queryQueue;
        //Dictionary<int, string> addedTrans;
        //List<Entry> temp5Entries = new List<Entry>();
```

```
        //string connString = "Server=MA-
GRAD11.modular.ualberta.ca;Database=InventoryTest;User
Id=testinguser;Password=testingpass;";

        string connString = "Server=lbs-rfidsrv;Database=Estimating;User
Id=rfid;Password=Landmark1234;";


        public Form1()

        {

            InitializeComponent();

            //SubmitBtn.Click += new EventHandler(SubmitBtn_Click);

            barcodeText.Focus();

            connected = true;


            queryQueue = new List<SqlCommand>();

            //addedTrans = new Dictionary<int, string>();

            //temp5Entries = new List<Entry>();

            //fromBox.SelectedIndex = 0;

            //toBox.SelectedIndex = 1;

        }


        private void Form1_KeyDown(object sender, KeyEventArgs e)

        {

            if ((e.KeyCode == System.Windows.Forms.Keys.Up))

            {

                // Up

            }
```

```
    if ((e.KeyCode == System.Windows.Forms.Keys.Down))
    {
        // Down
    }
    if ((e.KeyCode == System.Windows.Forms.Keys.Left))
    {
        // Left
    }
    if ((e.KeyCode == System.Windows.Forms.Keys.Right))
    {
        // Right
    }
    if ((e.KeyCode == System.Windows.Forms.Keys.Enter))
    {
        // Enter
    }

}

private void VerifyInputs()
{
    if (LiftQuantityTextBox.Text == string.Empty)
    {
        LiftQuantityTextBox.Text = "0";
    }
```

```
            if (barcodeText.Text == string.Empty)
            {
                //MessageBox.Show("Information Missing");
                throw new Exception("Barcode Information Missing");
            }
        }
        private void SubmitBtn_Click(object sender, EventArgs e)
        {
            try
            {
                this.VerifyInputs();

                using (SqlConnection connection = new SqlConnection(connString))
                {
                    string saveTransfer = "INSERT INTO dbo.barcodedemo
(date,[from],[to],barcode,Action,EmployeeId,LiftQuantity,PcsQuantity,Comment
s) output inserted.Uid VALUES
(CURRENT_TIMESTAMP,@from,@to,@barcode,@Action,@EmployeeId,@Li
ftQuantity,@PcsQuantity,@Comments)";
                    using (SqlCommand querySaveTransfer = new
SqlCommand(saveTransfer))
                    {
                        querySaveTransfer.Connection = connection;
                        querySaveTransfer.Parameters.Add("@from",
SqlDbType.VarChar, 50).Value = fromBox.Text;
                        querySaveTransfer.Parameters.Add("@to", SqlDbType.VarChar,
50).Value = toBox.Text;
                        querySaveTransfer.Parameters.Add("@barcode",
SqlDbType.VarChar, 100).Value = barcodeText.Text;
```

```
                    querySaveTransfer.Parameters.Add("@Action",
SqlDbType.VarChar, 50).Value = ActionBox.Text;
                    querySaveTransfer.Parameters.Add("@EmployeeId",
SqlDbType.VarChar, 50).Value = EmployeeBox.Text;
                    querySaveTransfer.Parameters.Add("@LiftQuantity",
SqlDbType.Int, 32).Value = Int32.Parse(LiftQuantityTextBox.Text);
                    querySaveTransfer.Parameters.Add("@PcsQuantity",
SqlDbType.Int, 32).Value = Int32.Parse(PcsQuantitytextBox.Text);
                    querySaveTransfer.Parameters.Add("@Comments",
SqlDbType.VarChar, 1000).Value = commentBox.Text;


                    if (connected)
                    {
                        try
                        {
                            connection.Open();


                            int uid = (int)querySaveTransfer.ExecuteScalar();
                            MessageBox.Show("Transaction Successes");
                            LiftQuantityTextBox.Text = "1";
                            PcsQuantitytextBox.Text = "0";
                            ActionBox.Text = "Transferred";


                            //addedTrans.Add(uid, uid + ",");


                            //var entry = new Entry();
                            //entry.UID = uid;
                            //entry.From = fromBox.Text;
```

