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Work Order and Subassembly Identification and Tracking System

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Work Order and Subassembly Identification and Tracking System

By

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Work Order and Subassembly Identification and Tracking System

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ABSTRACT

The research encompassed in this thesis includes the development of a work order and subassembly identification and tracking software system created in-house and tested at SPM Automation (Canada) Inc. The research is motivated by the significant losses the company is enduring and the recurring problems occurring at the facility (i.e., excess inventory, late ordering, reordering, misplaced components, etc.). These problems are critical in the progress and profits of the company.

An extensive literature review was completed, and the research gaps were presented. The optimal work order and subassembly process was created using Process Mapping Methodology, Cause-and-Effect Diagrams, and 5Why Analysis. The software architecture diagrams were developed and used to code and program the software. The software was tested on five work orders and results were compared against a previous job. Application of the developed system minimized late ordering by 67%, reordering by 50%, and number of changes to project timelines by 71%. The occurrences of misplaced components for the specific job tested were eliminated using the developed solution.

A cost structure model was used to illustrate the associated costs and benefits of the developed system. There would be a one-time cost for training SPM employees, however, the benefits outweigh the training cost significantly. It was estimated that the implementation of this software system could give the company an average annual cost saving of approximately $40,884 and a time decrease of 77.78%. Since the software system is created in-house, there would be minimal additional costs for implementation and continuous software support. Work order and subassembly tracking issues are not unique to SPM Automation (Canada) Inc. Many small and medium size manufacturing companies are facing these challenges. The methodologies developed in this research would be applicable and useful to other discrete parts manufacturers.

DEDICATION

To my family and friends

ACKNOWLEDGEMENT

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF EQUATIONS

CHAPTER 1: INTRODUCTION

1.1 SPM Automation (Canada) Inc.

SPM Automation (Canada) Inc. (SPM) is a Tier 1 equipment supplier that manufactures automation equipment for plastics joining, finishing and assembly applications. Their work is tailored towards the automotive industry. Their customers vary from companies like Flex-N-Gate, YAPP USA Automotive, and Magna International.

1.2 Subassembly Definitions and Importance

(Shi et al., 2020) states that the "assembly [process] is the most important and time-consuming step in the whole product life cycle." This is because it plays a crucial role in the build of the final product. That being said, it accounts for approximately "50% of manufacturing hours and [at least] 20% of total costs" (Shi et al., 2020). To properly build and manage assemblies, subassemblies are created prior and combined with other subassemblies, according to a specific project timeline that must be achieved.

Merriam-Webster Dictionary defines a subassembly as "an assembled unit designed to be incorporated with other units in a finished product" (Merriam-Webster Dictionary, n.d.).

Universal Logistics Holdings Inc. also defines a subassembly as "the process that combines or builds components into component assemblies for inclusion in larger end items. It is the combining of components to create a new parent that requires assembly. This is a manufacturing process in and of itself" (Universal Logistics Holdings Inc, 2016).

It is proven that subassembly identification reduces the time for overall assembly (Venkata Rao, 2017). It is also proven that separating an assembly into subassemblies aids in the design, manufacturing, and assembly of the final product (Mathew et al., 2013). Moreover, tracing subassemblies throughout the entire manufacturing process ensures detailed documentation and flow of its history (Keating, 2011).

1.3 Research Problem Statement

SPM Machines are broken down into assemblies and subassemblies. All items needed for the build of a machine at SPM are categorized with their respective subassemblies. These subassemblies are placed into bins and labelled with their respective work order number for easier access for the assemblers. There is no tracking of the work orders within the facility. Once the bin is complete, meaning all items on the work order are in the bin, the assembler grabs the bin and begins to work on it. This is done manually, and there is no tracking of where the subassembly bin is once it is taken out of the Crib, who has it, and how long they have had it. This leads to recurring problems like reordering parts that may have been taken out of a bin, misplaced parts and waiting for subassembly bins. Sometimes, employees must double-check if items have been ordered or arrived and where they are within the facility.

One of the main goals of any company or facility is to minimize wastes. Waste, also known as Muda, is anything that does not add value to a product or service. Typical examples of Mudas within a manufacturing facility would be rework and a surplus of inventory (Khan, 2019).

Bernie Roseke, P.Eng, PMP, wrote an article that lists and explains the seven recognized types of Muda within the manufacturing world. They are (1) overproduction, (2) waiting, (3) transportation, (4) over processing, (5) movement, (6) inventory, and (7) making defective parts (Roseke, 2019). Recall the information presented above; it is evident that these wastes are affecting the facility's performance. Figure 1 below illustrates the wastes related to recurring work order and subassembly tracking problems.

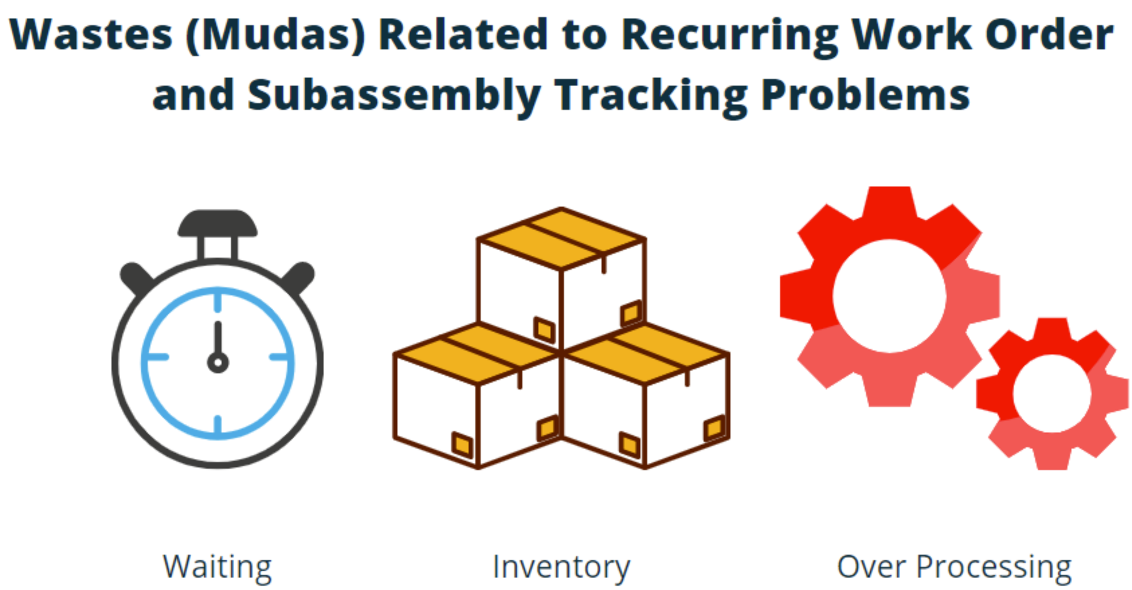


Figure 1- Wastes (Mudas) Related to Recurring Work Order and Subassembly Tracking Problems

1.4 Research Motivation

The motivation of this research stems from the significant losses the facility is enduring. Time and money are being unnecessarily spent, resulting in excess expenses. Moreover, because of SPM's unique environment, it is challenging to find and purchase a software system that can be used for their specific needs. The Crib has an entirely different purpose and process compared to other facility environments. Also, looking at the research gap discussion in Chapter 2, one can see the research gap presented regarding the development of a work order and subassembly identification and tracking software system.

