Customized Manufacturing Enterprise Resource Planning System for Offsite Modular Light Gauge Steel Construction

By

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Abstract

The research presented in this thesis describes the implementation of an Enterprise Resource Planning (ERP) system that works in parallel to an offsite modular construction production line. The framework, which integrates lean manufacturing construction and time study, is used to diagnose production bottlenecks and streamline current processes by digitizing records and data. The proposed database has been developed into a cloud-based platform, which allows flexibility, accessibility, low maintenance, and scalability in order to facilitate smooth workflow and automate processes and reports. The research is developed in collaboration with industry partner, Fortis LGS Structures Inc., and is presented as a case study to demonstrate how the proposed software integration can be put into practice to efficiently help diagnose and continuously improve the modular construction manufacturing process.

Preface

This thesis is the original work of Gordon Fan under the supervision of Dr. Mohamed Al-Hussein. The research-related topics, proposed methodology, and paper writing were completed by Gordon Fan with guidance from Dr. Al-Hussein. One conference paper related to this thesis has been published and is listed below.

List of Proceedings:

1. Zhang, Y., **Fan, G.,** Lei, Z., Han, S., Raimondi, C., Al-Hussein, M., and Bouferguene, A. (2016). "Lean-based diagnosis and improvement for offsite construction factory manufacturing facilities." Proceedings, *International Symposium on Automation and Robotics in Construction (ISARC)*, Auburn, AL, USA, Jul. 18-21, pp. 1090-1098.

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I would like to take this opportunity to express my sincere appreciation to many wonderful people who have supported me during my studies. Along, the journey, I have learned valuable lessons, and inspired by family, friends, and co-workers.

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Secondly, I would like to express my thanks to Claudio Raimondi, General Manager at Fortis LGS Structures and Zole Raimondi, VP Finance at Fortis LGS Structures Inc. for their mentorship, trust, and support. The hands-on experience and opportunities given to me to be part of the business team is critical to the foundation of my research work.

Thirdly, I want to express my great appreciation to Claire Black and Jonathan Tomalty for their assistance by proofreading my work; to Zhen Lei, Xinming Li, Wang Meng, and Hexu Liu for their help and moral support. It has been a great adventure to work with you and produce interesting results.

Finally, my deepest gratitude is given to my family, who has been a great support behind me over countless years. They have always encouraged me during my studies and provided valuable guidance.

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List of Abbreviations

AEC	Architect, Engineer, and Construction
API	Application Programming Interface
AVB	Air Vapor Barrier
BIM	Building Information Modelling
BOM	Bill of Material
CAD	Computer-aided Design
CEIS	Construction Enterprise Information System
DCC	Digital Curation Center
ERP	Enterprise Resource Planning
HR	Human Resources
IIC	Industrial Internet Consortium
IIoT	Industrial Internet of Things
IoT	Internet of Things
IT	Information Technology
JIT	Just-in-time
LTE	Long-term Evolution (4G)
MIS	Management Information System
NSF	National Science Foundation
OSHA	Occupational Safety and Health Administration
PDF	Portable Document Format
PO	Purchase Order
PTS	Production Tracking System

QC	Quality Control
RFID	Radio-frequency Identification
TPM	Total Preventive Management
TPS	Toyota Production System
TQM	Total Quality Management
USGS	United States Geological Survey

Chapter 1: Introduction

1.1 Research Motivation

The Enterprise Resource Planning (ERP) system concept originated in the 1990s as “a way to achieve an end-to-end connectivity bringing various diverse functions and divisions together resulting in a single uniform coordinated information system in order to be able to coordinated and monitor their performance in real time.” (Rajagopal, 2002). Given that powerful computers are becoming more viable options for businesses and software applications are becoming more complex, organizations must develop more competitive business practices. The purpose of applications such as ERP or the Management Information System (MIS) is to help businesses track information, materials, assets, and details in a digital format. In addition to reducing time and increasing productivity, and providing forecasting ability and a centralized database, the end result of implementing such systems is to provide high quality and innovative products to the customer.

Many vendors offer variations of the ERP system as a commercial product. The MIS system was originally used to manage information, while ERP has been used for planning in the early stages of a project. Currently, the differences between these systems have become indistinguishable, resulting in two interchangeable terms. The primary purpose of ERP is to ensure the appropriate type and number of resources, whether material or personnel, is allocated. It also stores records of transactions that occur throughout the manufacturing process and directs information through the necessary channels. The most efficient method for resource planning is to ensure that the resource arrives just prior to the processing of the task for which the resource is required, also known as Just-in-Time (JIT) (Shah & Ward, 2003).

The use of the ERP system in a manufacturing setting is ideal as it allows for proper budgeting and planning of materials and personnel. The manufacturing setting for construction seeks to leverage the benefits of mass production and lean production concepts in an attempt to achieve manufacturing-level production time and quality. This leads to reduced waste since the ERP system dictates material needs based on calculations that are carried out using the inputted information, which contributes to a lean manufacturing process where the product conversion process involves minimal waste and elimination of any non-value added activities. Applying the concepts from lean manufacturing companies—such as Toyota, the Japanese automobile manufacturing company—to construction can be a challenging process. Current construction processes in North America are largely carried out onsite and in an outdoor environment. The lean construction concept, however, moves the construction process indoors, adopting a manufacturing process, thereby mass producing modular units, which are then transported to and pieced together on the construction site. Construction is an established industry that is historically slow to adapt to change. Current construction projects continually confront delays as a result of insufficient or incorrect materials, lack of personnel, or the misunderstanding of necessary information for the completion of a project. The functionality of the manufacturing setting for construction combined with lean manufacturing concepts will be bolstered by the introduction of an ERP system. Current-state knowledge and understanding of the manufacturing process via digital means is beneficial for project managers, plant supervisors, manufacturing personnel, and owners.

Table 1. Benefits of ERP Implementation

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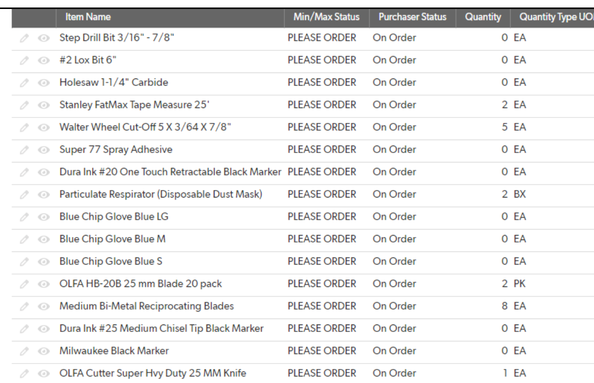
-visual system, not live</td><td>
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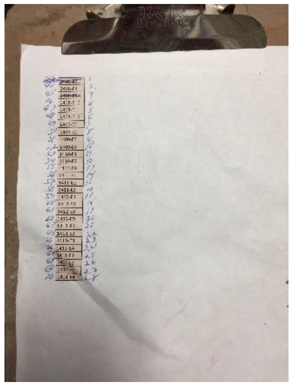
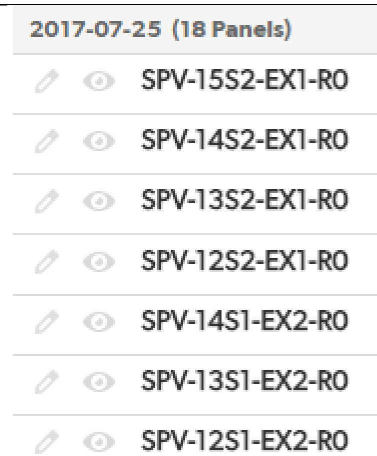
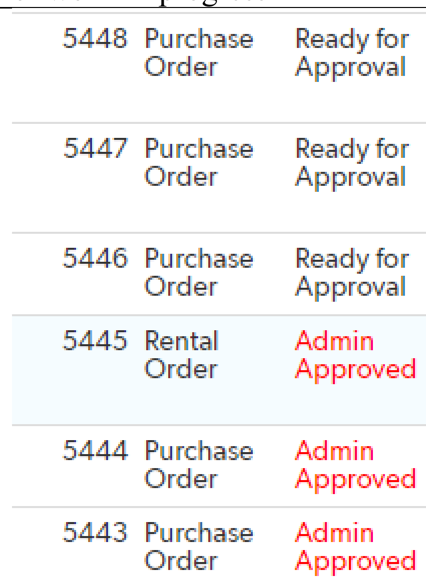
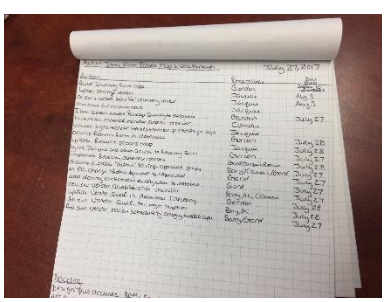
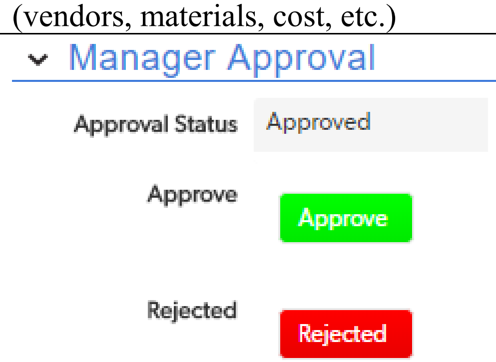
Production Tracking	 -paper quota	 -live real-time production count and location of work-in-progress
Purchasing	 -paper copies of PO, packing slips, and invoices -stacks of paper to be filed daily	 -digital record of all transactions -able to filter based on specific attributes (vendors, materials, cost, etc.)
Human Resources	 -paper requests -no records of employees	 -directory of active and inactive employees -direct control of request approval process and delivery to correct manager

1.2 Research Objectives

The research presented in this thesis focuses on the development of an ERP system for offsite light gauge steel construction. The goal of this study is to deploy this highly customized system to prepare the appropriate amount of material for production and track the various materials as they progress from individual parts, to a work-in-progress, and finally to a finished project. In current practice, inventory is monitored by daily visual inspections and orders are placed as needed, resulting in little cost control and frequent production line halting due to material shortages, thereby causing additional rushed orders by the procurement department. Ultimately, as a result of this practice projects are often constructed at a much slower pace due to low output by the production plant, and the onsite construction team is continually sent home due to lack of work. Therefore, from the manufacturing perspective, the goal of this research is that all planned materials are ordered beforehand and the amount of rushed order are decreased significantly.

The proposed ERP system is based on the following hypothesis:

"developing an automated, internally-integrated ERP system will reduce waste and operating costs for a residential manufacturing production line, thereby promoting the value of investing in technology."

In order to verify the hypothesis, this research encompasses the following objectives:

- Identify the information gap for production management.
- Integrate technological automation to reduce and remove non-value added activities.
- Develop a paperless strategy to reduce resource usage.

- Develop an Enterprise Resource Planning (ERP) system able to handle the following aspects of a project:
    1. Production Planning
    2. Purchasing
    3. Inventory Control
    4. Quality Control
    5. Production Tracking

1.3 Thesis Organization

This thesis is organized into four chapters. Chapter 1 (Introduction) is an overview of the ERP system and outlines the hypothesis and research objectives of this study.

Chapter 2 (Literature Review) is an extensive study on current practice and available research on ERP systems for the manufacturing industry. Previous work on lean construction is also explored. Other areas of exploration include big data, the recent interest in Industry 4.0, and the Internet of Things (IoT).

Chapter 3 (Proposed Methodology) presents the prototype ERP system in a conceptual framework. This chapter includes a description of various functions of the system, various technological decisions, and various entity relationship diagrams.

Chapter 4 (Case Study) presents a case study with the industrial partner involving implementation, beta testing with feedback, and the results of the proposed methodology within the industry partner's panelized fabrication plant.

Chapter 5 (Conclusion) concludes the discussion of the ERP system and summarizes the current state of development. It highlights the critical academic and practical contributions of this research. Limitations of the system and future improvements are also discussed.

Chapter 2: Literature Review

2.1 Introduction

The purpose of this literature review is to identify the current state of knowledge and previous research that provides the basis for this thesis. First, the concept of lean production or lean manufacturing will be explored. Lean initiatives within the construction industry will also be reviewed. Second, the current state of the ERP system in a manufacturing setting will be reviewed as well as its effects on the construction industry. Additionally, Industry 4.0 and two of it subtopics, Big Data and IoT, will be presented. Finally, BIM will be explored to gain an understanding of its benefits and how it can improve the construction industry.

2.2 Lean Production

Lean philosophy is primarily rooted in the Toyota Production System (TPS) developed in Japan by industrial engineers, Taiichi Ohno and Shigeo Shingo. The initial principles developed for the Toyota Automotive Company for the mass production of automobiles involves both manufacturing and logistics and includes suppliers and customers; these principles laid the foundation for the "Toyota Way" and are an integral part of the lean production system (Glass, Seifermann, & Metternich, 2016). Lean production can be "bundled into four inter-related and internally consistent practices: just-in-time (JIT), total quality management (TQM), total preventive maintenance (TPM) and human resource management (HRM)” (Shah & Ward, 2003). The concept of lean includes the following five principles: identify products (value specification); identify processes (value stream); review factory layout (flow); select appropriate pull strategy (pull); and continuous improvement (perfection) (Jones & Womack, 1996).

The practices most commonly associated with lean production include: bottleneck removal (production smoothing), cellular manufacturing, competitive benchmarking, continuous improvement programs, cross-functional work force, cycle time reduction, focused factory production, just-in-time/continuous flow production, lot-size reductions, maintenance optimization, new process equipment/technologies, planning and scheduling strategies, preventative maintenance, process capability measurement, pull system/Kanban, quality management programs, quick changeover techniques, reengineered production process, safety improvement programs, self-directed work teams, and total quality management (Mrugalska & Wyrwicka, 2017). Pedram (2011) reveals several lean implementation benefits:

- Multifunctional teams, including operators who are flexible, multi-skilled, and possess a high level of responsibility for work within their areas.
- Active shop floor problem-solving structures, central to kaizen or continuous improvement activities.
- Lean manufacturing operations, where problems are identified and corrected by maintaining low inventories, quality control management, prevention rather than detection and correction, a small number of direct onsite workers, and small-batch, just-in-time production.

- High commitment of human resource policies emphasizing a shared destiny within the organization, meaning involvement of all employees as well as management is necessary for effective implementation of production.
- Closer relationships with suppliers.
- Cross-functional development teams.
- Retailing and distribution channels that facilitate improved customer interaction.

The key principle of lean production is to reduce waste without sacrificing production efficiency. The aim is to minimize the amount of necessary resources thereby minimizing the cost while maintaining appropriate quality and high response speed. Any item or activity that does not add value to the production process must be eliminated, such as inappropriate process, unnecessary transportation of materials, unnecessary movement of workers, and any types of stock that would result in the unnecessary increase of costs (Arunagiri & Gnanavelbabu, 2014). Other factors, from the point of view of both the customers and suppliers, include delays in service waiting time, deliveries, queues, technical responses, and products not fulfilling customer or supplier expectations.

One area that directly affects manufacturing is inventory control. Hofer et al. (2012) prove that lean production implementation not only carries direct financial benefits, but also results in greater inventory leanness which, in turn, contributes to improved financial performance.

The objectives of lean initiatives within the construction industry involve the use of less space for operations and storage, which, in combination with less error-prone production, decreases the use of energy and resources, thereby promoting substantial environmental advantages (Saieg, Sotelino, Nascimento, & Caiado, 2018). According to Sacks et al. (2010), within the AEC industry, two fundamental changes are being implemented: (1) the application of lean production principles for construction projects and management; and (2) the transformation of information technology such as Building Information Modelling (BIM). Considering the definition of waste in lean production, lean construction is increasingly concerned with environmental sustainability and environmental waste (Gonzalez, 2016). This includes the unnecessary use of resources or substances that are released into the air, water, or land that could affect human health or the environment. Information inefficiency is another type of waste within the construction industry. Since project locations vary, most construction projects utilize manual processes and traditional methods of communication such as phone calls, faxes, and emails; although communication issues have been studied extensively, a long-term solution has yet to be discovered (Zhai, Goodrum, Caldas, & Haas, 2009). The problem with computer systems is the need to develop connections among each point of contact and, in most cases, they do not extend to site-based processes (Tatari, Castro-Lacouture, & Skibniewski, 2007). A project comprises several interdependent tasks, and focusing on optimizing each task independently leads to sub-optimization of the overall project, thus specific tasks should not be considered as isolated, independent activities, but as interconnected parts of a whole project, such as improving planning reliability along an entire production chain (Froese, 2010).