```
                //entry.To = toBox.Text;
                //entry.Action = ActionBox.Text;
                //entry.Barcode = barcodeText.Text;
                //entry.Employeee = EmployeeBox.Text;
                //entry.LiftQuantity = int.Parse(LiftQuantityTextBox.Text);
                //entry.PcsQuantity = PcsQuantitytextBox.Text;

                //temp5Entries.Add(entry);
            }
            catch
            {
                queryQueue.Add(querySaveTransfer);
                MessageBox.Show("Failed to update database. Transaction
stored.");
                LiftQuantityTextBox.Text = "1";
                PcsQuantitytextBox.Text = "0";
                ActionBox.Text = "Transferred";

                connected = false;
            }
        }
        else
        {
            queryQueue.Add(querySaveTransfer);
            MessageBox.Show("Failed to update database. Transaction
stored.");
            LiftQuantityTextBox.Text = "1";
```

```
                PcsQuantitytextBox.Text = "0";
                ActionBox.Text = "Transferred";
            }
        }
    }

    barcodeText.Text = "";
    barcodeText.Focus();
}
catch
{
    MessageBox.Show(" Barcode Information Missing");
}
    //comboBoxUid.Items.Clear();

    //while (addedTrans.Count > 5)
    //{
    //    addedTrans.Remove(0);
    //}

    //foreach (int item in addedTrans.Keys)
    //{
    //    comboBoxUid.Items.Add(item);
    //}

    //while (temp5Entries.Count > 5)
```

```
        //{
        //    temp5Entries.RemoveAt(0);
        //}

        //foreach (var item in temp5Entries)
        //{
        //    int it = (int)comboBoxUid.SelectedItem;
        //    if (item.UID.Equals(it))
        //    {
        //        fromBox.Text = item.From;
        //        toBox.Text = item.To;
        //        ActionBox.Text = item.Action;
        //        barcodeText.Text = item.Barcode;
        //        EmployeeBox.Text = item.Employeee;
        //        LiftQuantityTextBox.Text = item.LiftQuantity.ToString();
        //        PcsQuantitytextBox.Text = item.PcsQuantity.ToString();
        //    }

}

private void DeleteBtn_Click(object sender, EventArgs e)
{

}
```

```
private void Form1_Load(object sender, EventArgs e)
{
    //Define DB & Develop connection

    //string connString = "Server=192.168.0.37;Database=InventoryTest;User
Id=testinguser;Password=testingpass;";
    SqlConnection conn = new SqlConnection(connString);
    DataTable dbdataset = new DataTable();

    //generate Filter Panel
    //Define Database table EmployeeList
    try
    {
        conn.Open();
        SqlCommand command = conn.CreateCommand();
        command.CommandText = "SELECT FirstName+LastName FROM
dbo.EmployeeList";
        SqlDataReader reader = command.ExecuteReader();
        while (reader.Read())
        {
            if (reader[0].ToString() != "")
            {
                string item = reader[0].ToString();
                EmployeeBox.Items.Add(item);
            }
            else MessageBox.Show("Incomplete Info from Database");
        }
```

```
reader.Close();

//Define Database table BarcodePartList
command.CommandText = "SELECT PartNum FROM
dbo.BarcodePartList";
reader = command.ExecuteReader();
while (reader.Read())
{
   if (reader[0].ToString() != "")
   {
      string item = reader[0].ToString();
      PartNumBox.Items.Add(item);

   }
   else MessageBox.Show("Incomplete Info from Database");

}
reader.Close();

//Define Database table ActionList
command.CommandText = "SELECT Action FROM dbo.ActionList";
reader = command.ExecuteReader();
while (reader.Read())
{
   if (reader[0].ToString() != "")
   {
      string item = reader[0].ToString();
```

```
            ActionBox.Items.Add(item);

        }
        else MessageBox.Show("1");

    }
    reader.Close();
    ActionBox.SelectedIndex = 0;

    //Define Database table LocationList
    command.CommandText = "SELECT Location FROM
dbo.LocationList";
    reader = command.ExecuteReader();
    while (reader.Read())
    {
        if (reader[0].ToString() != "")
        {
            string item = reader[0].ToString();
            fromBox.Items.Add(item);