1.5 Objectives

The objective of this research encompasses the identification and tracking of work orders and subassemblies for more efficient retrieval, tracing, and handling. This will include the development of an in-house work order and subassembly identification and tracking software system.

1.5.1 Hypothesis

If work orders and subassemblies are identified and tracked within a software tracking system, then recurring problems, such as:

- Excess inventory
- Late ordering,
- Reordering,
- Misplaced components, and
- Changes to project timeline

will be minimized or eliminated.

1.6 Stakeholders

The stakeholders of this research are the employers, employees, customers, and suppliers of SPM and the Faculty of Engineering at the University of Windsor.

1.7 Resources Required

The primary resource required to complete this research is access to relevant data from the Crib at SPM, along with the shop floor and any other departments involved. Other resources include computers, barcode scanner, SPM Connect software, and the Mechanical Designer / Software Developer used for the coding, programming, and testing of the developed software.

1.8 Thesis Outline

The following chapters dive into the conducted research, data gathering, analysis, and conclusions of this thesis. Chapter 2 presents the literature review on a variety of topics covered within academia and industry. Chapter 3 discusses the initial work order and subassembly process, optimal work order and subassembly process, software architecture diagrams, and other tools and concepts (i.e., IDEF0, Pahl and Beitz, Zachman Framework, etc.). Chapter 4 is the testing of the data presented in Chapter 3 (case study example). Chapter 5 goes over the results and discussion of the case study example. The last chapter, Chapter 6, includes the research contribution, significance and conclusions, and areas for future research.

CHAPTER 2: LITERATURE REVIEW

2.1 Overview

Industry 4.0 (I4.0) has been around for almost a decade and has drastically improved society's functionality regarding to accessibility, productivity, and efficiency. It has introduced various technologies that are constantly used by thousands of companies worldwide. Figure 2 below illustrates the technologies that I4.0 has introduced over the years, adapted from (Saturno et al., 2017). One can see how many of these pillars can be applied to this thesis—the first being cybersecurity.

Cybersecurity aims to protect online private information and data from external attacks and access (Groot, 2020). This can be applied because SPM is already centred around cybersecurity and uses it every day to ensure external attacks do not happen. This thesis will have cybersecurity incorporated in it, as the SPM Connect software utilizes the tool. This follows into the second pillar, which is RFID technologies. RFID stands for radio-frequency identifier and is defined by AB&R as "a technology whereby digital data encoded in RFID tags or smart labels are captured by a reader via radio waves" (AB&R, 2020). RFID technologies are used within inventory management systems and would be a potential pillar used in this thesis. These are just some of the pillars that can be integrated into this thesis. Others include the Internet of Things (IoT), data analytics, mobile APS, and cloud computing. One can see that inventory management systems have a broad range of I4.0 pillars that can be utilized to aid in security, efficiency, and effectiveness.

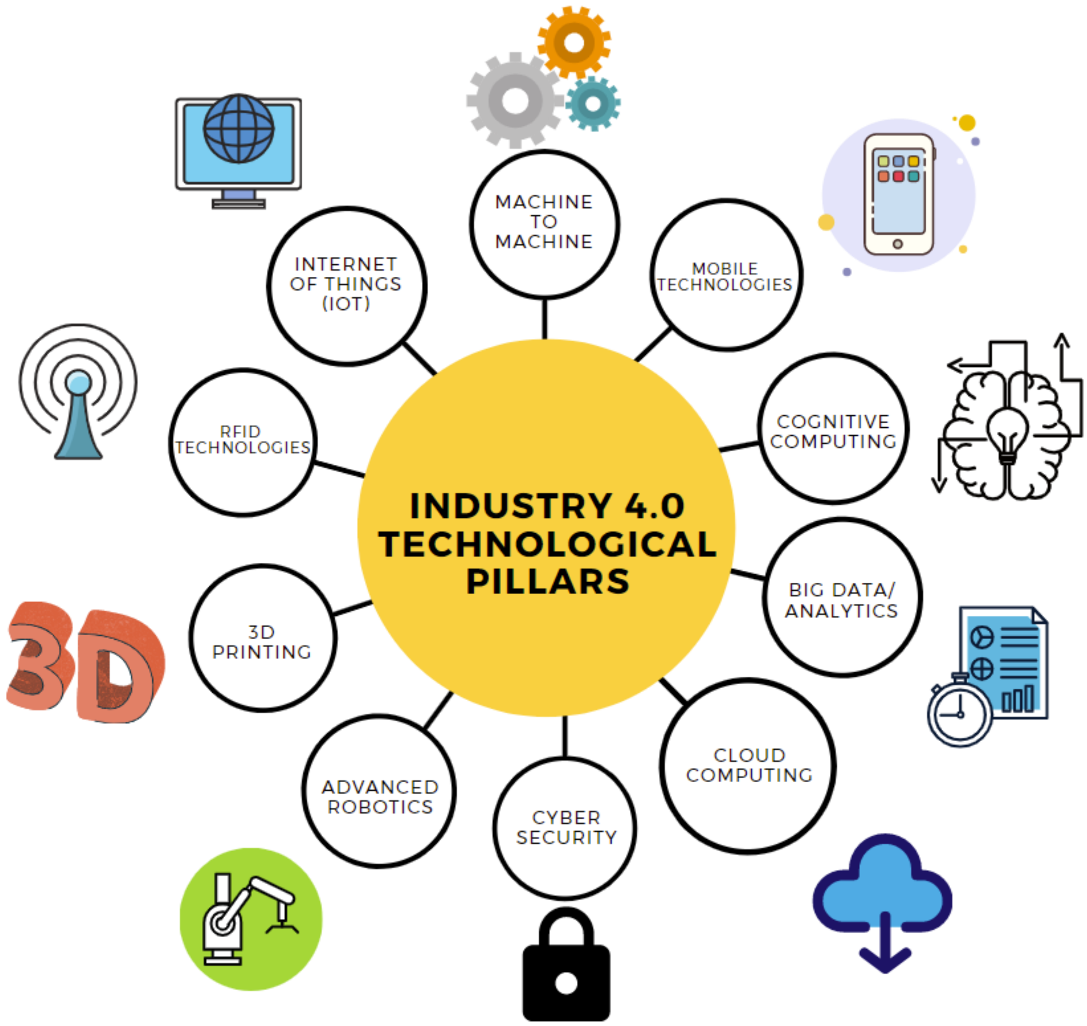


Figure 2- Industry 4.0 Technological Pillars, adapted from (Saturno et al., 2017)

Below is the literature review that was conducted for this thesis. It is separated by each respective topic and includes research catered to both academia and industry.

2.1.1 Product/Part Traceability

(Hu, Zhu, & Zhou, 2018) proposed using a document type, NoSQL, to solve three main recurring problems when dealing with complex data for product traceability systems. The system is composed of an entity-relationship model and a relational database. When there is a large amount of data that the system cannot handle, specific problems occur. These are entity/table explosion, query disaster, and sorting. Entity/table explosion occurs when the system cannot track all the data and ends up "exploding." Query disaster is a result of entity/table explosion. This is due to too much detailed data inputted into the system. Sorting problems happen when there are multiple streams the data can flow to. This problem was addressed by using NoSQL. NoSQL, as defined by the authors, is a "database [that] provides a mechanism for storage and retrieval of data that is modelled in means other than the tabular relations used in relational database." Since NoSQL is non-relational, it can store multiple data structures linked to a product under one "table." This characteristic can solve entity/table explosion, and therefore, solve query disaster. This was implemented in a case study for pleurotus eryngii, a type of mushroom agriculture. It was concluded that using NoSQL can eliminate the three problems stated. It can also be applied to products with higher complexity.