2.3 Enterprise Resource Planning (ERP) System

ERP systems are defined as "comprehensive, packaged software solutions that seek to integrate the complete range of a business's processes and functions in order to present a holistic view of the business from a single information and IT architecture" (Klaus, Rosemann, & Gable, 2000).

From the business perspective, ERP can be viewed as a business approach, integrating strategic and operational functions, such as procurement, production control, human resources, and financial accounting, through the entire organization, and can also be regarded as a driving technology in the reengineering of the business process. ERP benefits are summarized in Table 2 below.

Table 2. ERP Benefits

Operational	Managerial	Strategic	Organizational	IT
Process standardization	Greater information availability	Supports new partnership opportunities and supplier management	Improves overall financial performance	Supports global IT systems
Improves inventory management	Higher quality information	Supports core business strategy	More flexible organization	
Facilitates customer customization and services	Improves planning and control	Increases transparency of marketplace and global negotiation power	Facilitates changes	
Improves efficiency	Eliminates limitations			

A value provided by the ERP system that is more difficult to measure in terms of financial means is the value of a seamless, efficient, and reliable process (Nofal & Yusof, 2013). ERP users are more successful in communicating the progress of a project and maintaining agreement with customers with respect to delivery in a timely manner. For the IT department, ERP integrates information into a single database and eliminates redundant or duplicate data extraction processes, allowing for simplified data delivery (DecisionPath Consulting, Williams, & Williams, 2003). E-commerce's operational foundation can currently be deployed with ERP since it enables business owners to manage operations with high levels of customer service and productivity and simultaneously lower costs and inventories by providing high degrees of cross-functional integration among sales, marketing, manufacturing, operations, logistics, purchasing, finance, new product development, and human resources (Chofreh, et al., 2016). Advancement in IT infrastructure is fundamental to any ERP system implementation in any manufacturing operation. Working under the assumption that these organizations operate multiple facilities, enabling technologies such as Workgroup, Electronic Data Interchange (EDI), Internet, Intranet, and data warehousing, among others, is necessary to facilitate data transfer transactions (Madanhire & Mbohwa, 2016). Similar to the various departments within an organization, within the ERP software, multiple software modules separate the various functions and data, but still allow the crossover of data based on the economic and technical feasibility. The basic modules which are normally incorporated in the ERP system include (Zhang, Lee, Huang, Zhang, & Huang, 2005):

- production planning module;
- purchasing module;
- inventory control module;

- sales module;
- marketing module;
- financial module; and
- human resources (HR) module.

Proper training and guidance as well as support from management are necessary to ensure proper usage and adoption of the new technology as employees may be hesitant toward such changes (Umble, Haft, & Umble, 2003). Support and training in turn promotes proper business operations by rejuvenating the competitiveness of the business as a whole due to the reengineering process that is in line with the adopted ERP model (Ross, 1998).

The team of employees at the construction site requires accurate resource information regarding construction tasks in order to effectively conduct forecasting and weekly planning activities. In this dynamic and fragmented environment, the exchange of information and integration between various organizational information systems and sources is crucial for efficient production management (Caldas, Soibelman, & Gasser, 2005). Due to the nature of the construction industry, work is divided among projects and information that is crucial to two or more projects may not be readily available, resulting in major hurdles to reaching information efficiency (Perumal, Ramli, Leong, Samsudin, & Mansor, 2010). ERP systems have recently been implemented for the sole purpose of addressing disintegration issues by creating one-to-one connections between information systems (Rezgui, et al., 1996).

The key purpose of implementing ERP systems into the construction industry is to reduce duplication of work and increase efficiency in general (Bergstrom & Stehn, 2005). The goal is to integrate several internal and external functions, such as procurement, accounting, human resources, asset management, etc., into some form of Construction Enterprise Information System (CEIS) (Desouza, 2007). The major limitation of ERP system implementation is the lack of full integration across the whole supply chain. Only 1.3% of organizations have carried out complete integration both externally and internally, while 12.7% have achieved full internal integration (Tatari, Castro-Lacouture, & Skibniewski, 2007). Of 101 construction enterprises studied, only 16% were fully satisfied with their current level of integration and progress.

One of the most important types of information in terms of production planning and scheduling is resource flows or constraints, such as information regarding the status of any constraints throughout the lifetime of a given task, from the planning of the task, to the removal of the constraints, to the execution process (Koskela, 1999). The flow of information related to these activities is largely dependent upon the type of project and the supply chain configuration, as well as the type of information systems implemented in each organization.

The issue of system fragmentation in the construction industry is primarily due to the absence of established relationships involving a significant amount of time and resources, which in turn affects the decision-making process (Jardim-Goncalves, Grilo, Agostinho, Lampathaki, & Charalabidis, 2013). The necessary condition for maintaining the continuous alignment of processes and information is rarely met primarily due to the fact that large construction enterprises dominate the industry and hire subcontractors and specialist firms to managed the delivery of construction projects (Teicholz, 1999).

2.4 Data Management

Big data is becoming increasingly relevant to organizations, regardless of how technologically advanced a particular industry may be. Data is used by advertising agencies to track consumer preferences and then target specific demographics through advertising campaigns. The lifecycle of data has been extremely important in terms of enhancing current operational practices and transforming future system management. The United States Geological Survey (USGS) developed a data lifecycle model "to facilitate shared recognition and understating of the necessary steps to document, protect, and make available the Bureau's valued data assets (Plale & Kouper, 2017)." The primary elements of the data lifecycle model include: plan, acquire, process, analyze, preserve, and publish/share. The *plan* stage involves deciding how and what data needs to be collected and analyzed. The *acquire* stage is the data collection stage whether generated, collected, or retrieved. The *process* stage involves the transformation of data into a certain format and preparing it for the next step. The *analyze* stage includes the interpretation and exploration of the data to generate meaning and results for usage in publications or reports. In the *preserve* stage, data is prepared for long-term storage in consideration of future usability. Data must be presented in a way that allows anyone in the future to be able to use it and understand the purpose of its collection. This is closely related to the final step, *publish/share*, in which the results of the analysis of the data are disseminated to other outputs such as papers or presentations. In addition to these seven elements, there are also critical data activities such as documentation of data, quality control of data, and backup/security of data. Data combined with metadata or documentation about the data provides context and value. Quality control of data can ensure the data is accurate and precise, while backup/security of data takes preventative steps against data corruption or loss. DataONE data lifecycle model, developed within the National Science Foundation (NSF), is extremely similar to the Data LifeCycle Model developed by USGS (Michener, et al., 2011). DataONE includes eight generic components to manage and preserve data for use and reuse. Another model created by the Digital Curation Centre (DCC), which provides details and support for managing the data once it has been collected and analyzed. The DCC emphasizes the creation and registration of appropriate metadata, ensuring data authenticity and integrity, and adhering to relevant community standards and tools.

IBM data scientists categorize big data into four dimensions of challenges: volume, variety, velocity, and veracity (Yin & Kaynak, 2015). One of the least difficult problems to identify is the sheer volume of data that is currently being collected and processed daily. Approximately 1,000 Exabytes[1] (10^{18} bytes) of data is generated globally each year by devices and solutions in the current digital age (General Electric Intelligent Platforms, 2012). The amount of generated data will continue to grow exponentially, hence finding cost-effective storage methods is imminent.

[1] 1 byte = A single character; 5 Exabytes = All words ever spoken by human beings

Another identifiable data problem is that the type and amount of data gathered are continually changing. Some types of data include simple raw text, while others are complex video or audio files. Traditional structured data information such as date, time, or dollar amount can easily be categorized and stored, but there are no set rules for unstructured data thus it must be managed differently or converted to establish a coherent structure.

Veracity is the integrity and quality of data. Raw data may be missing values, have redundancy issues, or contain extra information. As a result, it is necessary to develop processes for data cleaning and enhancement.

The final challenge is the velocity of data. The flow of data can vary depending on certain factors such as time of day or the number of updates by pertaining to certain events. When the flow of data accelerates, systems may have difficulty keeping up, while a decreased flow of data can render systems too costly to operate.

Although these four challenges are confronted by every major database, ultimately, the data must hold some value for the end user. Certain values of big data that can be conveyed to the end user include product and market development, operational efficiency, market demand predictions, decision making, and customer loyalty (Information Systems Audit and Control Association (ISACA), 2013).

2.5 Industry 4.0

The term Industry 4.0 represents the fourth industrial revolution, which defines a new level of organization and control over the entire value chain of the life cycle of products by developing a manufacturing process that is more sustainable, complex, and automated, thereby allowing the machine operators to work more effectively (Gerbert, et al., 2015). This manufacturing revolution supersedes water and steam powered machines with mass production using electrical energy and the use of programmable logic controllers and IT systems for automated production. The objective of Industry 4.0 spans areas including sales management; research and development; and the delivery, utilization, and recycling of products. Industry 4.0 connects physical items such as sensors and electrical devices to one another and to the Internet (Sipsas et al., 2015). The term "Industry 4.0" originates from the German government as an initiative to increase collaboration among businesses, politics, and academia to further propel the German manufacturing industry (Bahrin, Othman, Azli, & Talib, 2016), the end goal being to transition to common, integrated, and interdisciplinary methods, processes, and IT solutions by designing and drafting methods in all disciplines and reviewing their suitability for a modern, interdisciplinary approach for production development. As such, Industry 4.0 relies on real-time data monitoring for tracking the status and position of products as well as delaying the instructions to control production processes by relying on the conversion to machine learning in order to improve the overall performance and maintenance management in a manufacturing facility (Almada-Lobo, 2015). The four key drivers of Industry 4.0 that help transform it into a fully digitized and intelligent manufacturing process are the Internet of Things (IoT), Industrial Internet of Things (IIoT), Cloud-based manufacturing, and smart manufacturing (Erol et al., 2016). The aim is to improve traditional production relationships between suppliers, producers, and customers, including between humans and machines, by transforming isolated and individual cell production into a fully integrated, automated, and optimized production flow.

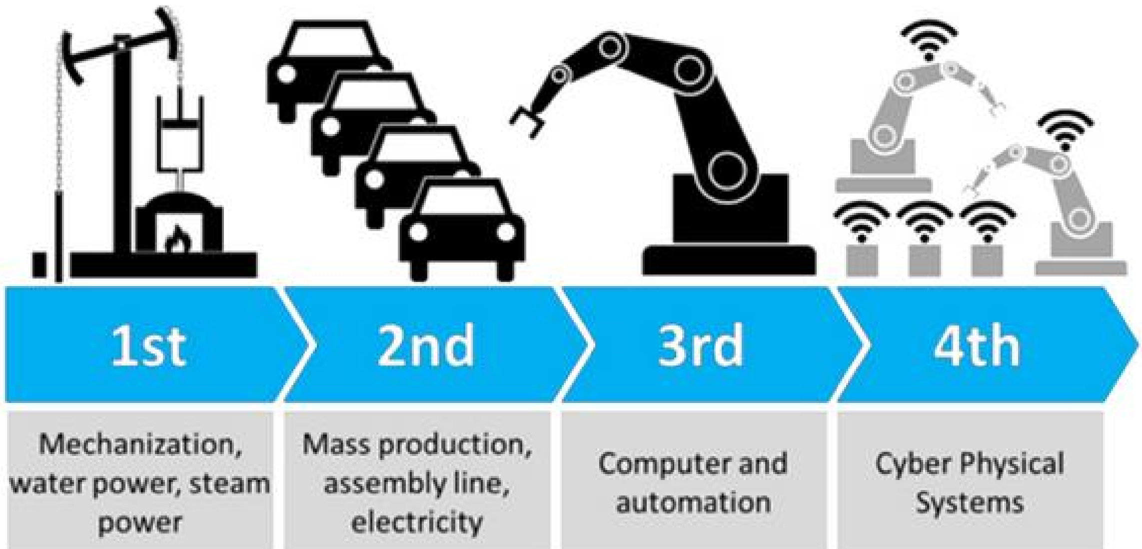


Figure 1: *Four Stages of the Industrial Revolution*

The cloud-based IT platform serves as a backbone for connections and communications within the Industry 4.0 concept due to its ease of data sharing across multiple sites and companies (Landherr, Schneider, & Bauernhansl, 2016). Such advancement paired with others, including 5G cellular data, data analytics, and robotics, are transforming products, processes, and business models in all sectors ultimately creating new industrial patterns and global value chains (European Commision, 2016). The implementation of new technology that is more responsive and adaptive to current dynamic market trends has its challenges such as maintaining the high quality and integrity of data as discussed in Section 2.4. One of the greatest challenges is Cybersecurity due to the increase in connectivity and use of standard communication protocols, but this issue has yet to be recognized as a legitimate threat due to its high cost and complexity. Another major challenge in implementing new technology is acquiring the necessary bandwidth for wireless communication and the transfer of a significant volume of data. A wired network is far superior in terms of connectivity and speed, but impractical as more IoT-compatible devices are installed (Wang, Wan, Li, & Zhang, 2016).

2.6 The Internet of Things (IoT)

IoT plays an astonishing role in various aspects of daily life, including healthcare, sports, entertainment, and manufacturing. It connects people with each other and their surroundings, and enriches their lives. IoT refers to the network of physical objects embedded within electronics, software, sensors, and connected to the Internet (Van Till, 2018). It is essentially an extension of the internet that aims to capture the physical world of things. In simple terms, IoT devices connect the physical world to the digital world. It facilitates the development of large-scale societal projects, such as smart homes, smart cars, and smart cities, by collecting sizeable volumes of data and exercising control over the world remotely. A subset of IoT is the Industrial Internet of Things (IIoT), which has its own association, consulting practices, software platforms, architectures, and practice standards. It is the non-consumer version of IoT. The Industrial Internet Consortium (IIC) describes IIoT as a convergence that will "transform industry through intelligent, interconnected objects that dramatically improve performance, lower operating costs, and increase reliability." These smart IoT devices can potentially benefit industry in many aspects such as forecasting, remote monitoring, real-time visibility, alerts, notifications, and scheduling adherence.

In construction, several attempts have been made to use IoT to increase safety and reduce accidents. In the United States, according to the Occupation Safety and Health Administration (OSHA), 360 industrial workers were killed from accidents from 2005 to 2010. Also, from 1992 to 2010, 7,681 deaths were a result of collisions with vehicles and mobile heavy equipment on construction sites (Kanan, Elhassan, & Bensalem, 2018). Mayton et al. (2012) presented Tracking Risk with Ubiquitous Smart Sensing (TRUSS), "a system that infers and renders a safer environment on construction sites by fusing data from wearable devices, distributed sensing infrastructure, and video". Wearable sensor badges stream real-time levels of dangerous gases, dust, noise, light quality, altitude, and motion back to a base station where all the data is synchronized in order for safety managers to localize workers and track risks. Another example of IoT application is a study by Teizer et al. (2013) that proposed two kinds of protection units, the Personal Protection Unit and the Equipment Protection Unit. These units create a proximity warning area around either the personnel or the equipment. When the warning areas overlap, the associated protection triggers visual and audible alarms informing the personnel of the impending collision. IoT also poses security challenges such as key management issues as well as confidentiality, integrity, privacy, and policy applications (Sicari, Rizzardi, Grieco, Piro, & Coen-Porisini, 2017). These challenges take on a new level of complexity which is difficult to overcome by means of traidtional solutions since the sheer number of IoT-enabled devices will continue to increase exponentially. Despite several issues still to be addresed, such as scalability and dynamism issues, IoT has become the *Internet of Everything* where humans, data, processes, and objects are evolving together in a highly dynamic and complex system.