        }
        else MessageBox.Show("1");
    }
    reader.Close();
```

```
            //Define Database table LocationList
            command.CommandText = "SELECT Location FROM
dbo.LocationList";
            reader = command.ExecuteReader();
            while (reader.Read())
            {
                if (reader[0].ToString() != "")
                {
                    string item = reader[0].ToString();
                    toBox.Items.Add(item);
                }
                else MessageBox.Show("1");
            }

            reader.Close();
        }
        catch (SqlException ex)
        {
            EmployeeBox.Items.Add("Beto Portilla");
            EmployeeBox.Items.Add("Everardo Perez Alvarado");
            EmployeeBox.Items.Add("Mohamed Jama");
            EmployeeBox.Items.Add("enrique ramirez");
            toBox.Items.Add("Shop B");
            toBox.Items.Add("Shop A");
            toBox.Items.Add("Yard");
            toBox.Items.Add("Supplier");
            fromBox.Items.Add("Shop A");
```

```
            fromBox.Items.Add("Shop B");
            fromBox.Items.Add("Supplier");
            fromBox.Items.Add("Yard");
            ActionBox.Items.Add("Received");
            ActionBox.Items.Add("Used");
            ActionBox.Items.Add("Transferred");

            connected = false;

            MessageBox.Show(ex.Message);
        }
        ActionBox.SelectedIndex = 2;

    }
    private void Form1_KeyDown_1(object sender, KeyEventArgs e)
    {
        if ((e.KeyCode == System.Windows.Forms.Keys.Up))
        {
            // Up
        }
        if ((e.KeyCode == System.Windows.Forms.Keys.Down))
        {
            // Down
        }
        if ((e.KeyCode == System.Windows.Forms.Keys.Left))
        {
```

```
            // Left
        }
        if ((e.KeyCode == System.Windows.Forms.Keys.Right))
        {
            // Right
        }
        if ((e.KeyCode == System.Windows.Forms.Keys.Enter))
        {
            // Enter
        }
    }
    private void barcodeText_LostFocus(object sender, EventArgs e)
    {
        string barcode = this.barcodeText.Text;
        try
        {
            if (connected)
            {
                SqlConnection conn = new SqlConnection(connString);
                conn.Open();
                string query = "select PartNum from dbo.BarcodePartList where
barcode = @barcode";
                SqlCommand cmd = new SqlCommand(query, conn);
                cmd.Parameters.AddWithValue("@barcode", barcode);
                string partNum = (string)cmd.ExecuteScalar();
                if (string.IsNullOrEmpty(partNum))
                {
```

```
                labelError.Text = "Code Does Not Exist";
            }
            else
            {
                labelError.Text = string.Empty;
            }
            PartNumBox.Text = partNum;
            conn.Close();
        }
    }
    catch
    {
    }
}
private void ButtonforofflineTrans_Click(object sender, EventArgs e)
{
    this.VerifyInputs();
    int count = 0;
    try
    {
        using (SqlConnection conn = new SqlConnection(connString))
        {
            conn.Open();
            List<SqlCommand> updatedTrans = new List<SqlCommand>();
            foreach (SqlCommand cmd in queryQueue)
            {
```

```
                try
                {
                    cmd.Connection = conn;
                    cmd.ExecuteNonQuery();
                    count++;
                    updatedTrans.Add(cmd);
                }
                catch
                {
                }
            }
            foreach (SqlCommand cmd in updatedTrans)
            {
                queryQueue.Remove(cmd);
            }
        }
    }
    catch
    {
    }
    LiftQuantityTextBox.Text = "1";
    PcsQuantitytextBox.Text = "0";
    ActionBox.Text = "Transferred";
    MessageBox.Show(count + " transactions complete.\n" +
queryQueue.Count + " transactions failed.");
}
private void ButtonforTryConnect_Click(object sender, EventArgs e)
```

```
        {
            try
            {
                SqlConnection conn = new SqlConnection(connString);
                conn.Open();
                connected = true;
                MessageBox.Show("Connection Success");
            }
            catch
            {
                connected = false;
                MessageBox.Show("Connection Failed");
            }
        }
    }
}
```