(Lu & Xu, 2017) proposed a method to trace products using a blockchain system. This system, OriginChain, replaces a company's current central database with a blockchain. As defined by the authors, a blockchain is "an ordered list of blocks that contain transactions such as monetary transfers and smart-contract creation and invocation." The problem was addressed by altering a company's service provider traceability and replacing it with OriginChain. This resulted in improvements to traceability and clarity through all the processes involved. Because of OriginChain's lack of data privacy, it poses a security risk. The authors concluded adopting this method would cost a lot of money. There will also be a big learning curve, as it is a new system that all users must learn how to use correctly. Lastly, it is not a secure system, making it an option many companies would avoid.

(Savino, Xiang, & Menanno, 2017) proposed creating a software system that traces items throughout a production process. The motivation behind this idea links to the standards of ISO 9001:2015. It is required by employers to have some sort of traceability system to be ISO certified. This was addressed by developing a traceability software using Unified Modeling Language (UML) and a traceability software tool. The authors define UML as "a formal graphic tool that can be used to describe structure and behaviour of a software system." The traceability software tool used was Traceability Link System Software (TLSS). This system consists of four phases. They are as follows: software requirements, product identification, data linking, and database core design. The prototype was tested at a juice production facility. It was concluded that the software improved product quality and traceability. However, it does not focus on specific processes within the overall production process. This means data extracted from this study was based on the bigger picture.

(Sánchez et al., 2015) proposed a new computerized framework based on cyber-physical systems (CPS) for developing traceability systems in small manufacturing companies. The framework (TF4SM) allows real-time traceability and process monitoring through a flexible, open architecture capable of adapting to all types of manufacturing companies. This was done by taking the reference CPS architecture regarding RFID-based traceability systems and altering it to meet the requirements needed for small manufacturing companies. Once the TF4SM architecture was created, the system was tested using RFID tags to scan to track their progress. This was done to keep track of the number of items in the warehouse and what the employee was working on. It was concluded TF4SM decreased inefficiencies compared to traditional traceability systems. Although the system reduces inefficiencies, it does not eliminate them. Moreover, it is not catered for dynamic environments.

(Nelson, 2003) proposed a traceability system that aids with and prevents product defects/recalls. A process implementation breakdown is provided to improve the delivery and recalls of products. The two goals of this system are to decrease the number of recalls/defects and prevent them or catch them prior to being shipped to the customer. In order to achieve these goals, a series of processes must be implemented and created. Firstly, process planning and manufacturing execution systems (MES) must be present. These are critical factors in the development of a traceability system. Linking these two together will result in product and component traceability. Moreover, the steps needed in a traceability system are as follows: identification, tracking and process management, and verification. The system must also track all information related to the product's process. This means who worked on the product, the machines utilized, the location it was assembled, etc. Lastly, a step-by-step verification management system must be integrated to prevent unnecessary tasks and errors. This is similar to an online checklist, where an operator is walked through the entire process and has a list of things they should have completed before sending the product to the next station. The system was developed and tested using data collected. It was concluded that a decrease in defects/recalls was present. If used properly, it is predicted that this system can eliminate recalls and improve the overall process of any facility.

(Jansen-Vullers, Van Dorp, & Beulens, 2003) proposed a method for designing traceability information systems. This was done using the concept of gozinto graphs. A gozinto graph is defined as an overall collection of all the raw materials, parts, intermediates, and subassemblies. Their primary purpose is to illustrate the process flow from the beginning (raw materials) to the end (final product), along with the operations performed. This method takes the gozinto graph and applies the concepts of traceability. A reference data model was established to test the proposed method. It was concluded that future work could involve the ability to conduct multiple inputs and output processes. There is also room for improvement of the system with regards to product quality and recalls.

(TruTrace Technologies, 2019) Deloitte and TruTrace Technologies Inc. have partnered up and proposed a product traceability solution targeted towards the cannabis industry. This is implemented using blockchain databases. Aside from tracking products, the database keeps information secured for Intellectual Property (IP) protection and strain validation. This means that all products must complement their credibility source. This also plays into the safety and quality of the products and process, making it more reliable and transparent. This solution increases customer trust, loyalty, and satisfaction. It also provides accurate information and shipment dates and ensures credible and verified products.

(Ford, 2016) Michael Ford from Mentor Graphics, an industry corporation, developed a standard for tracing parts. This standard, IPC-1782, is flexible in terms of its adaptability within any industry setting. The goals of the standard are to increase efficiency, productivity, quality, and reliability. It is comprised of four (4) levels.

Level 1 “Basic”:

- Manual data entry (potential mix with a computerized system)
- Assemblies grouped and identified using work orders
- Materials and parts not identified

Level 2 “Standard”:

- Fully computerized system
- Materials and assemblies identified

Level 3 “Advanced”:

- More specific processes and materials
- Faster
- “Smarter” (automation and data)

Level 4 “Comprehensive”:

- Highest level
- Material and traceability data collected
- Extreme detail to processes and data

2.1.2 Inventory Management Systems

(Silver, 2008) discussed the concept of inventory management, along with various practical applications within Canadian companies and organizations. Some examples include the Canadian Army, Royal Canadian Mint, IBM, and Bell Canada. The paper also identifies the gaps between theory-based inventory management methods and practical implementation of the concept. Although researchers have come a long way in understanding and developing the concept, there is still research to be done to merge both aspects further together. Several potential research topics are introduced for the contribution of minimizing the gaps.

(Atieh et al., 2016) proposed two main concepts in their investigation of a warehouse for a telecommunications service provider in Jordan. The first concept was to study the supply chain processes in the warehouse and customize a software that will increase efficiency and reliability. The software was tailored to this specific warehouse and its environment. The warehouse management system consists of three phases of the product life cycle. They are receiving, processing, and distribution. These phases were discussed in detail. This solution proposed their second concept of adding a production station that will include three stages – bundling, labelling, and repackaging. The primary outcome of this study is the breakdown of the similarities and differences of software and traditional management systems and how they can be utilized for increasing productivity. It was concluded a software management system outweighs a manual management system in many positive aspects. One main aspect is the controlling and monitoring of product handling. The overall warehouse process has increased in efficiency, reliability, and productivity.

(Kara & Dogan, 2018) investigated the inventory management system of perishable goods to determine which type of ordering policy would be best suited to ensure products are being tracked by age information. Two different policies were proposed that can aid in this problem. The first policy, stock-based policy, involves the replenishment of stock based on their quantities. The second policy, age-based policy, involves the replenishment of stock based on the level of inventory and age of products. These policies were tested using a model software called Reinforcement Learning (RL) and algorithms called Q-learning and Sarsa. A cost analysis was created for both policies to compare policies with regards to long-term financial benefits. It was concluded that the age-based policy provided overall better results. Moreover, the Sarsa algorithm presented better results concerning cost performance. This solution can aid in the management of perishable inventory systems and minimize total retail costs.