2.7 Building Information Modelling (BIM)

Building Information Modelling (BIM) has been readily adopted into the construction industry to overcome various challenges such as building design, design checking or evaluation, quantity take-off, cost estimation, and project scheduling (Kaner, Sacks, Kassian, & Quitt, 2008). BIM is essentially an extension and enhancement of conventional computer-aided design (CAD) software for building designers and is expected to improve productivity of building design through enhanced functionalities in terms of visualization, navigation, and parametric modelling (Oh, Lee, Hong, & Jeong, 2015). BIM supports the effective incorporation of prefabrication and collaboration early in the design and construction process. Certain prefabricated components can be developed into standardized BIM objects that can be stored in a BIM object library and re-used in future designs. In traditional construction practice, most building components are produced from their constituent materials and can only be designed in real time without the possibility of selecting existing components from a repository. Implementation of a BIM system can increase the efficiency of contractors on design and building projects in terms of reducing labour hours, requests for information, and rework, as well as increasing on-time completions and the ability to use more prefabricated elements (Mitchell & Keaveneyy, 2013). In the United Kingdom, BIM has been defined as "a digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it forming a reliable basis for decisions during its life cycle, from earliest conception to demolition" (NBIMS, 2018). BIM is generally being acknowledged as a process, where BIM software system technology is proven to enhance the lifecycle of construction process. As a system or technology, BIM is used to foster collaboration amongst project teams and to share project information. The benefits of BIM, in addition to enhancing collaborative processes, are that it has the potential to increase productivity, efficiency, infrastructural value, quality, and sustainability throughout the construction project. Other benefits include reductions in lifecycle costs, lead times, and duplications; minimization or elimination of waste; and improvement in coordination between design disciplines (Ciribini, Ventura, & Paneroni, 2016). The greatest fundamental strength of the BIM system is that it allows projects to be constructed in a virtual setting before contractors begin the actual construction process. During the design process in current practice, conflicts and inconsistencies can be difficult to identify on paper. By completing the project construction in a virtual environment, quantity and quality issues can be overcome that may be impossible to detect during traditional design methods (Zhang, Zayed, Hijazi, & Alkass, 2016). Informed decisions can be made based on the various iterations generated in the virtual environment.

Material waste in the building industry in unavoidable, partially due to the fact that some building elements are generated from preset material sizes and subtractive manufacturing. However, waste can be minimized by implemented effective material management such as mathematical algorithms for material cutting and information technology such as BIM. BIM can also affect other areas of work such as safety and risk management. Zhang et al. (2013) developed a BIM-based automatic safety check for construction models and schedules in order to prevent fall-related accidents prior to construction. Additionally, financial risks can include budget overrun and delays in the construction schedule. By addressing both safety risks and financial risks using BIM, the possibility of these hazards can be minimized by conducting a thorough review of potential liability during the planning and design phase since traditional risk management is heavily reliant on experience and mathematical analysis (Shim, Lee, Kang, Hwang, & King, 2012). Furthermore, BIM is driving other construction industry initiatives such as lean construction, sustainability, and offsite manufacturing.

2.8 Summary

In summary, lean manufacturing process and principles have been introduced as well as its adaptation into the construction industry. By shifting construction toward a manufacturing approach combined with the ERP system, offsite construction settings have become more common and have been briefly reviewed. Various manufacturing practices have been introduced, along with their benefits and shortcomings. Industry 4.0 is becoming an unspokentrend that has progressed into multiple industries, including both the manufacturing and construction industry. By incorporating IoT devices to assist management in decision-making and data analysis, powerful tools can be developed and implemented in manufacturing facilities. A significant aspect of Industry 4.0 that has been studied in recent years is that of data collection and the challenges in dealing with the volume, variety, velocity, and veracity of data, and ultimately, its value. The recent advancements in technology will inevitably contribute to the current dynamic market trends by becoming more efficient and powerful.

Chapter 3: Methodology

3.1 Introduction

Chapter 3 introduces the ERP system that can effectively assist management staff in obtaining real-time information about current production and inventory. This digital approach can potentially improve lead time for inventory uncertainties while avoiding high inventory holding cost due to overstocked material. Real-time data can help detect and minimize minor problems during production rather than reacting to complications that may arise after project fulfillment.

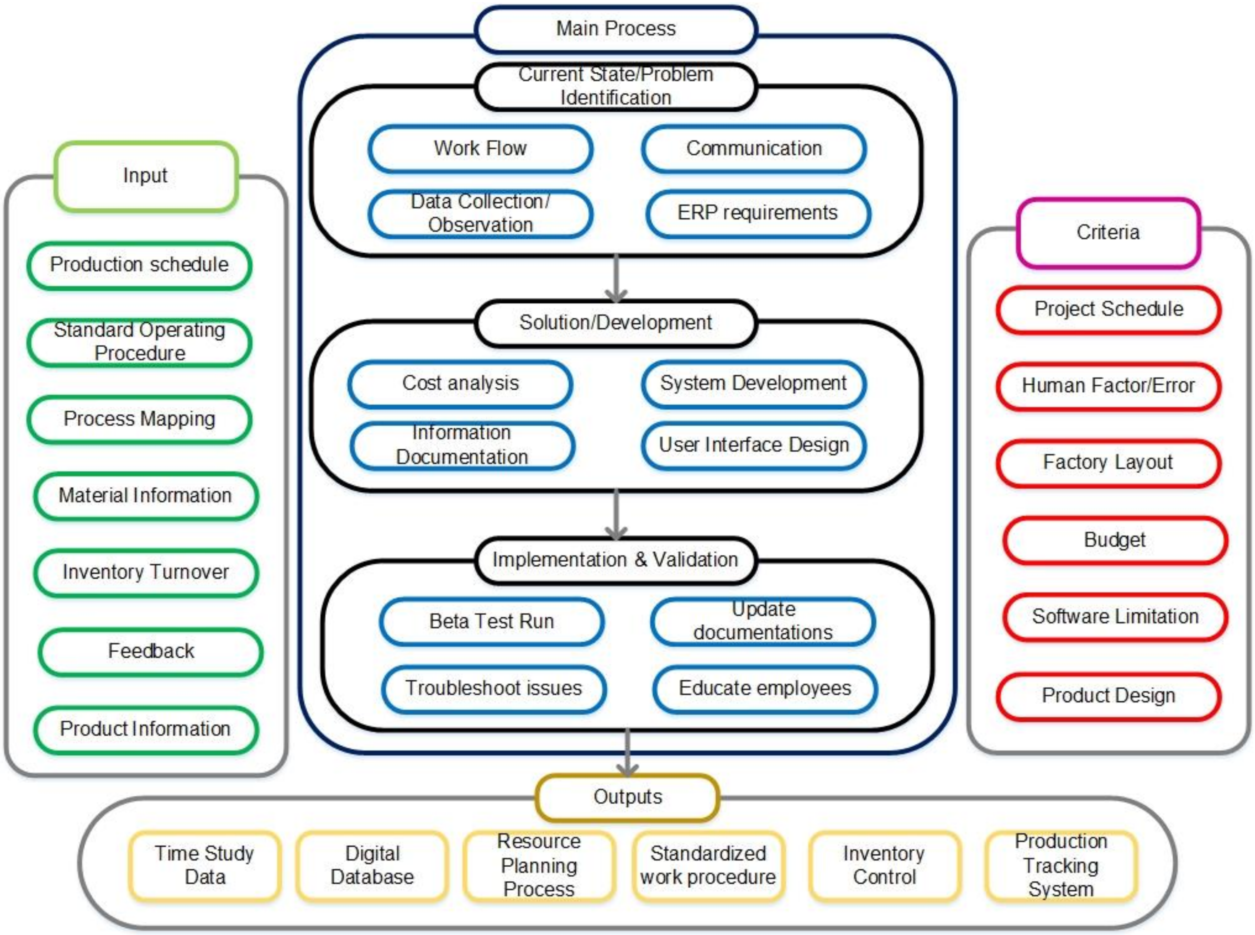


Figure 2: Overview of Proposed ERP Development Process

Figure 2 presents an overview of the proposed real-time ERP system, including time production data collection and a newly developed material control system for a panelized homebuilding facility as well as potential future expansion in onsite construction control. The chart outlines the input parameters, the criteria it is measured against, the overall process for development, and finally, the outputs of the methodology. The inputs are based on current practice and information gathered within the case study partner company such as materials being used, current standard operating procedures, feedback from staff on current issues, and other information from a management point of view. The main process is also constrained by criteria, including restricting factors such as the initial schedule that was agreed upon with the clients, budgets, and limitations on the software design, such as which components can be easily created and implemented, while other features in the software will be discussed in detail in Chapter 4 of this thesis. The methodology is broken down into three steps. The first is to gather information to create a scope of work and to determine the amount of production that will eventually be reliant on the new system. The next step is to design the software to provide a simple user interface to be continuously developed in the background, allowing for the addition of new modules while at the same time in the background, the software is being developed to work seamlessly integrating within itself. At the same time, documentation is being developed or revised to update current work processes for training and proper usage. The final step is the continuous testing and updating of the new system with trial runs, proper expansions, and taking feedback from users to determine what can be improved upon. The output or end goal of the proposed methodology is to produce a digital system able to collect time data and plan inventory in advance while continually monitoring current production. Through continual revisions to documentation, work processes will become more standardized and efficient and inventory will become more controlled, all of which will be managed digitally thereby eliminating the inefficient and error-prone traditional method of using pen and paper.

3.2 Real-time Data Management

The proposed ERP system, as presented in Figure 3 and Figure 4, will be developed for use by the management of the partner company. This thesis primarily focuses on the production (Offsite) section as presented in Figure 4; solid lines signify the transfer of materials while dotted lines represent the transfer of information.

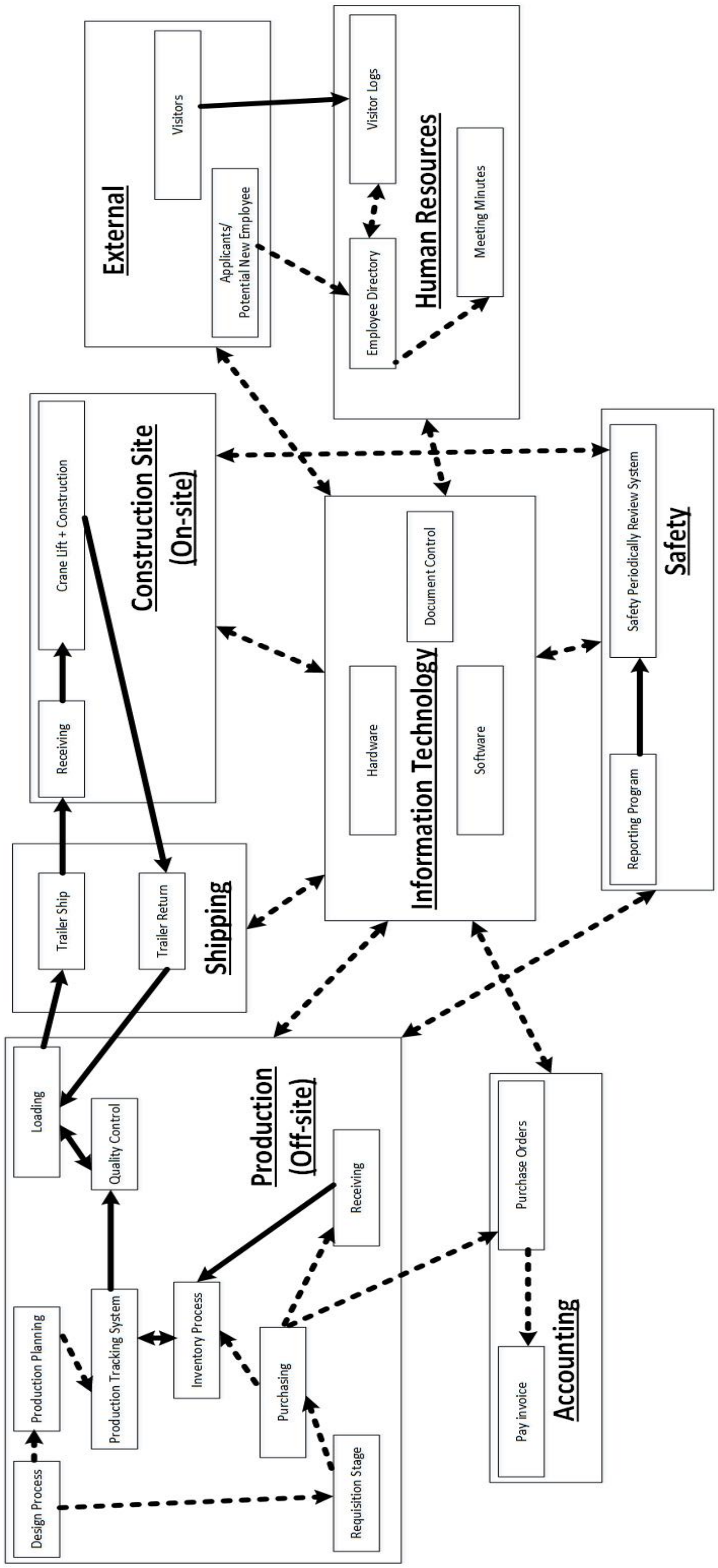


Figure 3: Future ERP System Plan

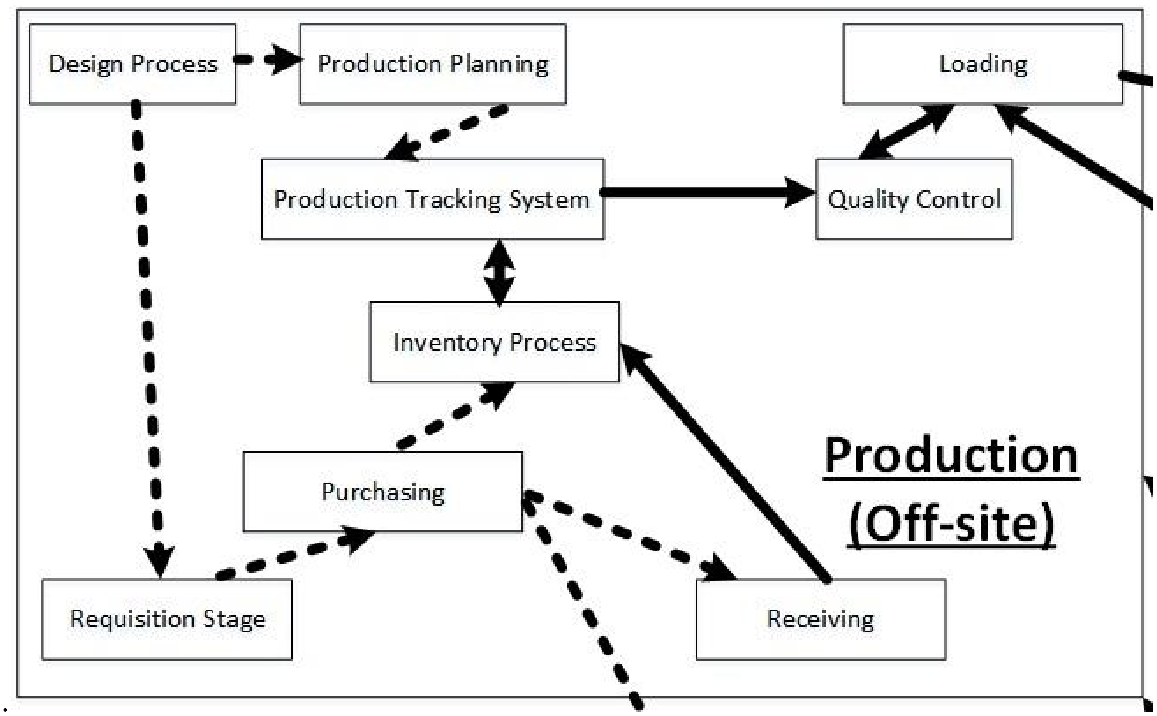


Figure 4: Proposed Production Tracking System with other ERP functions

The developed modules as observed in Figure 4 include the following:

- Purchasing (Procurement)
- Inventory Control
- Production Planning (within the Production Tracking System)
- Production Tracking (within the Production Tracking System)
- Quality Control (within the Production Tracking System)

3.3 Real-time Data Acquisition Technology

Figure 5 provides the technology overview, including iPad tablets, existing wireless network access, and the new ERP system designed using QuickBase, the backbone of the database program.

Figure 5: Overview of Proposed Hardware and Other Technology

The iPad tablet is selected as a data input device given that the case study company (introduced in Chapter 4) was already in possession of several iPads from previous projects. All of these tablets are equipped with cellular coverage, thus even in areas with limited or no Wi-Fi coverage, the tablets remain operational. Other methods such as RFID require continuous connection to a Wi-Fi network, and the drawback to the barcode method includes the cost of continuous printing of barcode labels for all products. The proposed database can be accessed by any device with an internet connection and will be further discussed in Chapter 4. As a result, for the proposed system, any initial cost for this project is minimal in comparison to other technologies.

Specifications of iPad Tablets:

- Wireless capability: 802.11a/b/g/n/ac; dual band (2.4 and 5 GHz), Bluetooth 4.2 and LTE
- 32 GB internal storage capacity
- iOS 11 (regularly updating)
- Safari browser

3.4 Proposed IoT-based ERP Integration System

The following section provides an overview of the basic architecture and elements of IoT integrated into the ERP system. Understanding the structural layers associated with the function presented in *Figure 2* is crucial in developing and implementing the future system and its network connections. Based on the proposed architecture, the proposed cloud-based ERP system can provide seamless assistance between departments for an offsite construction project. It connects the information from external suppliers to multiple departments within the manufacturing facility, beginning with the first stage of project workflow and finishing with onsite construction assembly. This allows for better tracking of product location and collecting of real-time information, which can be used to determine a particular product's availability, lead or lag time, cost, and level of quality through the cloud-based system.

Certain types of information may be relevant to one department yet unimportant to others. In order to ensure the necessary information is sent to the correct department, each department is assigned a specific display as presented in Figure 6.

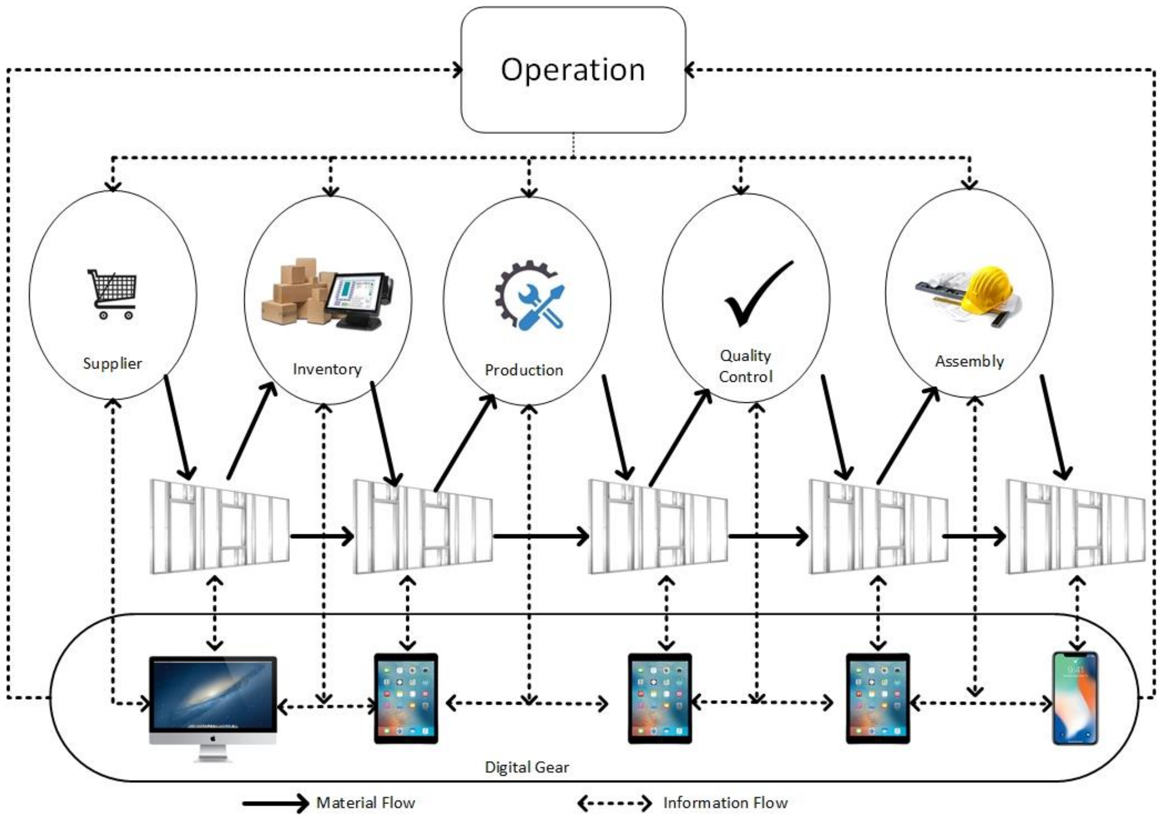


Figure 6: IoT integration

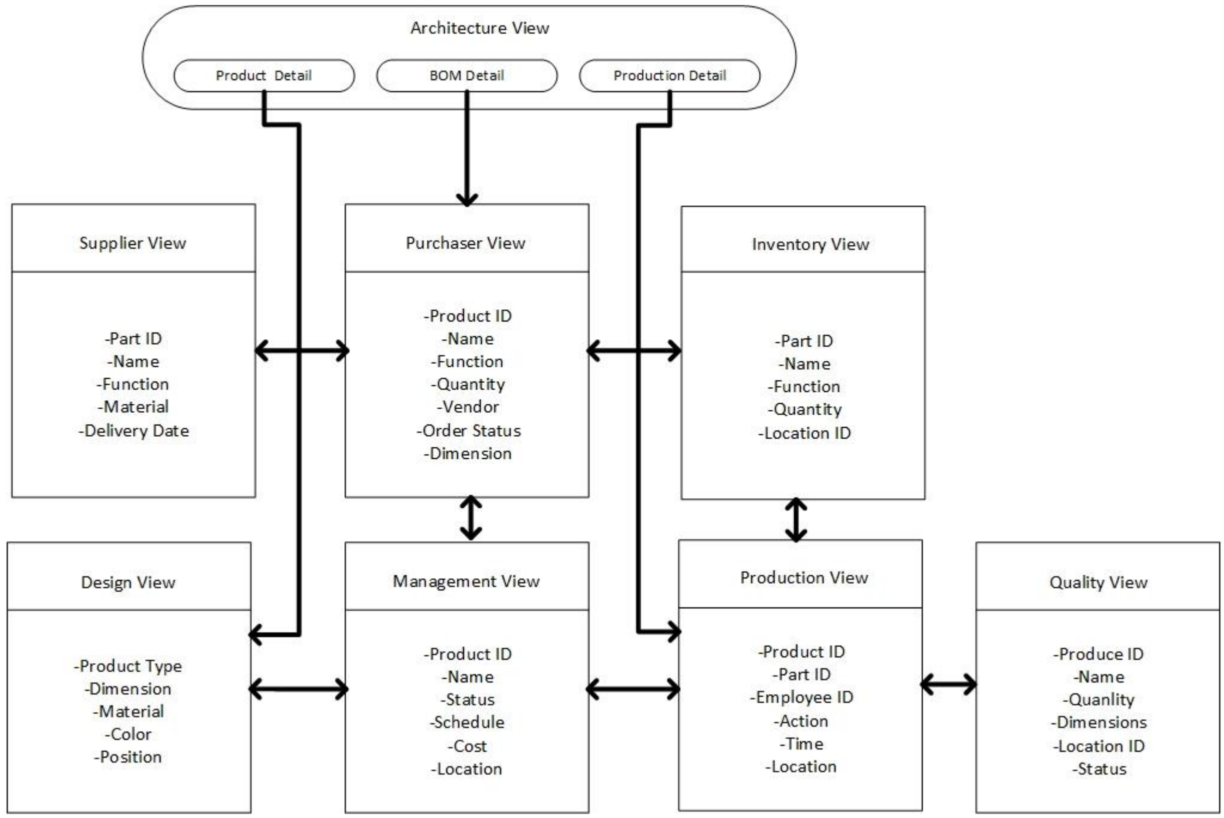


Figure 7: Multi-view Representation

The multi-view feature provides a specific view for each phase of the product lifecycle and production process. Figure 7 illustrates the relationship among the different viewing options. The architecture view consists of details such as bill of material (BOM), the product, and the production process, items all of which are necessary for the creation of the final product. The purchaser orders the materials according to the BOM list, ensuring the correct material and the correct quantities are procured. The product details are sent to the design team to ensure the correct materials with the accurate dimensions are accordingly provided to the production team, who receive the production details such as the design specifications. This step is vital since the production team aims to collect and track all the real-time data when transferring and receiving materials. This information will then be relayed to the management team in order to determine cost and schedule to ensure optimal productivity based on the status information provided from all areas of operation.

Chapter 4: Implementation (Case Study)

4.1 Introduction

In this chapter, the proposed methodology is implemented in a real-world setting. First, specific ERP modules are developed for a manufacturing production line. Then during the production process, the ERP system is implemented to collect production data and maintain certain operations. It should be noted that, prior to the development of this ERP system, it is necessary to understand the production line, sequences, tasks and subtasks, inventory requirements, quality expectations, and prerequisites for purchasing.

4.2 Case Study

The implementation of this program takes place at an offsite manufacturing facility operated by Fortis LGS Structures Inc. in Edmonton, Alberta, Canada. Currently, the company constructs modular wall panels for residential projects using 12- to 20-gauge light gauge steel studs. Analysis is conducted for the entire production line and the program is implemented, beginning with the office of the purchasing department and terminating at the end of the production line where panels are loaded onto trailers via the shipping department. The project deployed to test the system involves two identical residential buildings. Both are five-storey condominium complexes, but steel construction is only required for the second through fifth floor. Each floor comprises 92 bathroom wall panels, 71 exterior wall panels, and 127 interior wall panels, totalling 290 wall panels per floor. A total of 2,320 wall panels are manufactured to test the system.

4.3 System Development

4.3.1 Production Planning

Prior to the start of the project, architectural and engineering drawings are converted in shop drawings via CAD software external from the ERP system. These drawings meet the structural requirements dictated by the engineers and ensure windows and doors are in proper locations. The industrial engineer then creates a spreadsheet, which includes each wall panel. This is the start of the Production Tracking System (PTS). Each row within the sheets presented in Figure 8 and Figure 9 represents the amount of data collected for a single panel.

	A	B	C	D	E	F	G	H	I
1	Building	Floor	Product Type	B or M	Room Number	Type of Wall Panel	Wall Panel	Revision	Scheduled Production Date
2	1	4	Interior		1	B	2		2017-04-04
3	1	4	Interior		1	PT	7		2017-04-04
4	1	4	Interior		1	CR	8		2017-04-04
5	1	4	Interior		1	PT	10		2017-04-04
6	1	4	Interior		1	B	12		2017-04-04
7	1	4	Interior		1	B	13		2017-04-04
8	1	4	Interior		1	B	14		2017-04-04
9	1	4	Interior		1	B	17		2017-04-04
10	1	4	Interior		2	PT	7		2017-04-04
11	1	4	Interior		2	PT	10		2017-04-04
12	1	4	Interior		2	PT	11		2017-04-04
13	1	4	Interior		2	B	12		2017-04-04
14	1	4	Interior		2	B	13		2017-04-04
15	1	4	Interior		2	B	14		2017-04-04
16	1	4	Interior		2	B	17		2017-04-04
17	1	4	Interior		2	B	2		2017-04-04
18	1	4	Interior		2	CR	8		2017-04-04
19	1	4	Interior		3	PT	5		2017-04-05
20	1	4	Interior		3	CR	6		2017-04-05
21	1	4	Interior		3	CR	7		2017-04-05
22	1	4	Interior		3	PT	8		2017-04-05
23	1	4	Interior		3	PT	9		2017-04-05

Figure 8: Production Planning Spreadsheet (Part 1)

J	K	L	M	N	O	P	Q	R
Assembly?	Framing?	RimTrack (A)?	Sheathing?	RimTrack (B)?	Pod Assembly?	AVB?	WBD?	Horizontal Dimensions (inch)
yes	yes	yes	no	no	no	no	no	65.625
yes	yes	yes	no	no	no	no	no	34.375
yes	yes	yes	no	no	no	no	no	200.875
yes	yes	yes	no	no	no	no	no	78.375
yes	yes	yes	no	no	no	no	no	24.25
yes	yes	yes	no	no	no	no	no	78.375
yes	yes	yes	no	no	no	no	no	154.875
yes	yes	yes	no	no	no	no	no	65.375
yes	yes	yes	no	no	no	no	no	126.5
yes	yes	yes	no	no	no	no	no	78.375
yes	yes	yes	no	no	no	no	no	143
yes	yes	yes	no	no	no	no	no	24.25
yes	yes	yes	no	no	no	no	no	78.375
yes	yes	yes	no	no	no	no	no	154.875
yes	yes	yes	no	no	no	no	no	65.375
yes	yes	yes	no	no	no	no	no	65.625
yes	yes	yes	no	no	no	no	no	200.875
yes	yes	yes	no	no	no	no	no	183.75
yes	yes	yes	no	no	no	no	no	117.25
yes	yes	yes	no	no	no	no	no	156.75
yes	yes	yes	no	no	no	no	no	89.75
yes	yes	yes	no	no	no	no	no	166.75

Figure 9: Production Planning Spreadsheet (Part 2)

Details of the data collected in these spreadsheets are as follows:

- Building number
- Floor
- Wall type (Interior, Exterior, Bathroom, Elevator, Roof, Floor)
- If bathroom wall, master bathroom or regular bathroom
- Room number
- Wall panel number
- Revision (walls that were damaged or defected)
- Schedule production date
- Which production line (which station it travels through before finishing)
- Horizontal and vertical dimensions
- Any openings (windows or doors) and their dimensions
- Number of steel studs needed
- Number of rimtracks and their dimensions
- Location it will be placed for finishing or pod assembly

The stations through which each wall travels are standardized based on the wall type, but adjustments may be made in the event of a wall revision where the product only needs to go to certain stations. An example wall panel number, which provides significant information, is presented in Figure 10.

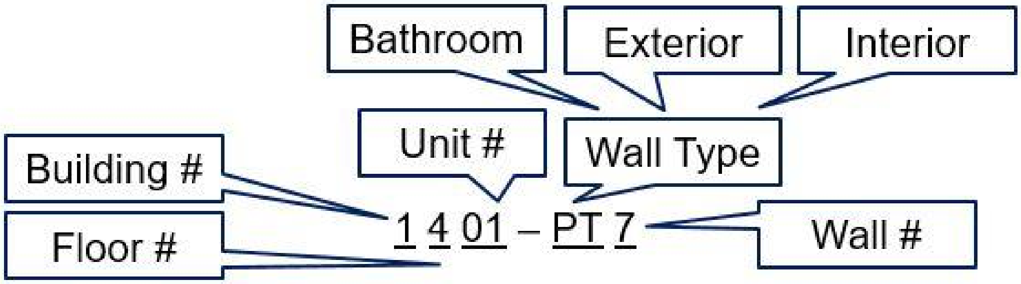


Figure 10: Product Identification

The building number dictates which building is build first, followed by which floor, and then by the unit number in chronological order. The wall type dictates which of the three production routes is taken. For each floor, the bathroom is always built first since all 4 walls are load bearing, followed by interior, then exterior. Afterward, the schedule order is in sequential order by wall number. Based on the dimension information and number of steel studs required, which are provided in the production planning spreadsheet and shop drawings, the ERP will calculate the necessary amount of material down to the number of screws, as presented in Figure 11 and Figure 12. The dimension information can be the reference point for Quality Control inspection and can also dictate shipping orientation for ease of offloading.