(Duong, Wood, & Wang 2015) proposed a simulation model with specifically tailored metrics to investigate an inventory management system catered towards perishable and substitutable products. This model is intended to be easily understandable and integrable for professionals. It manages realistic situations by including various inventory methods that coincide with cross-functional continuous improvements. Moreover, an analysis of inventory theory was conducted to examine products that have multi-period lifetimes, lead times, and customer service levels. It was concluded that the model presented can analyze various input factors. These include product lifetime, lead time, and substitution ratio. These factors provide a foundation and understanding of how perishable and substitutable products can be managed, and performance metrics can be improved.

(Alyahya, Wang, & Bennette, 2016) proposed an algorithm that manipulates RFID-tacked items to determine where their final location should be and send them there. It also eliminates long wait times by prioritizing items with longer travel times. This is done by assigning each item a priority using pre-defined metrics. This was implemented by conducting a pilot test to determine if the application is feasible in an RFID-based management system. Theoretically, this system can be used and adapted to fit into any RFID-based system by adjusting the pre-defined metrics. However, due to the pilot test being based on a small number of items, an accurate representation is not given. Warehouses contain large amounts of items, so this process may bring up issues and concerns. It was concluded that further analysis and studies are needed. Future work tailored towards different computerized simulation softwares would be the next step in improving RFID-based warehouse systems.

(Almaktoom, 2017) proposed a method of measuring the reliability of inventory management systems. The method introduced the idea of creating a model that is capable of assigning and scheduling time while considering uncertainty factors. This is done by determining the target time for each step in the process and scheduling accordingly. It also has the ability to decrease buffers and downtime. The processes investigated using the model are listed as follows: purchasing, shipping, receiving, tracking, warehousing, storage, and turnover. The model was implemented at a furniture company in Saudi Arabia to determine the overall effectiveness. It was concluded that the model created and tested minimized the uncertainty in the company. This resulted in improved customer satisfaction.

(Deloitte, 2020) proposed a method to optimize inventory by introducing Supplier Managed Inventory (SMI). This inventory method consists of suppliers managing specific inventory for a specified period. This was implemented using a case study at a utility company. It was concluded that 80% of total inventory decreased and 6% of total costs. Moreover, 1500 transactions that were originally done annually were no longer necessary. Lastly, the company experienced an increase in revenue due to the availability of the warehouse since inventory is no longer being stored there.

(Ellingrud, 2020) published an article in Forbes that discusses supply chain resilience. With the unprecedented year of 2020 and its overall uncertainty, companies are now looking into new inventory management approaches instead of the traditional Just-In-Time (JIT) approach, with 93% planning to increase their supply chain's flexibility and transparency. It is stated that McKinsey Global Institute researched the risk and resilience associated with

23 different value chains. It was concluded that companies could lose a year's worth of profit from a significant disturbance in the supply chain. One way to increase the resilience of supply chains is to develop a database that includes all suppliers and parts. Also, the use of digitalization plays an essential role in supply chain transparency. Having fully computerized systems increases efficiency and effectiveness and decreases costs and time. A case study about a chemical manufacturer is discussed. The company decided to increase its use of digitalization by 30%. It was concluded that this increase helped the company by identifying issues and increased its production throughout the COVID-19 Pandemic.

(Inbound Logistics, 2020) discusses an industry example of a company that increased its inventory performance using drone technology. Romark Logistics was having issues with its inventory management system. The aisles that stored their inventory are too narrow, and counting the inventory resulted in excess time and labour. Inventory is placed in wooden pallets with assigned barcodes on the front. The company decided to invest in drone technologies to increase efficiency and productivity. It was concluded that drone technologies were the most efficient method of counting the pallets. They are also used to determine which pallets are empty. The drones can scan and read the barcodes on the pallets. This solution does not interfere with production and ensures the safety of employees working on the floor.

(Bustamante et al., 2020) published an article in McKinsey & Company that discusses the positive impacts of digital twin on warehouse performance. The ability to experiment with various warehouse metrics digitally saves companies time and money. Two metrics stated in this article are floor plans and workflows. This method is a part of inventory management, as it directly affects a company's tangible assets. Moreover, seeing potential results prior to physically moving around items in the warehouse is a game-changer for many companies. A digital twin is also proven to increase overall efficiency by 20-25%. An example of a North American manufacturer is discussed. The company decided to use a digital twin to mimic their warehouse. This was used to analyze three main sections: warehousing, kitting, and value-added operations. It was concluded that the company decreased its overall costs by over 30%. Another example of another company is discussed. This company used digital twin technology to experiment with potential operational improvements within the warehouse. This was done without disturbing the current production flow. This allowed the company to choose a design that was best for them, all while ensuring their production is not disturbed. This resulted in an 18% decrease in expenses.

(Lyu et al., 2020) introduced a model named Zero-Warehousing Smart Manufacturing (ZWSM). The purpose of this concept is to minimize and eliminate non-value-added activities that exist within warehousing environments. To do so, a ZWSM platform was created. This platform consists of three main levels. They are as follows: smart infrastructures, Data Source Management Service (DSMS), and Decision Support Service (DSS). IoT-enabled infrastructures and tools are also used to ensure efficiency and accuracy. A case study of a construction company in Hong Kong is discussed. It was concluded that the integration of ZWSM and the ZWSM platform improved the logistics and overall communication.

2.1.3 Spare Parts Inventory

(Yang & Niu, 2009) proposed a model for spare parts inventory management. They stated that the management of spare parts inventories consists of a correspondence of inventory costs and costs and risks of no stock available on hand. Different inventory classification methodologies were present and explained. These include ABC Classification, Maintenance Mode Classification, FSN Classification, VED Analysis, and ADI Classification. It was concluded that spare parts play an active role in industries related to capital equipment. Various manufacturing and assembly process companies deal with spare parts in their inventory systems. Depending on the type of inventory environment, classification methodologies can be implemented to minimize unnecessary inventory costs and costs and risks associated with no stock available on hand.

(Liu, Liu, & Deng, 2020) proposed two second-order cone constraints and an outer approximation algorithm that can be integrated into a mixed-integer nonlinear programming problem. This problem was based on a level of repair analysis and inventory control problem used in the article. It was concluded that the algorithm improved efficiency within many spare parts in inventory. It also made the inventory process flow smoother.

(Bousdekis et al., 2017) proposed a decision model for predictive maintenance and enhancements of spare parts inventory. This model can be integrated into an Event Drive Architecture (EDA) to improve the overall processing time of the scenario. The model was tested in a lighting equipment company. It was concluded that inventory and maintenance costs decreased drastically after implementing the model in the company. This was due to replacing the traditional time-based strategy with a Condition Based Maintenance (CBM) strategy.

(Hasan et al., 2020) proposed a blockchain solution to track spare parts from the first point of contact, manufacturing facilities, to the last point of contact, customers. This system tracks storage using Interplanetary File Systems (IPFS) to communicate specific data about any available spare part in inventory. Testing was conducted to ensure the system flows smoothly and effectively. A cost analysis was also presented to illustrate the overall breakdown of the system and how a blockchain solution is more efficient and effective in the long run. It was concluded that blockchain spare parts tracking has many benefits. It is cost-efficient, reliable, fast, and secure. Like any new system, integration and implementation in a new environment will take some time. However, the learning curve is exponential and therefore, it will be a smooth transition for all parties involved.