TOTALS

	Floor	Number of Panels	# of Studs	# of Columns	# of Cripples	# of Rimtracks	# of Openings	Invent: (ASS) 362-54 Clip	Invent: (ASS) 600-54 Clip	Invent: (ASS) Insulation	Invent: (ASS) 34Z Waffer	Invent: (FRA) 10 x 3/4" LOX
		Graph	Graph	Graph	Graph	Graph	Graph	Graph	Graph	Graph	Graph	Graph
DETAILS	2	397	1882	0	514	162	0	3764	1572	17.644444444444	13,880	5352
DETAILS	3	489	3040	0	742	343	0	6080	1570	21.733333333333	19,984	8036
DETAILS	4	598	4519	1104	1209	508	460	9038	3150	26.577777777778	27,644	11,430
DETAILS	5	618	4541	1104	1214	604	460	9082	3150	27.466666666667	28,052	11,554
	Totals (4 groups)	**2102**	**13,982**	**2208**	**3679**	**1617**	**920**	**27,964**	**9442**	**93.422222222227**	**89,560**	**36,372**

Figure 11: Required Material Quantities Calculations (Part 1)

Invent: (FRA) Horizontal Bracing	Invent: (SHE) 6 X 1-1/4" Self Drilling	Invent: (SHE) Drywall	Invent: (SHE) R12 Insulation	Invent: (RIM) 10-16 x 1" Self Drilling Hex	Invent: (RIM) 12-14 x 1-1/2" Self Drilling Hex	Invent: (EXT) 37Z	Invent: (EXT) XP403 Mesh	Invent: (EXT) EIFS Tape	Invent: (EXT) SUPER 77	Invent: (EXT) AVB GreenGaurd	Invent: (EXT) WINDOW FILM
Graph	Graph	Graph	Graph	Graph	Graph	Graph	Graph	Graph	Graph	Graph	Graph
342.02	22,894	11,869.351453993	1888.259765625	9250	2358	0	35.12	2.35	48.333333333333	14.5	12.39
580.08	39,520	12,905.852430556	1888.259765625	18,545	2355	0	35.12	2.35	48.666666666667	14.6	12.39
851.88	58,747	24,904.70421007	1888.259765625	27,825	4725	0	68.5	4.69	48.666666666667	14.6	24.78
856.14	64,884	32,390.447048611	2266.6299913194	33,605	4725	0	75.9	4.75	49	14.7	25.08
2630.12	**186,045**	**82,070.35514323**	**7931.4092881944**	**89,225**	**14,163**	**0**	**214.64**	**14.14**	**194.66666666667**	**58.4**	**74.64**

Figure 12: Required Material Quantities Calculations (Part 2)

Since the final construction of the building is conducted from the bottom up, the production sequence is carried out in the same manner; thus the material ordering is carried out in the same order. This also provides an excellent estimate of the final amount of material required, assuming no loss of material or rework is needed. The total cost can also be projected by calculating based on the unit cost of each type of material provided by a quote from suppliers.

With the schedule production date, the PTS will sort the wall panels that need to be completed first and will not show any future work beyond the production date. Although this function can be overridden in the event of work shortage, the case study project did not have this issue.

4.3.2 Purchasing Module

Purchase Orders (POs) are essential to an ERP system as they allow the program to keep track of expenses and material usage for various parts of the project. Also, BOM is deployed in the production process to allow for proper planning. The case study project involves the construction of two residential multi-unit residential buildings. Residential construction differs from commercial construction given that the BOM for each floor generally includes the same materials since each level of multi-unit residential buildings are nearly identical. Therefore, the process is to order the necessary material for one floor and, approximately two weeks prior to the start of production of the subsequent floor, the necessary material for the next floor is ordered. The PO can be duplicated in the case of multi-storey buildings since the BOM for each floor is identical. In the implemented ERP system, two types of POs are created, Purchase or Rental. This allows the purchaser to know which items are rentals and the length of time the item is to be rented for. The purchaser can extend the rental time for items if needed or can terminate the rental once the item is returned. Regular POs can be generated by inputting information such as shipping cost, address, and expected delivery date as seen in Figure 13. There is also an area on the form to indicate the purpose of the rental or purchase, which allows management to track orders that are not standard or regular in nature, and allows management to place irregular orders or add extra shipping cost. Extra shipping cost can be tracked based on the information entered into the PO.

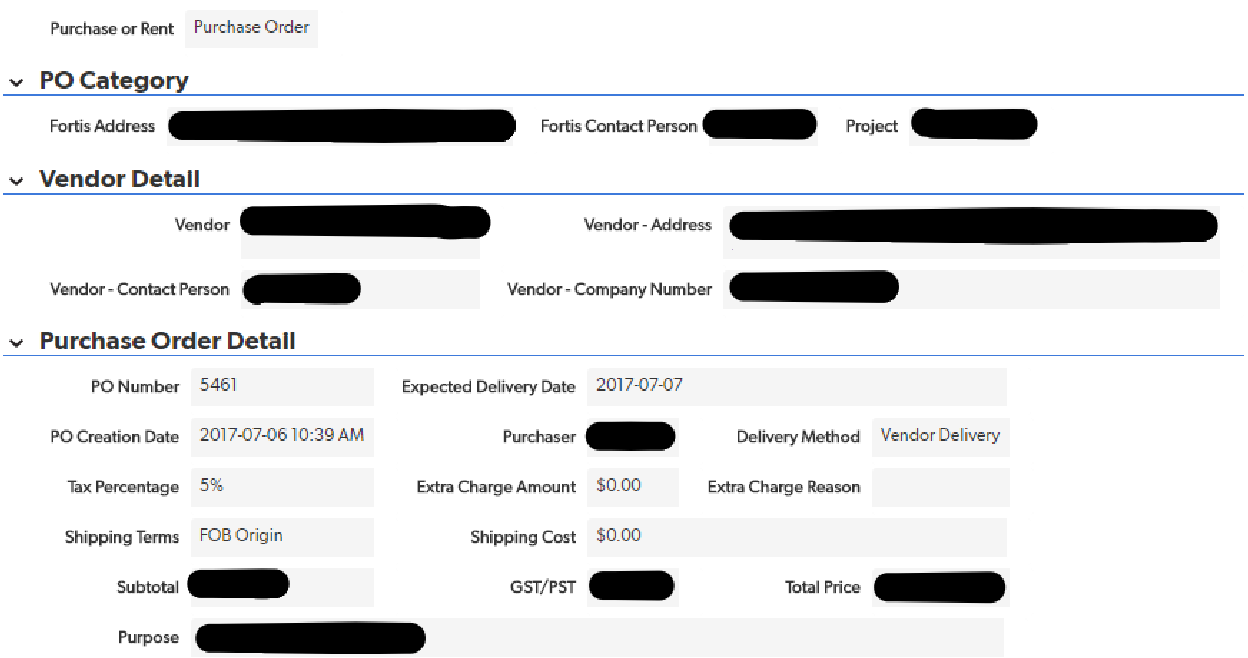


Figure 13: PO initial Information Requirement

Figure 14 presents the item lines of the PO, which are drawn from the inventory database that contains every previously ordered item or by adding new items within the same window.

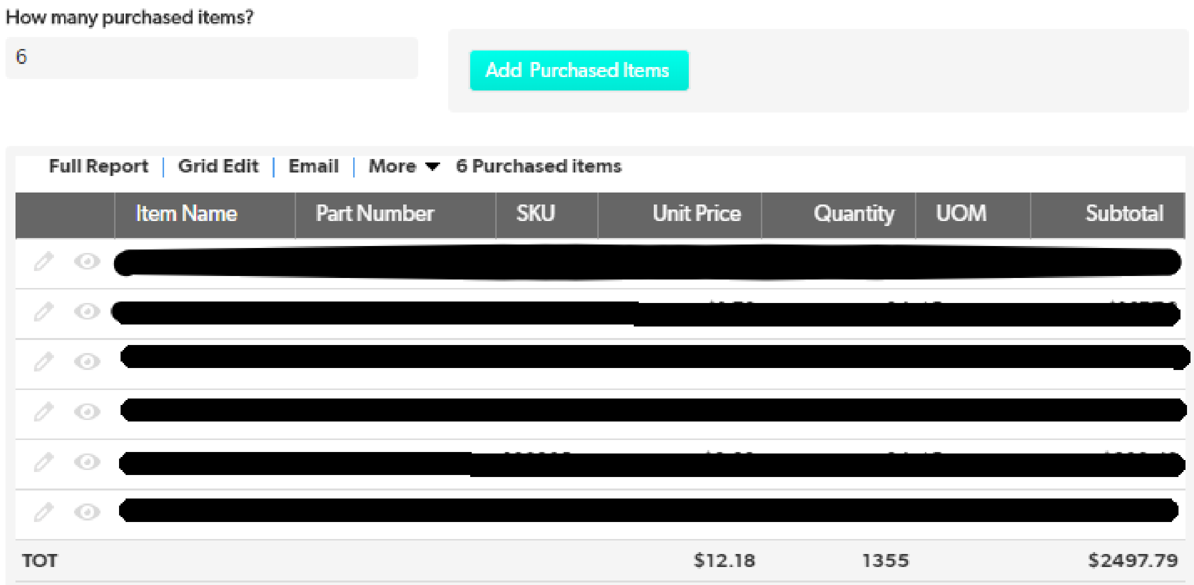


Figure 14: Items on a PO

When all of the necessary information is entered, the default status of the PO is “Work in Progress”, but can be changed by clicking “Purchaser Finished”, as can be seen in Figure 15, which will change the status to “Ready for Approval”, indicating that the PO has been sent into a manager queue and that the manager is notified by email. The manager can then decide to “Approve”, “Please Revise”, or “Reject” the entire PO depending on their judgment. A text box is also provided if the manager wishes to write any comments. The purchaser will be notified of any status changes made by the manager. If the management decision is “Please Revise”, the PO will be sent back into the purchaser’s queue, while an approved PO can be sent to approved vendors by means of an email or a PDF version from the purchaser.

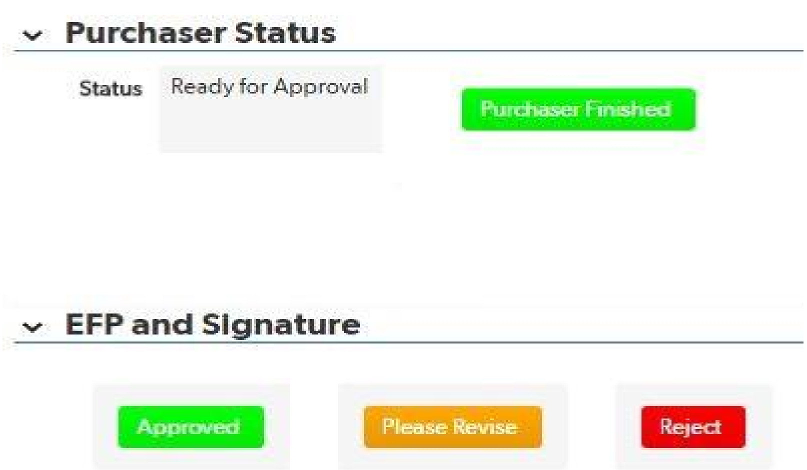


Figure 15: PO Status

4.3.3 Inventory Module

The purchasing module of the ERP is maintained by the purchaser. Ordering of material is based on requests per department and is non-systematic. To ensure a steady supply of material during peak operation, while not overstocking during slower times, an inventory control module is needed. This is developed for repetitive consumable materials that are essential to continuous manufacturing operation, while the Purchasing module is developed to buy unique material. To solve this problem, a recount of all material in inventory is carried out and inputted into the inventory control system. A simple catalog view of the inventory control system is presented in Figure 16.

Item Name	Quantity	-1 Button	Part Number	-5 Button	Quantity Type UOM	-10 Button	Categories	+1	Location	+10
5" Stretch Wrap	9	-1		-5	EA	-10	Wrap/Tape	+1	Locker 1-2	+10
5/32" Drill Bits 6" long	13	-1		-5	EA	-10	Bits	+1	Locker 1-4	+10
5/32" Drill bits short	3	-1		-5	EA	-10	Bits	+1	Locker 1-4	+10
7" Aluminium Rafter Angle Square	5	-1		-5	EA	-10	Tools	+1	Locker 1-4	+10
Aluminum Hawk	3	-1	15215	-5	EA	-10	General	+1	Locker 1-5	+10
Arbor Bit 1L	5	-1		-5	EA	-10	Bits	+1	Locker 1-2	+10
Arbor Bit 2L	4	-1	1779801	-5	EA	-10	Bits	+1	Locker 1-2	+10

Figure 16: Inventory Control View

The quantity can be altered due to any withdraw or addition of materials by selecting from the pre-configured buttons, “+1”,”+10”,“−1”, ” −5”, or “−10”. The codes for these buttons can be found in the Appendix. These numbers are pre-determined based on the most frequently used quantities for withdrawal or addition. With a real-time count of the inventory, the next step is to design a simple minimum/maximum (Min/Max) system in order to alert the purchaser when any material reaches a certain level as seen in Figure 17. When an inventory number of a specific item falls below the pre-determined “Min” number, that item will move into the “Please Order” queue and the purchaser will be notified by the system.

Min #	Max #	Min/Max Status	Purchaser Status
2	6	OK	Receiving Complete
50	1000	OK	On Order
1	5	PLEASE ORDER	Receiving Complete
3	5	OK	On Order
5	100	OK	Receiving Complete

Figure 17: Mix/Max System

The purchaser may delay placing an order for a few days in order to combine multiple POs. The “Min” set figure accounts for lead-time for ordering, processing, and shipping, totalling approximately three days. Therefore, the “Min” set number is based on the assumption that any remaining quantity can sustain the production line for up to one week. This will prevent the quantity amount from reaching zero in the event of a problem or delay with the item arriving into inventory. When the purchaser has produced an approved PO and has obtain a delivery confirmation, they will select a button called “On Order” in the system to change the “Purchaser Status” of the item from the default “Receiving Complete” to “On Order” status. This process is summarized in Table 3.

Table 3. Item Purchase Status Order

Order of Events	Min/Max Status	Purchaser Status	Location of item (which queue)
Inventory is plentiful	OK	Receiving Complete	Inventory
Inventory has reached the “Min” pre-set number meaning inventory is low	PLEASE ORDER	Receiving Complete	Purchaser’s “TO ORDER” queue
Item has been ordered and pending delivery	PLEASE ORDER	ON ORDER	Purchaser’s “TO RECEIVE” queue
Inventory has been received and added into inventory	OK (This will auto-change due to the quantity not below “Min” pre-set number)	Receiving Complete	Inventory

This ongoing real-time status update about an inventory item will provide clarity between all involved parties (purchaser, receiver, etc.) and will ensure the receiver will always obtain the most correct and up-to-date information. To reduce the amount of human error, the only status that can be modified is the “Purchaser Status”. If the “Purchaser Status” is

“ON ORDER” while the Min/Max Status is set to “OK”, a sequence error has occurred and the purchaser will need to investigate. Extra materials are occasionally ordered in preparation for a project. This inventory control system is only applied to inventory consumables, in which the exact quantity of primary panel production materials (steel, drywall, screws) are ordered according to the BOM. Consumables can vary depending on several factors such as the number of workers and are thus impossible to predetermine for each project. A simplified diagram as presented in Figure 18 is used to explain the inventory control concept.

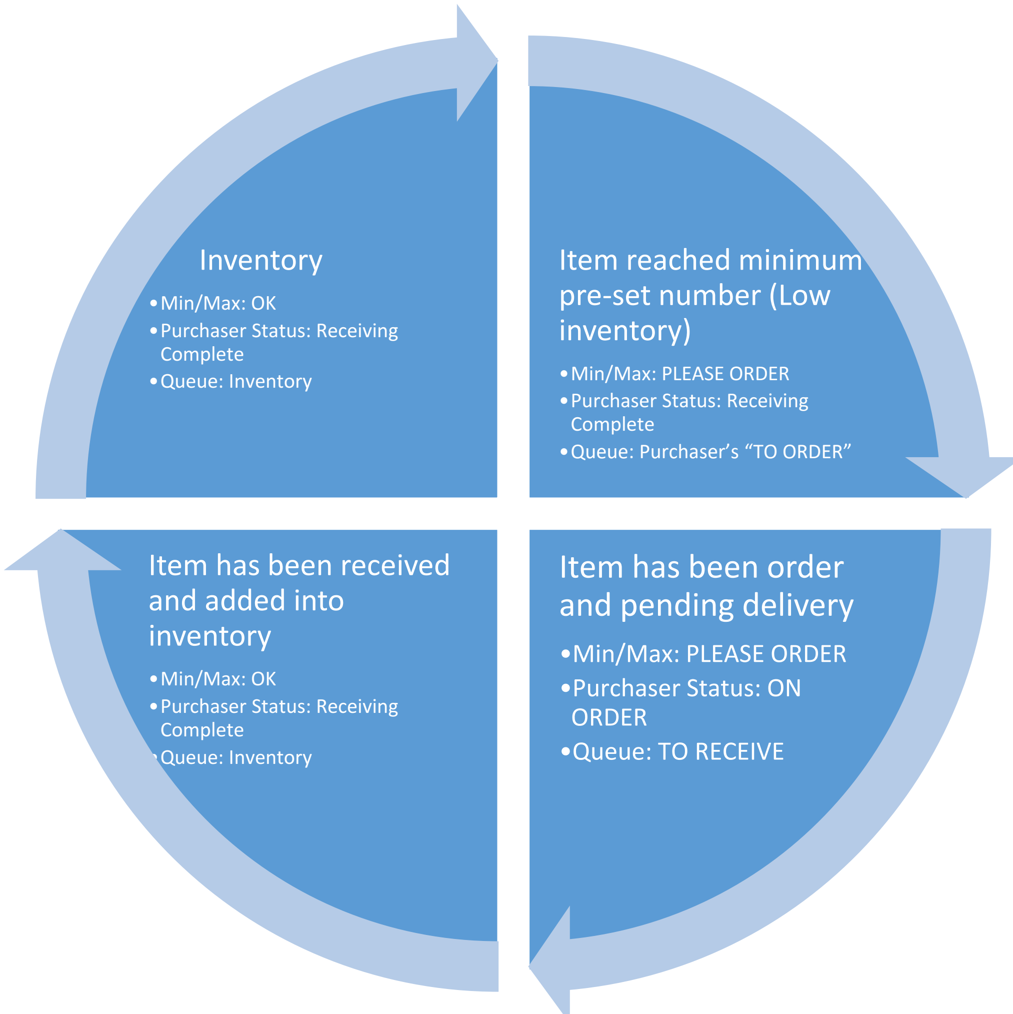


Figure 18: Inventory Control Cycle

The inventory can be express as Equation 1:

$$\beta - \alpha = \theta \tag{1}$$

$$\alpha < x < \beta \tag{2}$$

$$\gamma \leq \alpha \tag{3}$$

where θ represents the difference between the minimum and maximum; this is the quantity that the purchaser orders when notified by the ERP system. In Formula 2, x represents the current real-time inventory quantity of an item; and α represents the minimum and β represents the maximum amount of inventory at a given time. In Formula 3, γ represents the value of x after 2 weeks of lead time, assuming a 2-week delivery time; therefore, α must always be larger than γ or the quantities for that item will be too low. The 2 weeks of lead time accommodates any mishaps that occur during delivery and prevents x from reaching 0.

Prior to the implementation of inventory control, production was always affected due to missing materials or tools. This resulted in a significant amount of Purchase Orders as well as costly rushed order fees. Other problems can also arise, including product name confusion, lack of knowledge of the location of certain inventory items, and inventory count, must occur weekly to minimize the effect of poor inventory control. However, by introducing automated inventory control, purchase order notifications have become an automated process by means of indexing inventory. This eliminates several of the previously mentioned problems. As a result of implementation, only one rushed order was created for the remainder of the project (spanning approximately eight months), thereby reducing unnecessary purchase order creation efforts and rushed shipping fees. Another positive outcome observed through the case study implementation is that the system promotes responsibility and honesty among employees due to inventory logging.

4.3.4 Quality Control

Quality Control (QC) is essential to any manufacturing line. In order to limit product defect yet avoid unnecessary reduction in production due to inspections at each station, certain stations have been predetermined to require QC reports. The diagram presented in Figure 19 depicts the various stations within the case study production line. Here a wall panel begins at the assembly station, followed by the framing, rimtrack, and sheathing stations. Then, depending on the type of wall panel, it is either transported to the exterior or bathroom pod station. An interior wall is transported directly to the shipping area since no other work is required.

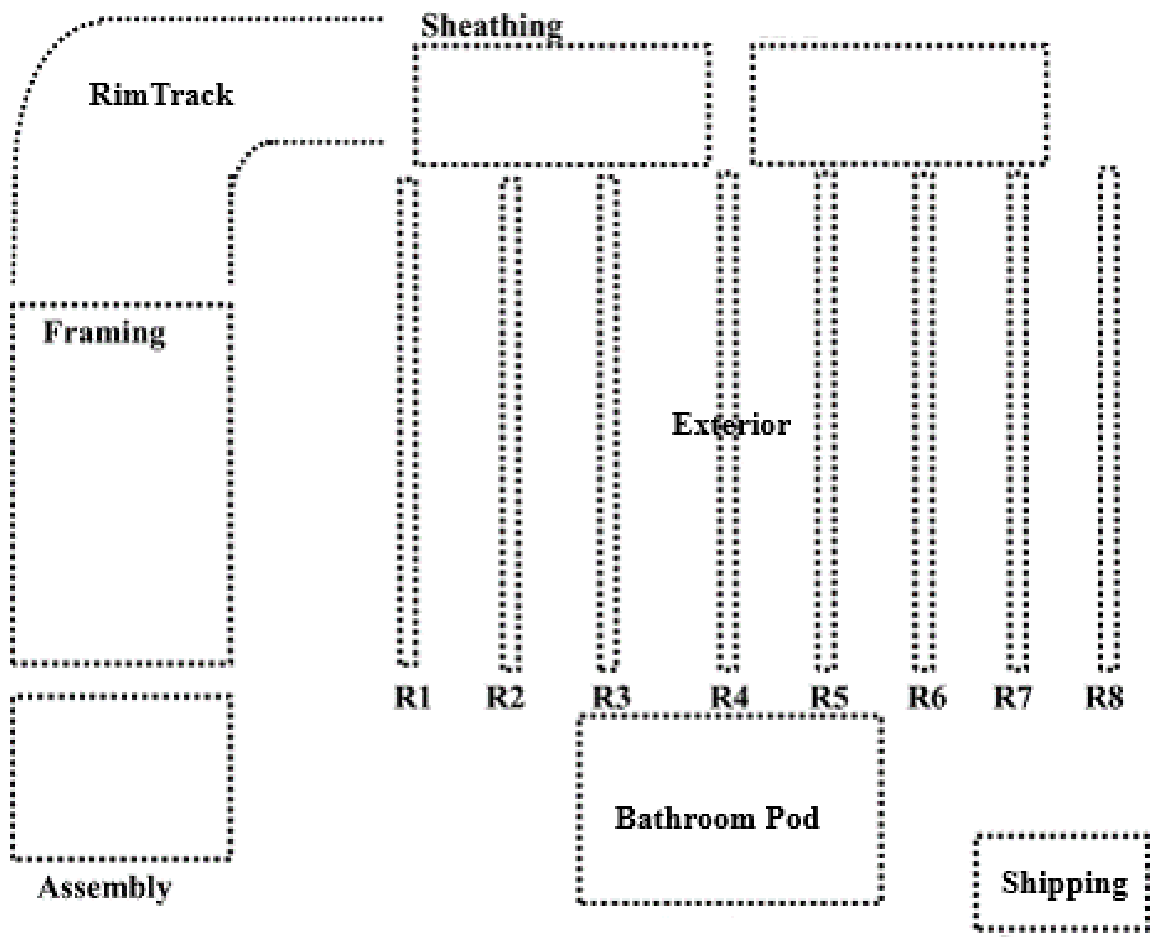


Figure 19: Production Line Flow

The following stations are determined to require a QC inspection: framing, rimtrack, sheathing, exterior, and bathroom pod; however, not all panels require an inspection report. As previously mentioned, the interior station is completed after the rimtrack and before sheathing; therefore two inspection reports are required, one for framing and one for rimtrack. This is under the assumption that all panels pass their respective inspection at the two stations during the first inspection. Bathroom pod panels will require four QC checks (framing, rimtrack, sheathing, and bathroom pod) while exterior panels also require four checks, but rather than the bathroom pod QC report, exterior panels require an exterior inspection report. All inspection report forms are designed to be straightforward due to the sheer number of panels being assembled and thus the number of inspections to be carried out. Previous attempts at using the method of random sampling did not eliminate quality problems as damaged or incomplete panels were discovered on shipping trailers or even at the construction site. The primary purpose for conducting electronic QC reports is to reduce the amount of time spent filling out and auditing paper-based reports. The framing and rimtrack reports for the number of wall panels (approximately 92 walls) that comprise the main floor of a single-family home would fill a 4-in binder, resulting in a significant amount of paperwork for the production team. Also, a paper-based system can result in loss of paperwork. The process of auditing QC reports and identifying trends among defects and problems is an envisioned step for future research in assisting the industry partner to improve the production line, and the step toward electronic management of these processes is a future-proofing method to ensure this step is always carried out. Although the auditing step has yet to be developed and implemented, the QC section of the program is designed with this idea in mind. For example, a simple search of electronic inspection reports that failed on first yield can provide information such as a simple pass percentage of specific sections within the production line.

All inspection reports will be registered to a specific user in order to determine the party responsible for the inspection and to also determine whether issues are due to human error or negligence. In order to measure the time required to complete each section and the report overall, each section of the report provides a start and end button for each panel. This also allows the program to place the inspection report in the correct queue since some reports, such as the exterior inspection report, have multiple sections resulting in more than one queue. The person conducting the inspection is required to select “YES”, “NO”, or “N/A” if it does not apply, and an algorithm runs in the background that will dynamically calculate whether the panel receives a pass or fail depending on the user input. This reduces the complexity of completing inspection reports and also ensures that if necessary, training new QC inspectors is a simple process. The default inspection report number for each panel is 1, but in the event of a second or third report due to a failed inspection, the program will understand that an inspection report has already been completed, thereby prompting the inspector to update the report number and bringing to their attention that it is a re-inspection. This is primarily to eliminate duplicate report numbers, but also to create a trail for an auditor to see that multiple inspections were carried out due to either damage or other issues. As a result, the production team is better able to keep track of first pass percentage yield for weekly, monthly, or quarterly QC reports.

4.3.4.1 QC Framing Inspection Report

The primary concern of the framing inspection report is to ensure that the panels exiting the framing station have correct dimensions, the proper number of screws, and are completely squared. Correct dimensions allow for some tolerance if the panel is smaller by up to ⅛-in, but not larger. This is primarily due to the supplier’s method of steel fabrication. According to the supplier, the cause of this variance is that the machine is not re-calibrated prior to the framing of each panel, resulting in as much as an ⅛-in difference. (This issue does not affect the quality of a building since the proper procedure on construction sites is to fill any minor gaps of this nature with spray foam.) The second reason for this variance in panel dimensions is due to the nature of the track forming. The curvature of the track alters the panel dimensions in comparison to the drawings. For this reason, an override button is built into the planning system, as indicated in Figure 20. If the panel does not match the drawing, it is an automatic fail; however, the QC inspector is able to override the failure in this section and change the algorithm to ensure the system reports a pass. It should be noted that this is not a manufacturing defect, but rather a vendor supply deficiency. The inspector must input a reason from a list of two reasons, which allows the system to track the number of panels with this problem, and this information will be used in future discussions with the vendor.

Figure 20: Framing Inspection Report

The other two sections, which check for panel squareness and correct number of screws, offer no leniency or an override button. Any number of missing screws need to be inputted for data collection purposes. Due to the simplicity of the report and since this is one of the first reports to be created along the assembly line, the average time for inspection is approximately 1.4 minutes (84 seconds). Wall panels may have openings for doors or windows. There is a section that will allow the inspector to select the number of openings and determine “YES” or “NO” for the vertical and horizontal dimension checking. A full inspection report can be observed in Figure 21. Future plans will draw the information about the number of openings from the BOM that is upload by the Industrial Engineer at the start of the project as mentioned in Section 3.3.1. This improvement will reduce the amount of input needed from the inspection report and ensure fewer chances for human error while filling out this section.

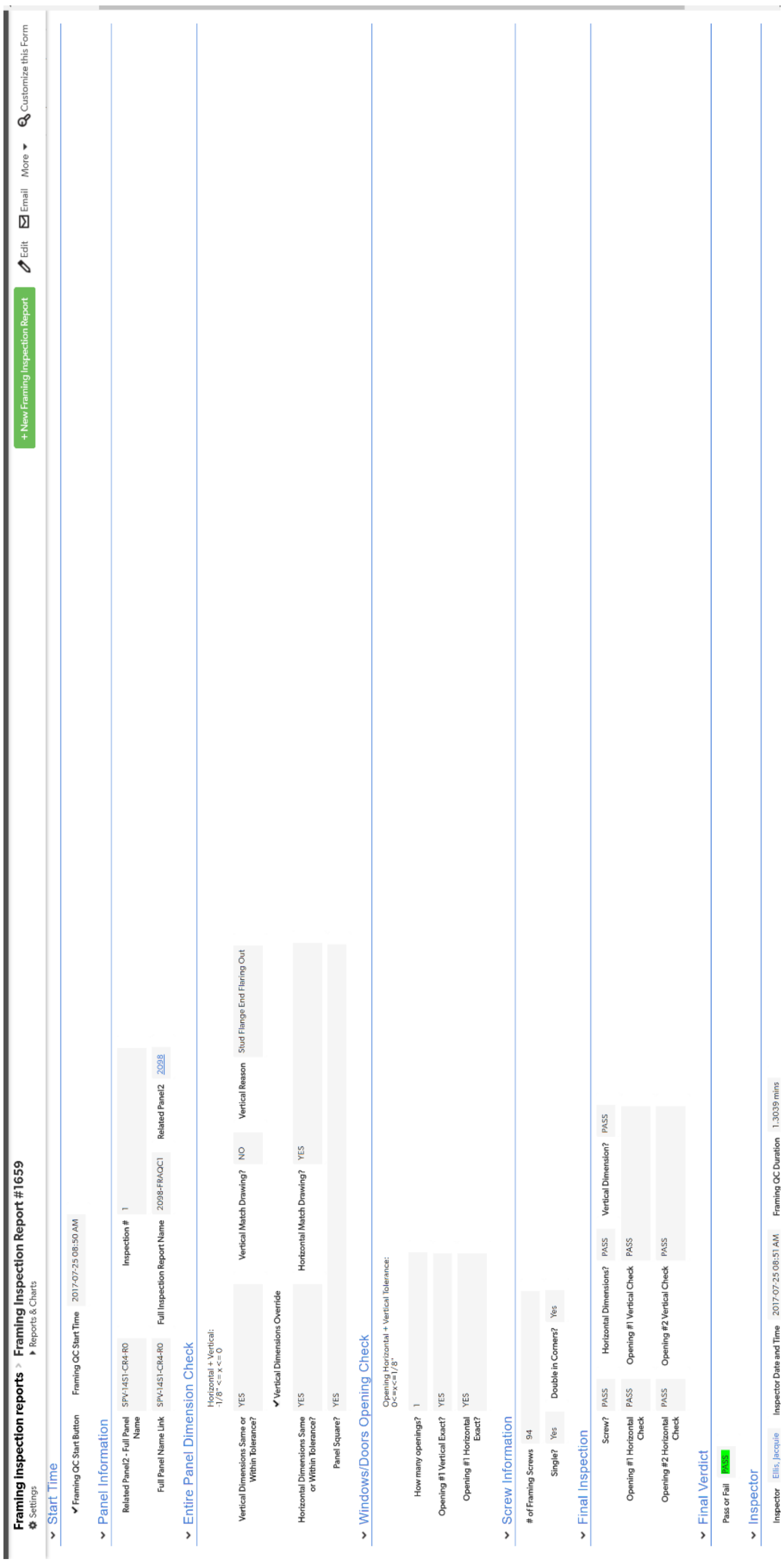


Figure 21: Framing QC Inspection Report

4.3.4.2 QC Sheathing Inspection Report

The concept of the inspection report and its background design are similar to the framing inspection report, with the addition of the "N/A" option at this station. The current practice for drywall cutting is dictated by the standard measurements of commonly available drywall sheets. If when the drywall sheets are laid out on the panel, two edges touch, creating a seam, and no stud is behind the seam, a backer stud is needed in order to ensure the area is structurally sound at the seam. Not all wall panels require a backer stud; therefore, the "N/A" option will ensure that the wall panel still passes inspection even in cases where no backer studs are needed, as presented in Figure 22.