(Zhang & Wu, 2017) proposed a spare parts inventory management system that considers two different types of spare parts classifications. These classifications are consumable and contingent parts. Consumable parts are for preventive maintenance, while contingent parts are for repairs and breakdowns. Depending on the type of part, the system tracks them through a cyber-physical inventory management system, having a system for each part type. This system collects data on the parts and develops a guideline for each machine to ensure the correct components and quantities are being utilized and ordered. Two main concepts needed for this system to function are the Internet of Things (IoT) and Big Data Analytics. The system was created and tested in a manufacturing company in Singapore. It was concluded that the system could improve the ordering, tracing, and reliability of spare parts. It also allows users to have a better understanding of when contingent parts should be ordered, depending on time and cost constraints.

(Zhu, Jaarsveld, & Dekkerc, 2020) proposed a forecasting solution that consists of a maintenance plan and dynamic inventory control method to predict spare part demand distribution. It was concluded that this proposed solution improved overall costs by 23-51% compared to traditional solutions currently being used in Industry. It is evident that this method of forecasting demand has outstanding benefits for both short- and long-term timelines.

(Wang, 2012) proposed a model that uses enumeration and a stochastic dynamic programming algorithm to improve the process of ordering spare parts, specifically spare parts quantities. Preventive maintenance (PM) is also a touchpoint that is investigated and integrated into the model. It was concluded that the model was successful in generating the best possible solution. Moreover, it was stated that the testing of the model showed the commonalities between spare parts and PM and how they should be tracked and monitored simultaneously for optimal efficiency.

(Molenaers et al., 2012) proposed a classification method that ranks spare part items by priority. The method ranks each item given the information inputted. The rankings are four categories: high, medium, low, no. The categories represent the items' critical, or priority, level. The method was tested in a petrochemical plant. It was concluded that the implementation of the method increased the overall efficiency of the spare parts inventory control process. Moreover, identifying and locating priority spare parts was easier, as they have been grouped into a classification and can be easily found.

(Sheikh-Zadeh, Farhangi, & Rossetti, 2020) proposed a new method for developing an optimal inventory grouping system for spare parts. This method is adapted from the multi-echelon repairable parts stocking model. A heuristic optimization model was also created to enhance the ability for the integration of both methods. Conditions placed on the model abide by the constraint that all the parts have similar stocking policies. It was concluded that grouping parts with similar stocking policies decreased costs and increased efficiency with regards to inventory management. It also made the ordering and tracking parts easier, as parts with similar stocking policies have similar characteristics.

(Baldesi, Kervazo, & Lavandier, 2019) published an article in McKinsey & Company that discusses the financial impacts of spare parts inventory. It is stated that "10-40 percent of inventory is made up of slow-moving items". These items are usually kept because of contract agreements or in case any potential opportunity arises. A case study about an equipment manufacturer is discussed. The company implemented a plan to identify and separate parts based on their age (length of time in inventory) and demand. This helped see which items are actively being used, excess, and obsolete or "slow-moving" items. A service-level review and cash metrics were also implemented. Sales and operational planning processes were also revised and improved. It was concluded that after six months of these improvements, the "slow-moving" inventory decreased by one-third in 3 months, while spare parts revenue increased by approximately 3%.

2.1.4 Dynamic Environments

(Lim et al., 2015) proposed implementing a planning and scheduling software system to solve daily production challenges of make-to-order high-mix-low-volume small and medium scale industries (MTO HMLV SMIs). This was done by addressing factors like products, processes, and resources using the software created. It was implemented in two local manufacturing companies over the course of one year. It was concluded that the system improved the company's overall production and efficiency of the processes. Although the system was deemed successful, it did not specifically trace products through the system, meaning it has no access to product traceability.

(Jain et al., 2020) published an article in McKinsey & Company that discusses dynamic risk management. Companies need to implement and monitor their approach to dynamic risk management to ensure a plan is present when unprecedented times occur. The importance of this is especially seen in 2020's economy, with the COVID-19 Pandemic. Dynamic risk management consists of three main components. They are as follows:

- Detect risks and control weaknesses
- Delimit risk appetite
- Decide on risk management approach

It is essential for companies to start investing time and resources into building a dynamic risk management approach. The economy has shifted, and uncertainty is growing faster than before. It was concluded that companies could take the following five actions for dynamic risk management:

1. Reset aspiration for risk management,
2. Establish agile risk management practices,
3. Harness power of data and analytics,
4. Develop risk talent for the future, and
5. Fortify risk culture

(Ferrari et al., 2020) proposed a model that can aid in the monitoring of dynamic manufacturing environments. This model includes the application of Dynamic Life Cycle Assessment (LCA) systems and how they can be used within an Enterprise Resource Planning (ERP) software. LCA is an important factor companies must consider when analyzing their environments, as Life Cycle Inventory (LCI) is a part of this assessment. It is also mainly incorporated within Industry 4.0 environments. A case study of a ceramic tile manufacturer is discussed. An LCA tool was incorporated in their ERP system, with the help of Business Intelligence (BI) software. The model was tested on a variety of scenarios, specifically static and dynamic environments. It was concluded that Dynamic LCA could successfully monitor and analyze the manufacturing environment presented. This, in turn, can potentially increase a company's readiness and proactive measures related to any dynamic changes.

2.1.5 Product Families

(H. ElMaraghy et al., 2017) proposed a method of introducing a new product family within a dynamic environment. This involved a variety of steps to ensure smooth transition and effectiveness. The steps consist of four enablers. They are listed as followed: mobility, modularity, scalability, and convertibility. The method was tested on a new product family of belt tensions in the Intelligent Manufacturing Systems Center (IMSC). It was concluded that the steps presented in this paper were successful in implementing and integrating the new product family into the existing one.

(Takai, 2018) proposed a framework that encompasses commonality, product family design, and inventory decisions. The main purpose of this framework is to be able to optimize the three factors stated. This was done by introducing a profit formula that specifically included costs pertaining to inventory. They are as follows: holding cost, ordering cost, tracking cost, and understock cost. An example of beverage containers was discussed. It was concluded that considering inventory costs greatly impacts the commonality and product family design of the containers.

(Kim & Moon, 2017) proposed a methodology for the identification of sustainable platforms for product families. The platform consists of three elements. They are as follows: high sustainability, low risk to product design, and high commonality. Bayesian network and fizzy interference system are some of the tools used to create and implement the platform. The methodology and platform were tested on a group of coffee makers. It was concluded that the platform improved the visualization of the degree of sustainability for the coffee makers. It also made it easier to forecast potential designs with minimal costs.

(Yao, Moon, & Bi, 2016) proposed a methodology for product families applied within additive manufacturing platforms. This methodology is geared towards costs, as it primarily focuses on the estimation of production costs. A variety of tools and applications are used for the implementation of the platform. These include a fuzzy time-driven activity-based costing (FTDABC) approach, adaptive neuro-fuzzy interference system (ANFIS), and Mamdani-type expert system. A case study discusses the methodology's application on the design of a race car family. It was concluded that the platform increased performance while ensuring the minimization of production costs compared to other traditional platforms.

(Galizia et al., 2020) proposed a decision support system (DSS) that is used for product platform design. This system focuses on the selection of platforms in high-variety manufacturing environments. Median-joining phylogenetic networks (MJPN) are used for the design of the platform, while phylogenetic tree decomposition is used for the selection. The DSS was tested on a family of plastic valves. It was concluded that platform variety decreased by 60% and customization tasks by 20%. These reductions proved the system increased overall efficiency and decreased costs and time.

2.1.6 Product Structure / BOMs

(Jiao et al., 2000) proposed a data structure to integrate and analyze various business elements. These elements include customer ordering, product engineering, and operations planning. The data structure, Bill-of-Materials-and-Operations (BOMO), functions by combining both the bill of materials (BOM) and data transfer. The BOMO also monitors other internal business factors like order processing, engineering change control, production job planning, cost accounting, and capacity planning. A case study of a clock manufacturer is discussed. It was concluded that the production operations increased efficiency. Moreover, the overall management of production and internal factors stated improved.

(Kashkoush & ElMaraghy, 2013) proposed a new method of matching pairs of BOM trees within manufacturing environments. The purpose of matching pairs is to analyze and select the design with the greatest similarities. The significance of this method is that it uses linear time algorithms, whereas other traditional methods use state-of-the-art algorithms. A case study of centrifugal pumps is discussed. It was concluded that the implementation of BOM tree matching increased productivity and efficiency and decreased the time taken to retrieve information pertaining to designs and other processes.

(Kashkoush & ElMaraghy, Product Design Retrieval by Matching Bills of Materials, 2014) proposed a method to automatically recognize legacy designs that have the greatest similarities with one another. It is done by comparing legacy designs and then grouping them based on similar product BOM. This concept was adapted from the matching of phylogenetic trees within the stream of biological sciences. A case study of centrifugal pumps is discussed. It was concluded that using the method resulted in cost savings. An increase in productivity was also observed. This, in turn, increased overall efficiency. The increase was noticed within the following areas: process plans, fixtures, tools, programs, and relaying information.

(Kashkoush & ElMaraghy, Product family formation by matching Bill-of-Materials trees, 2016) proposed an integer programming model tailored towards BOM tree matching. This model focuses on the commonality and assembly structure of components. It is implemented by grouping product families by BOM tree matching and ranking them by hierarchical assembly structure. A case study of centrifugal pumps is discussed. It was concluded that the overall application of assembly increased. Moreover, the model has the ability to compute significant problems, making it more efficient and reliable.

2.1.7 Subassembly Identification and Tracking

(El Saadany & Jaber, 2011) developed a mathematical model for managing subassembly inventories. This was targeted towards returns' subassemblies. Returns' subassemblies are subassemblies that make use of used components. It was concluded that disassembled parts and components should be considered, as not doing so can lead to unfitting inventory choices.

(Wang & Liu, 2013) discuss various subassembly identification methods to increase the simplicity of assembly sequence planning for intricate products. The main goal is to break down subassemblies within an assembly for efficient identification and handling. In order to identify these subassemblies, assembly constraints must be acknowledged. They are as follows: topical, geometrical, and process constraints. These constraints are used in the assembly models to identify the subassemblies involved. It was concluded that there are three main steps to identify subassemblies. They involve a variety of tools like algorithms, programs, reasoning strategies, and virtual reality technologies.

(Shi et al., 2020) proposed a subassembly identification framework that is used within modelling programs that illustrate and design assemblies and products. It was concluded that this framework could help with the complexity of current subassembly identification methods.

2.1.8 Work Order Identification and Tracking

(Pendegraft, Kees, & Lawson, 1994) developed an in-house work order tracking system to eliminate the manual labour associated with work order tracking. This was done by creating a software system, which consisted of several databases, where all data would be stored, retrieved, and handled. The overall system cost the facility approximately $18,000. This amount did not account for the time associated with team meetings and research that was conducted. However, the amount was still cheaper than other alternatives. Moreover, implementing the system eliminated over time, and maintaining the software is done in-house, meaning there are no additional system fees. It was concluded that the implementation of the work order tracking system increased accuracy, efficiency, and reliability.

2.2 Literature Review Analysis

2.2.1 Subassembly Types

Analyzing the literature review presented, it was found that there are different types of subassemblies that are researched and discussed. The three main types are tangible and conventional, intangible and conventional, and tangible and returns.

Tangible – physical subassemblies that can be touched. These subassemblies are usually created by either personnel or machines.

Intangible – subassemblies that cannot be physically touched. Examples include subassemblies within design programs (i.e., AutoCAD, SolidWorks, Siemens NX, etc.). other examples are subassemblies within simulations or software programs.

Conventional – standard subassemblies. This is a term used to define a typical subassembly.

Returns – subassemblies that make use of used components (El Saadany & Jaber, 2011).

It is evident that there is research pertaining to intangible and conventional subassemblies (Wang & Liu, 2013), (Shi et al., 2020) and tangible and returns' subassemblies (El Saadany & Jaber, 2011). However, there is no research regarding tangible and conventional subassemblies tracking. These subassembly types are further analyzed in the Research Gaps in section 2.3 below.

2.2.2 Bibliometric Analyses

Bibliometric analyses for subassembly identification and work order tracking were created using the VOSviewer software and illustrated in Figures 3-6 below. The search engine used to determine the key words and form the bibliometric analyses was Scopus.

2.2.2.1 Subassembly Identification Bibliometric Analysis

The key words used in creating the figures below are Subassembly Identification, Subassembly, Manufacture, Planning, Assembly Planning, Assembly Sequence Planning, Assembly Sequence Generation, Assembly Sequence, Assembly Variations, Identification (control systems), Mechanical Assembly, Process Monitoring, Assembling Method, Assembly Analysis, Codes (symbols), Computer Implementations, Industrial Manufacturing, Database Systems, Parts Assembly, and Production Engineering.

A total of 23 documents, 14 articles and nine conference papers, were discovered between the years 1990-2021.

Figure 3 is the overall subassembly identification bibliometric analysis and Figure 4 is a zoomed in section targeting the key word Database Systems.

Looking at Figure 4, it is evident there is research opportunity regarding subassembly identification using database systems. It also shows the relationship between subassembly identification, control systems, database systems, planning, and assembly.