Figure 22: Sheathing QC Inspection Report

4.3.4.3 Rimtrack QC Inspection Report

The application of rimtrack varies depending on the wall type. For interior and bathroom walls, the rimtrack is applied directly onto the steel stud, but for exterior walls, the first rimtrack is placed on the steel stud and a second is applied on top of the drywall after it passes through the sheathing station. Due to this variation, the data pulled from the spreadsheet uploaded by the industrial engineer, as mentioned in Section 3.3.1, will specify whether the wall panel is exterior or interior. As a result, the details for the rimtrack, its dimensions, and the number of rimtracks required will be displayed on the QC inspection report as presented in Figure 23.

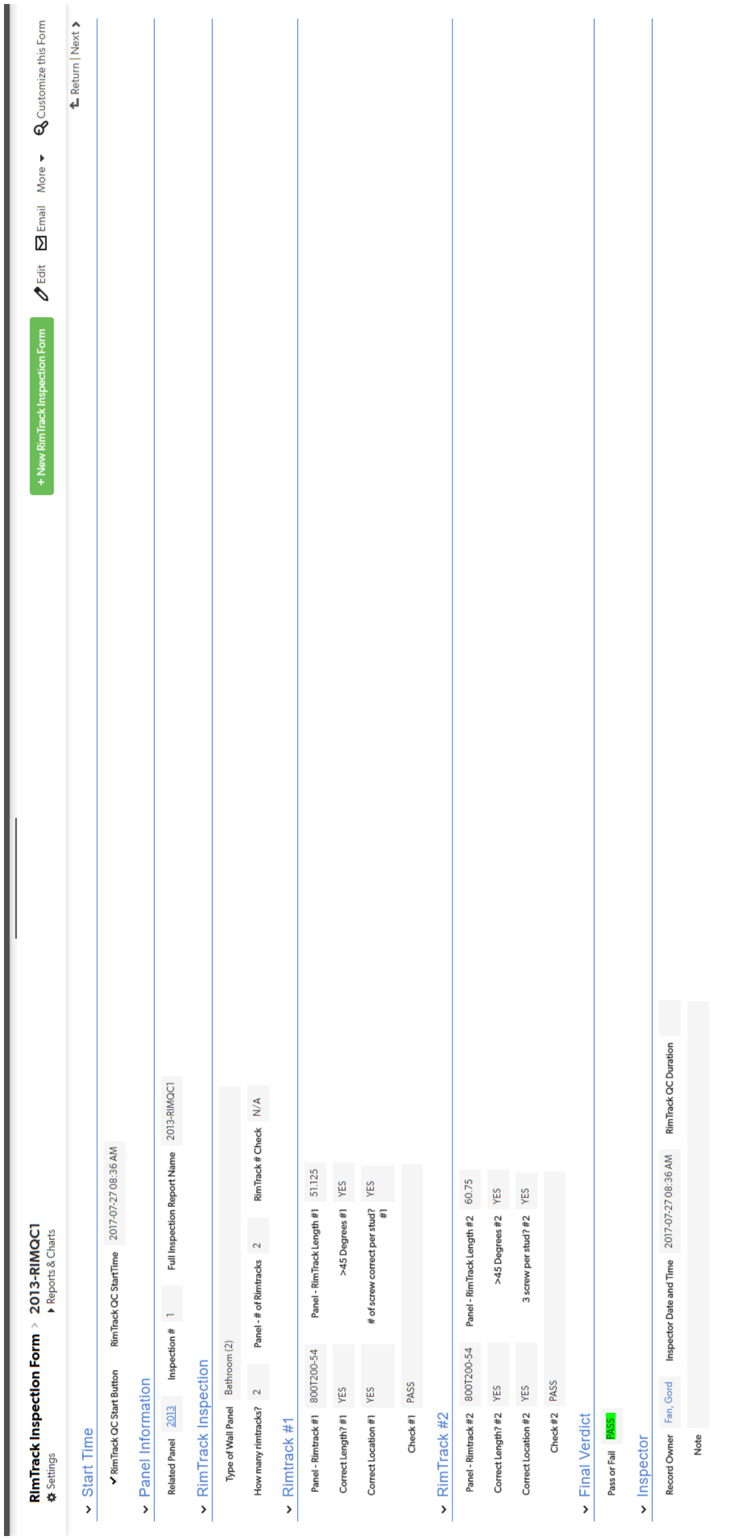


Figure 23: Rimtrack QC Inspection Report

4.3.4.4 Exterior QC Inspection Report

The exterior inspection report was initially designed to encompass three parts: moulding/mesh, air vapour barrier (AVB), and final coat/material; however, at the time of this writing the final coat and material section is left for onsite work. For the research presented in this paper, the first two sections are designed of the exterior QC report as presented in Figure 24. The final section is designed for use in future projects, but is currently disabled and will not affect current inspection efforts or algorithms. The first section is completed after the initial application of moulding and the first coat of waterproof paint. Moulding is the foam-based barrier used to cover the bottom of the panel. The "N/A" response is often selected in this section due to the fact that moulding is only applied on the second floor of the building, because the first floor of such buildings is cast from concrete and does not require any moulding. Due to the multiple sections involved in the exterior panel inspection report, rather than using the completion time of the first section as the finishing time of the report, there is a section "END" checkbox which records the finishing time of the first section. This allows the program to not only calculate the time required to complete the first section and separate it from the second section, it also allows the user to search using that checkbox as a filter and the "Pass" status of the first section to move the report into the queue for section two. If the status of section one is "Fail", the report will not be moved to the queue for section two, but it will appear when the auditor searches for an exterior QC report that failed in the first section. Due to the fact that the failed report did not appear in the next queue, but does exist, the new exterior QC report must be labelled as report number "2" as described in Section 4.3.4.1, Framing QC

Inspection Report, since there cannot be duplicate report numbers. In other words, any section of a report that fails will result in the entire report being classified as a "Fail" requiring the QC inspector to issue a completely new report. This is to ensure that the inspector rechecks the panel again since any work that was conducted earlier on the wall panel which is not to standard may cause issues for future work completed on the product.

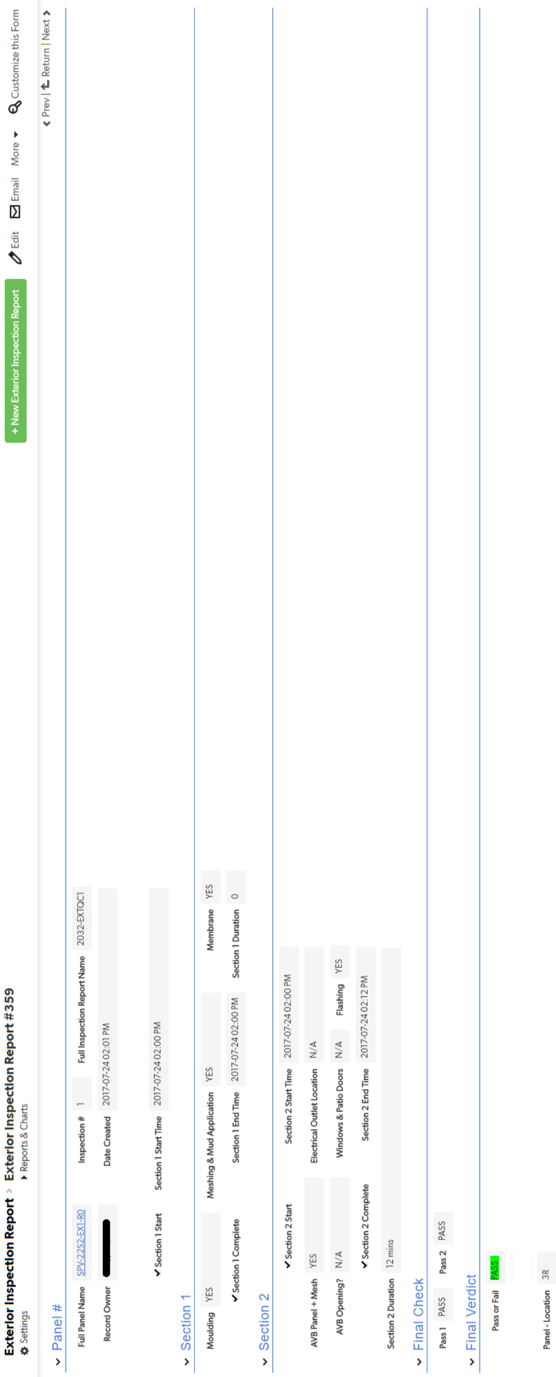


Figure 24: Exterior QC Inspection Report

4.3.4.5 Bathroom Pod Assembly Inspection Report

Each of the previous four inspection reports imposes a unique challenge in terms of the design and algorithm of an electronic QC inspection report. The bathroom pod QC inspection report encompasses all of the above challenges. This is the first application of this type of report and manufacturing technique for this project specifically given that the production of bathroom pods was not required for any previous projects. Generally, the work is subcontracted out to another company, but is carried out in-house for this case study in order to reduce cost for the owner of the project. Therefore, the inspection report presented in this research may not be the final report template used for future production. One difference in this report is that, rather than answering "YES" to all questions to ensure a "Pass" status, as is the case in all previous inspection reports, this report includes the field, "Gap in the Corners?", where the answer must be "NO" to ensure a "Pass" status as shown in Figure 25. In the future, the wording of this question may be changed to ensure that all answers can be "YES" in order to be consistent throughout all of the inspection reports.

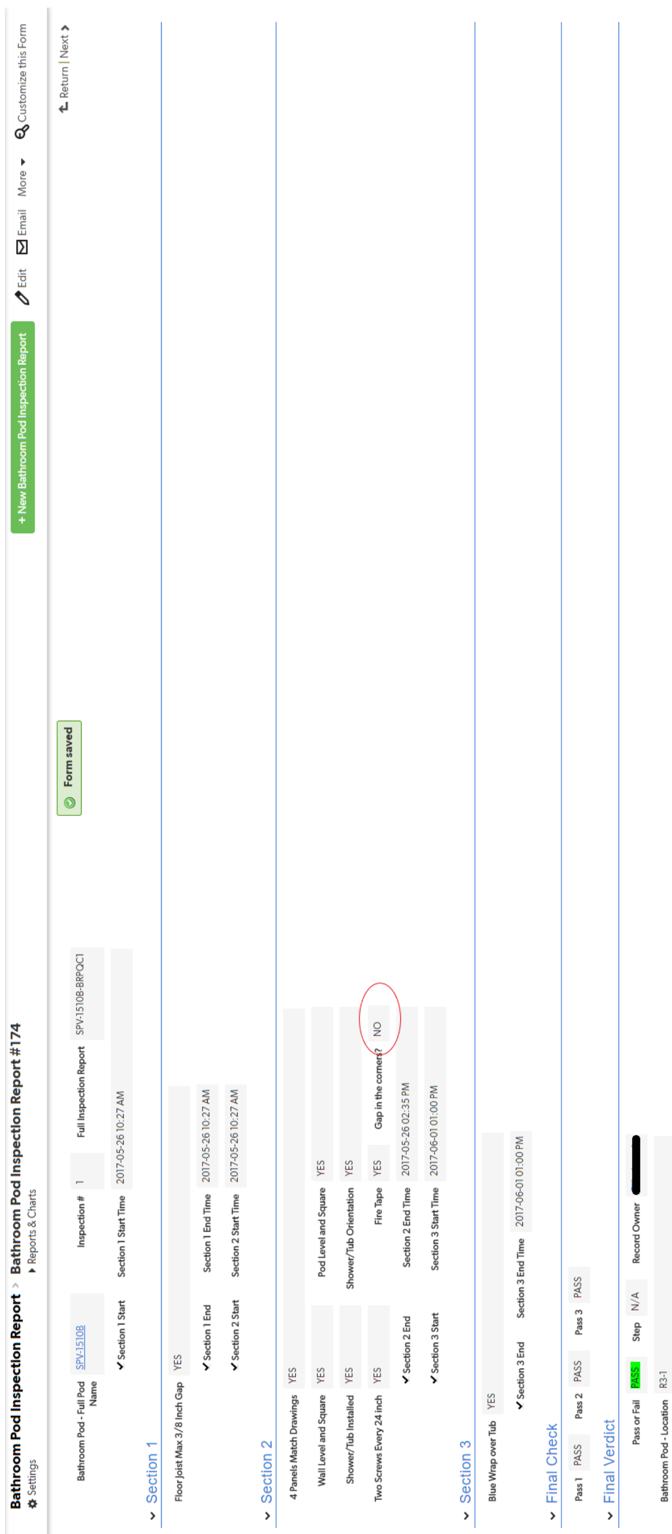


Figure 25: Bathroom Pod QC Inspection Report

4.3.4.6 Inspection Report Conclusion

Each section in this chapter introduces a unique feature due to the uniqueness of the Fortis LGS system. Changes requested by the case study company for future versions of this system include an additional section in the bathroom pod QC inspection report which will encompass the plumber's work such as waterworks and pipes. These inspection reports have dramatically reduced the number of problems discovered among panels before shipment and have dramatically improved the quality of work. Furthermore, QC inspection reports are now properly filled out and filed accordingly with minimal chance of human error. Prior to implementation of QC inspection, three defective panels were found each day after being loaded onto the trailer. On average, fifteen panels were produced daily during that time, resulting in a 20% defect rate. The introduction of frequent QC inspections allowed defects to be discovered more quickly, resulting in a reduced defect rate of 1.33% (one defect per week); however, this change introduced a non-value added activity: paperwork. By proposing the electronic QC report, the defect rate is reduced to 0.33% (one defect per month).

Assuming a production rate of 25 panels per day, an average of 3.12 QC inspections are carried out per panel, depending on the ratio of each wall type. By implementing the electronic QC report, approximately 1,560 pieces of paper are saved. In terms of the case study project size of 2,320 panels, 7,238 pieces of paper are saved (assuming that every panel passes on their first inspection and no redundancy due to errors or misfiling).

4.4 Production Tracking System Data Collection

4.4.1 Digitized Time Study

One of the most crucial studies for diagnosing problems within a manufacturing line is the time study. Manual time study can be conducted to record the time duration of any specific task and document any notes or details that may be significant to the study. The difficulty with manual time study is that a third party must conduct the study and will only provide an ongoing snapshot of the data collection. The third party also requires training in order to understand the manufacturing process as well as when to start and stop the time recording. Although an external third party may perceive problems that are normally overlooked by regular personnel, it is a tedious and time-consuming task. In general, time studies provide snapshots of the production line at certain time frames. To evaluate the full picture, a larger range needs to be observed, meaning more workhours need to be invested. Production can vary significantly from week to week, which could result in inaccurate data collection. The case study company is also interested in obtaining real-time data collection with the added benefits of product tracking visualization. Barcode and RFID are common methods for tracking products throughout the manufacturing industry. The developed approach presented in this thesis requires the employees working at each station to select a “START” button and an “END” button that appears on the tablet screen for simple time collection. Selecting the “END” button signifies the completion of work on that product, and that it can be moved into the next queue. As presented in Figure 26, the green “START” button will input the current time as the station start time, then the employees proceed with their work at that station. Once their work is completed, in this case, applying rimtrack to the steel wall panel, the team leader of the station will select the red “END” button to record the current time as the finish time. The difference between the start and end times will be the task duration for that station. This process is consistent for all stations throughout the production line.

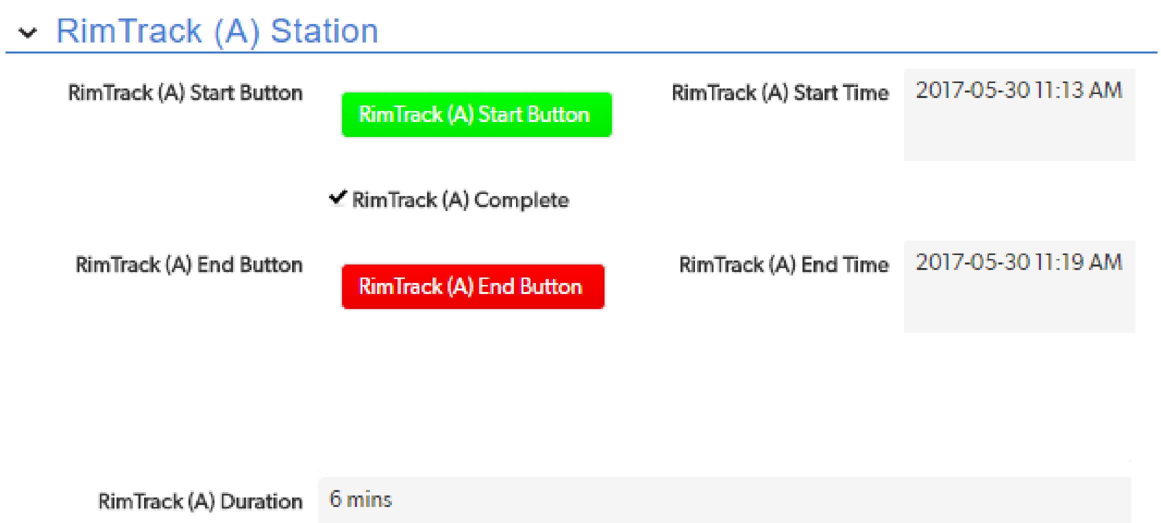


Figure 26: Real-time Time Data Collection for Rimtrack Station

In order to display the current panel information and to inform the team leader at each station which panel is to be worked on next, a queue is established at each station. This will dictate the order of work and indicate the amount of remaining work to be completed. Figure 27 presents a visual example of a case where there is one panel in the queue for which the framing process has yet to be started.

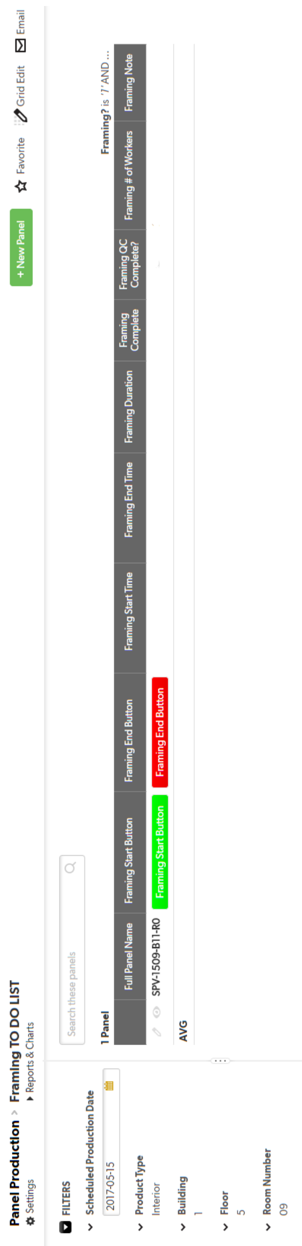


Figure 27: Framing Station Queue

Once the work has been completed, indicated by selecting the "END" button, the panel will be removed from this queue, but will appear in the following queue. In this case, because the framing station requires a QC inspection report, the panel will appear in the QC inspector framing QC queue as shown in Figure 28.

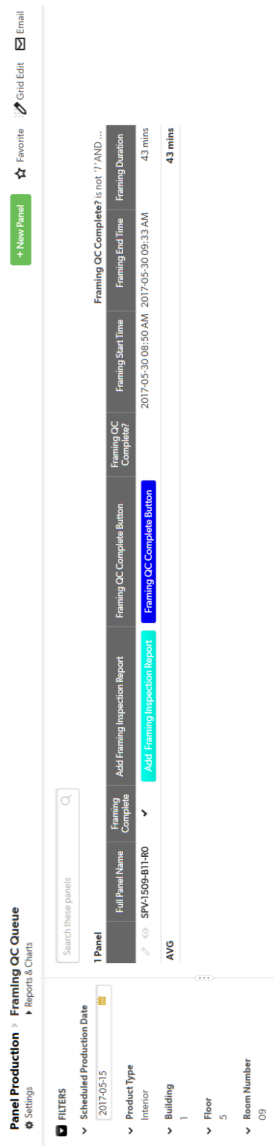


Figure 28: Framing QC Queue

Since all QC inspection reports are timed, as observed in Figure 27 and Figure 28, there is no need to carry out manual time study in order to determine the duration of activities within the manufacturing process. As a result, the QC inspector must only select “QC

Complete" when the completed inspection report administers a passing grade for the framing station. Upon completion of the inspection report, the current window on the display screen will close and the user display will return to the QC queue windows, thereby ensuring that the current wall panel is moved to the rimtrack station queue. Future research will develop a method to allow the ERP system itself to recognize a completed inspection report and automatically transfer the wall panel into the following queue.

Time study specifically targets the three main stations on the production line: assembly, framing, and sheathing. Every steel wall panel must pass through the assembly and framing stations, therefore any bottlenecks at these stations will affect the entire production down the line. Generally, at the case study facility, bottlenecks do not occur at the assembly or framing stations since the employees working at these stations are consistently assigned to these stations and thus have significant experience; however, the sheathing station is often the source of a major bottleneck due to machine malfunction, defective drywall, or inconsistent work being performed. Downtime is also included in the total duration of a wall panel at a specific station.

$$t = (y - x) \times 60 \quad (4)$$

where x represents the start time, and y represents the end time for the manufacturing process at a given station on the production line.

Currently, all times are measured in terms of hours (which is the default setting in the ERP system); however, all times are converted to minutes as expressed in Equation 4, given that the eventual goal is to optimize each station duration to under 30 minutes. This method (Equation 4) applies to each station individually; however, to combine all three station, the following equations can be expressed, where *A* represents the assembly station, *B* represents the framing station, and *C* represents the sheathing station.

$$t_A = (y_A - x_A) \times 60 \quad (5)$$

$$t_B = (y_B - x_B) \times 60 \quad (6)$$

$$t_C = (y_C - x_C) \times 60 \quad (7)$$

In order to determine the idle time between each station, the following equations can be expressed.

$$t_{AB} = (x_B - y_A) \times 60 \quad (8)$$

$$t_{BC} = (x_C - y_B) \times 60 \quad (9)$$

In , the idle time for a panel between the assembly station and the framing station is found by subtracting the panel's start time at the framing station from the panel's end time at the assembly station. The same method can be applied for the idle time between the sheathing station and the framing station as expressed in .

4.4.2 Tracking Results

Based on one test run of third-floor bathroom wall panels, the average assembly time for one panel lasted approximately 0.33 hr, framing time lasted 1.17 hr, and sheathing time lasted 2.87 hr; therefore, on average the assembly process of one panel is approximately

3.33 hr. Since no time study, either manually or digitally, was conducted for the case study production line, no historical data exists; therefore, any improvement to the manufacturing line cannot be quantified. However, the data collected during this study can now serve as a historical benchmark such that any lean improvement process applied to the production line should in theory decrease these production times while maintaining quality. Future work, in conjunction with the company's industrial engineers, can utilize this system to compare historical data with data collected after more recent changes to determine if the changes have any effect on the production time. Although no two projects are identical, wall panel production time can be compared in terms of area (ft^2). Wall panels of similar area should result in similar production times. As a result, these time study comparisons can be made despite the fact that projects may differ. By adopting a more automated production tracking system approach, the previous issues can be addressed. Additionally, employee engagement is increased as they learn about the program; seeing their task time can provide motivation to improve. Since every station is inputting data throughout the project, a better overall picture is provided; for example, the duration change for a particular station throughout the project can be observed, resulting from changes from introducing new lean concepts/techniques or changing the order of steps in a specific activity. Some effects are long-term as employees start to become more familiar with the new change. Information such as daily panel completion for each station can be collected to determine if a certain employee fits more naturally at a particular station. The increase in employee engagement divides what originally was a major task into smaller subtasks, and as such contributes to a higher volume of information available for analysis. This can significantly reduce or eliminate the initial data gathering phase of any improvement projects and allow more emphasis on analytics.

Chapter 5: Conclusion

5.1 Summary

This thesis introduces an ERP system for the purpose of data collection and to ensure proper material levels in order to maintain continuous production. The current practice employs simple spreadsheets and a significant amount of paperwork. The motivations behind the proposed system include the continuous improvement and technological advancement of manufacturing companies as well as their desire to go paperless. Another motivation is the reduction of confusion and information loss caused by constant emails, paperwork, and face-to-face or telephone conversations. By providing a unified system into which all information is entered, mistakes and confusion are substantially reduced. The developed ERP system is able to be scaled upwards to a larger corporation. Currently, the industrial partner is considered to be a small business; but, with programs such as the proposed ERP system in place, growth will occur naturally as the company becomes more organized and is able to consistently run at peak efficiency. The combination of QC inspection reports for each panel ensures that quality is maintained at the highest level. The inspector who carried out the inspection is listed on each report in order to instill a level of responsibility and to assist in addressing any identified issues, thereby leading to quicker problem-solving. Purchasing with inventory control is essential for maintaining continuous production. The proposed ERP system reduces the amount of work for users in order to reduce human errors and inefficiency. This assists the company to achieve their goals, which include applying lean principles to manufacturing operations; providing value according to the customer; working in value streams; maximizing the flow and pull; empowering company personnel; and seeking continuous improvement. The flexible nature of the QuickBase program allows for industrial engineers to apply continuous improvement to a custom product, which off-the-shelf ERP systems do not offer. Due to the highly customizable nature of light gauge steel construction and the variations among projects, and since light gauge steel can be applied to a range of building heights, it is essential to develop a program that is equally flexible and customizable, yet able to remain within its constraints.

By conducting time study within the program, the production team and owners are able to observe any changes made to any given station and the effects of these changes on production time. Any manufacturing improvements can use various indicators within the ERP system such as time or pass/fail threshold. For the proposed ERP system, by reducing the amount of manual paperwork and the errors that can result, cost-saving methods are being applied and the return on investment is the primary point of measurement for this program. The system has been proven to help reduce redundant tasks, simplify procedures, and become an efficient real-time information system.

5.2 Results and Contribution

The research presented in this thesis offers the following contributions:

(1) The development of a highly customized ERP system in conjunction with the industry partner's business plan and aim to "go paperless" in order to become a more environmentally-conscious corporation.

(2) Adjustment of procedure to incorporate the digital system into daily business operations. By implementing this program, tasks have been added to or updated for certain jobs.

(3) From a data collection point of view, fresh information can be continuously logged at a steady pace. When one person is responsible for collecting all information for an entire company, it becomes a tedious and repetitive task; but when every employee adds information, the amount of data and the speed at which it flows is significant. There may be a point at which the amount of data flowing in and out of the system renders some data points obsolete or useless, which can be distinguished via data analysis. Manual data collection can be tedious and may result in having insufficient and inaccurate data since it only provides a snapshot study of the process. Automated data collection will ensure both sufficient and accurate data capture.

(4) Due to the proposed system, information searching is less taxing. All information is housed within one database and the addition of a search function bar improves the efficiency of this process. Although the system interface is set up using several individual tables, information is more readily accessible as long as the user has the proper permission to access that specific information.

5.3 Research Limitation

This research and development is subject to several limitations as follows.

(1) The program itself, QuickBase, has limitations such that the visual representation of data, such as by a bar graph or line graph, is extremely limited in comparison to the various chart types available in Excel. QuickBase operates similar to an excel sheet where each horizontal line is recognized as one record. QuickBase primarily serves as a database program where information is entered and properly stored.

(2) Some inflexibility in QuickBase requires workarounds such as in creating Purchase Orders. The program forces the user to save the Purchase Order first and then allows them to "Add Purchased Items", which is an extra step in the Purchase Order process. Currently, users are bound by its API limitation, but future iterations of the software may reduce or eliminate these limitations.

(3) The amount of information collected on the production floor is limited. For the purpose of this thesis, it is assumed that at every station the operator will select the "Start" button at the beginning of their work on a particular wall panel and will select "End" when they have completed their task. The end goal is to develop a simple user-friendly interface that allows workers to effectively utilize new technology. The proposed ERP system is new to the industry partner, and the industry itself has a high turnover rate. As a result, training of new staff is a common occurrence. Due to the high turnover rate, new employees will require a training period to learn how to enter information as they work, resulting in errors and necessary corrections. This creates a gap in the collected data and the need for manual entry of information in order to make up for the gap; it also creates a need for constant supervision of workers to ensure proper data entry during the training process.

5.4 Future Improvement

The proposed methodology is the basis of an ERP system that will result in more effective manufacturing processes in terms of cost and time. The program is in a continuous development cycle and future updates will allow it to become as powerful as Out-of-box software found on the market. The following points outline some requests from the industry partner and other improvements that will be investigated and developed in the future:

(1) A more accurate and robust BOM will be developed and inputted into the ERP system. Currently, based on the information provided, the ERP provides a rough estimate of the materials needed for a specific panel. Also, certain items such as drywall and AVB paint are roughly estimated. Future work involves the optimization of material amounts, which will be used as inputs for the ERP system. The method of creating BOMs will also be changed and optimized as future production plans involve the in-house production of light gauge steel rather than the purchase of specific cut pieces from a third party supplier. This will help control steel inventory and also change how the BOM will be coded into the program.

(2) In order to truly become paperless, production drawings of the wall panel being produced need to be uploaded into the system and viewed by the workers at each station rather than the drawing being transported from station to station with the panel itself. The current process of manually transporting the paper-based shop drawings often results in the drawings being lost or damaged. Revisions made by

the design team will become easier to control and redistribute if the shop drawings are distributed electronically.

(3) Current connections between apps are minimal and constantly under development for optimization purposes. As the ERP system develops over time, the transfer of data between apps will become more complex. As QuickBase releases future updates, various unforeseen changes will need to be addressed. The program will be equipped with a central database, which will send and receive information from other databases; however, data analysis and optimization will occur at the central database at the highest level. The implementation of the ERP system within QuickBase at the industrial partner’s facility is a fresh change that requires continuous development and customization.

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Appendix

Excerpt from code for ERP technology design algorithm

```
URLRoot() & "db/" & Dbid() & "?a=API_EditRecord&rid=" & [Record ID#] &
"&_fid_10=1&_fid_xy=Shipped"
& "&rdr=" & URLEncode(URLRoot() & "db/" & Dbid() & "?a=dr&rid=" & [Record ID#])
```

```
URLRoot() & "db/" & Dbid() & "?act=API_EditRecord&rid=" &ToText([Record ID#])
& "&_fid_25=" & ToText([Quantity]-1) &"&rdr=" &
URLEncode(URLRoot() & "db/" & Dbid() &
"?a=dr&rid=" & [Record ID#])
```

```
Hours([Start Time]-[End Time])
```

```
<qdbapi>
<usertoken>********</usertoken>
<rid>[Record ID#]</rid>
<records_csv>
<![CDATA[
%RepeatOn%
[new.Record ID#.csv],[new.Now.csv]
%RepeatOff%
]]></records_csv>
<clist>3.25</clist>
<skipfirst>0</skipfirst>
</qdbapi>
```

```
URLRoot() & "db/" & Dbid() & "?a=API_EditRecord&rid=" & [Record ID#] &
"&_fid_15=Waiting on Admin Approval"
& "&_fid_80=" & URLEncode([User and Time] & " Request Ready")
& "&rdr=" & URLEncode(URLRoot() & "db/" & Dbid() & "?a=dr&rid=" & [Record ID#])
```

```
" If([Date Field A]] <= Today(), [Date Field B] - [Date Field A]) "
```