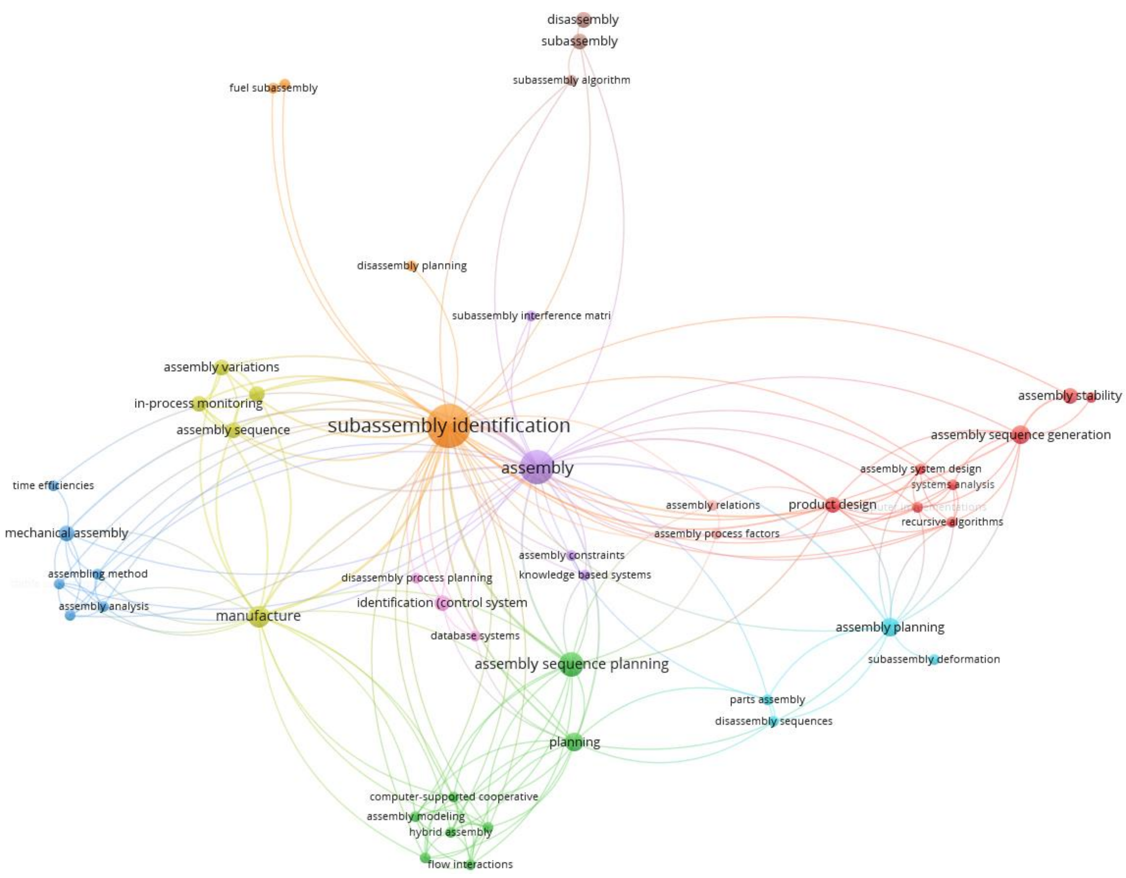


Figure 3- Subassembly Identification Bibliometric Analysis

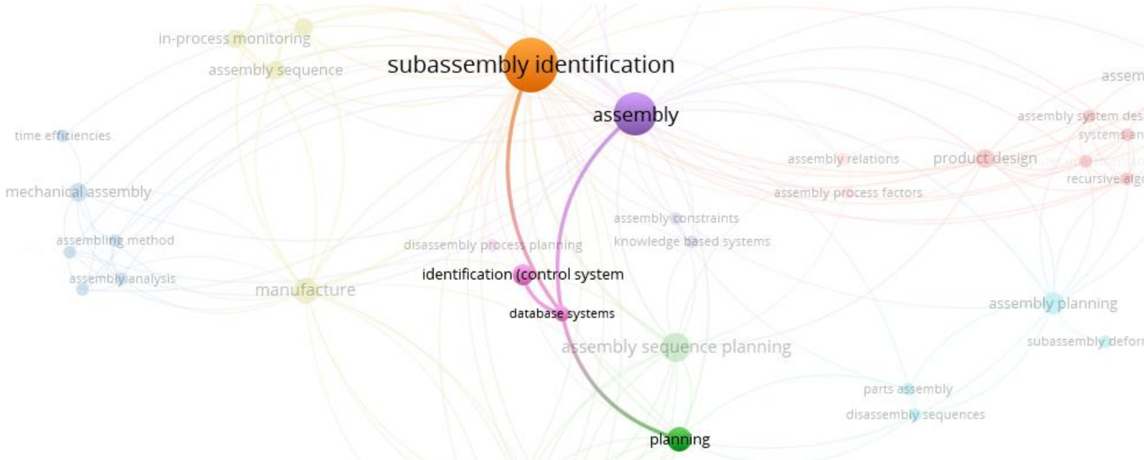


Figure 4- Database Systems Section

2.2.2.2 Work Order Tracking Bibliometric Analysis

The key words used in creating the figures below are Work Order Tracking, Work Order Tracking System, Work Order Identification, Computer Software, Database Systems, Systems Engineering, Bar Codes, Bills of Materials, Business Improvements, Business Process Improvements, Cost Control, Cost Effectiveness, Spare Parts Inventory Control, Information Management, and Production Planning. A total of nine documents, five articles and four conference papers, were discovered between the years 1984-2020.

Figure 5 is the overall work order tracking bibliometric analysis and Figure 6 is a zoomed in section targeting the key word Work Order Tracking System.

Looking at Figure 6, it is evident there is research opportunity regarding work order identification and tracking system. It also shows the relationship between work order identification, work order tracking system, bar codes, database systems, and computer systems.

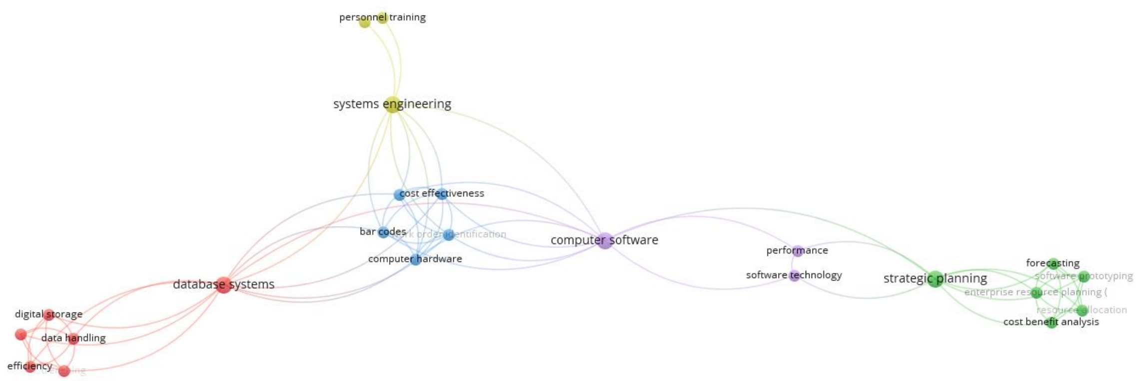


Figure 5- Work Order Tracking Bibliometric Analysis

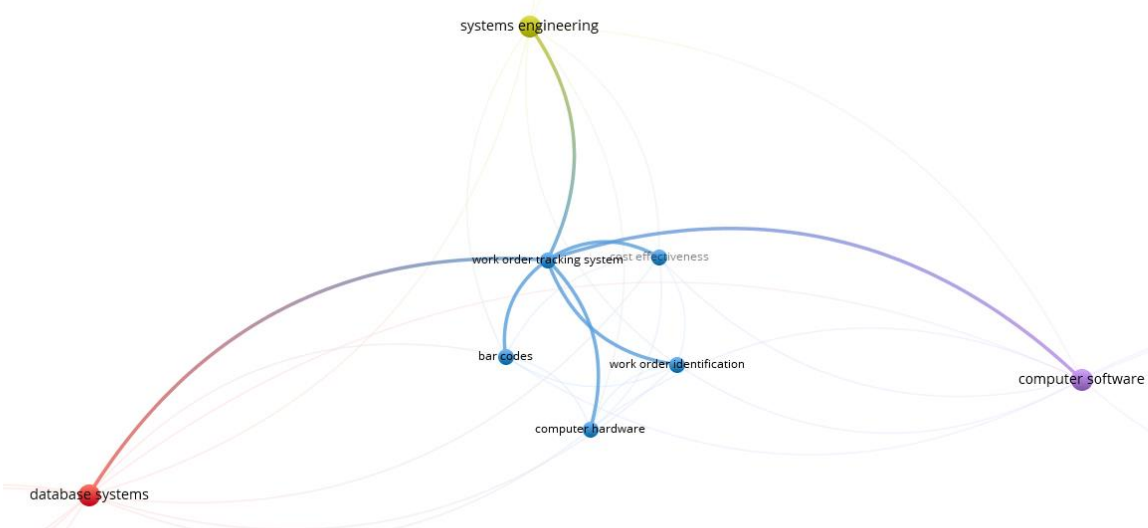


Figure 6- Work Order Tracking Section

2.3 Research Gaps

Table 1 below illustrates the research gaps presented in this research. The first publication by (El Saadany & Jaber, 2011) encompasses using a mathematical model for returns' subassemblies. Returns' subassemblies are subassemblies that make use of used components (El Saadany & Jaber, 2011). Although this method is done using tangible subassemblies, they are not conventional.

The second publication by (Wang & Liu, 2013) discusses subassembly identification methods for assembly sequence planning. The methods mentioned are pertaining to intangible subassemblies. The third publication by (Shi et al., 2020) is similar to the second, as it also focuses on intangible subassembly identification.

The fourth publication by (Ford, 2016) is the IPC-1782 Part Traceability Standard. This standard consists of four levels that traceability can fall under. This standard is being used as a reference and further proving why the need for a Subassembly Traceability Standard is critical. The work encompassed in this thesis does not fall into a specific level of the standard, rather a novel mix of three levels. Table 2 below shows the four levels of the standard, along with red boxes surrounding the "novel level" resulted from this research.

The fifth publication by (Savino, Xiang, & Menanno, 2017) consists of a software system for product traceability. The last publication by (Pendegraft, Kees, & Lawson, 1994) consists of a work order identification and tracking software system.

One can see the literature gap for developing a software system that encompasses the identification and tracking of both work orders and tangible and conventional subassemblies. Moreover, there is a literature gap for developing of a Subassembly Traceability Standard and tracking of tangible and returns' subassemblies.

This research will cover the development of a software system to identify and track both work orders and tangible and conventional subassemblies, a topic that bridges the gap between many of the publications mentioned in Table 1. This topic is crucial to have, as it can minimize or eliminate recurring problems such as late ordering, reordering, misplaced components, and changes to project timelines. It also increases efficiency by incorporating two variables within the same software (work orders and tangible and conventional subassemblies). These problems are prevalent within manufacturing facilities and are problems that facilities actively look to minimize or eliminate.

The other research gaps mentioned (Subassembly Traceability Standard and tracking of tangible and returns' subassemblies) are shown in colours green and blue in Table 1. They are also discussed in the Future Research section in Chapter 6.

Table 1- Research Gaps and Future Research

	Part Traceability Standard	Subassembly Traceability Standard	Product Traceability	**Work Order Identification and Tracking**	**Subassembly Identification**	**Subassembly Tracking**	Mathematical Models/Methods	**Software System**	Intangible Subassembly	**Tangible Subassembly**	Returns Subassembly	**Conventional Subassembly**
El Saadany & Jaber, 2011							✓			✓	✓	
Wang & Liu, 2013					✓		✓		✓			✓
Shi et al., 2020					✓		✓		✓			✓
Ford, 2016	✓		✓									
Savino, Xiang, & Menanno, 2017			✓					✓				
Pendegraft, Kees, & Lawson, 1994				✓				✓				
Research Gap				[red]	[red]	[red]		[red]		[red]		[red]
Future Research (two potential research topics - green & blue)		[green]				[blue]				[blue]	[blue]	

Table 2- IPC-1782 Standard (Ford, 2016)

	Level 1: "Basic"	**Level 2: "Standard"**	**Level 3: "Advanced"**	**Level 4: "Comprehensive"**
Material Traceability	**M1:** Listed to work-order by part number and incoming order	**M2:** Listed to batch/work-order by unique material ID (where applicable)	**M3:** Listed as loaded, by PCB-A, by unique material ID (subject to the constraints of the processes)	**M4:** Exact materials used on each PCB-A
Process Traceability	**P1:** Significant process exceptions against batch record/traveller	**P2:** Capture common key process characteristics, exceptions and test and inspection records to serialized PCB-A	**P3:** Capture all key process characteristics, exceptions and test and inspection records to serialized PCB-A	**P4:** Capture all available metrics: complete test results and process data
Data Integrity (in the range of)	3 Sigma	4 Sigma	6 Sigma	9 Sigma
Data Collection / Storage Automation	90% Manual	70% Automation	>90% Automation	Fully Automated
Reporting Lead Time	48 hours	24 hours	1 shift	Live Access
Data Retention Time	Life of product plus 1 year	Life of product plus 3 years	Life of product plus 5 years	Life of product plus 7 years

2.4 Summary

The technological pillars of I4.0 play a critical role in today's advancement in society and technology. Based on the conducted literature review for both academia and industry, it is evident that there are many case studies pertaining to product identification and traceability. However, subassembly identification and tracking is a research area with an opportunity for investigation. The research related to this area consists of tangible and returns and intangible and conventional subassembly identification. These topics include mathematical models, methods, or tools to develop a solution to the respective research area. It is evident that there is a research gap for the identification and tracking of tangible and conventional subassemblies using software systems. Moreover, there is no literature pertaining to a software system that incorporates both work order and tangible and conventional subassembly identification and tracking. Therefore, this thesis will focus on the development of a software system that identifies and tracks both work orders and tangible, conventional subassemblies in an inventory environment.

CHAPTER 3: DEVELOPMENT OF SOFTWARE ARCHITECTURE FOR SPM CONNECT

3.1 SWOT Analysis

The table below, adapted from (Shewan, 2021), illustrates the SWOT analysis for the development of the optimal process and software system. The strengths of the developed solution are:

- The ability to identify and track work orders and subassemblies within the facility,
- The potential to minimize or eliminate late ordering, reordering, misplaced components, and changes to project timelines,
- A software system that is built in-house, resulting in easier employee training and functionality, and
- Time and cost sensitive solution

The weaknesses of the software system are the research time frame and budget limitations. Since this research was completed within a certain time frame, it restricts the potential for additional functions and commands that could be integrated into the system. Moreover, the budget of this research was minimal, with the SPM Connect software being the sole resource provided.

One opportunity of the software system includes further work that could be completed and integrated into the software for more efficient and effective use. Potential SPM Connect additions are discussed in the Future Research section in Chapter 6. Another opportunity is the competitive advantage SPM has over other competitors of owning a work order and subassembly identification and tracking software system.

Threats include the possibility of the SPM Connect software malfunctioning, resulting in downtime of the software and time and money wasted and cyber threats or data breaches.

Table 3- SWOT Analysis, adapted from (Shewan, 2021)

S STRENGTHS	W WEAKNESSES	O OPPORTUNITIES	T THREATS
- Ability to identify and track work orders and subassemblies within the facility - Potential to minimize or eliminate recurring problems - A software system that is built in-house - Time and cost sensitive solution	- Research time frame - Budget limitations	- Further work that could be completed and integrated into software - Competitive advantage over competitors	- Software malfunctioning - Cyber threats, data breach, etc.

3.2 IDEF0 Design Process

The figures below illustrate the inputs, mechanisms, controls, and outputs necessary to solve the problem presented.

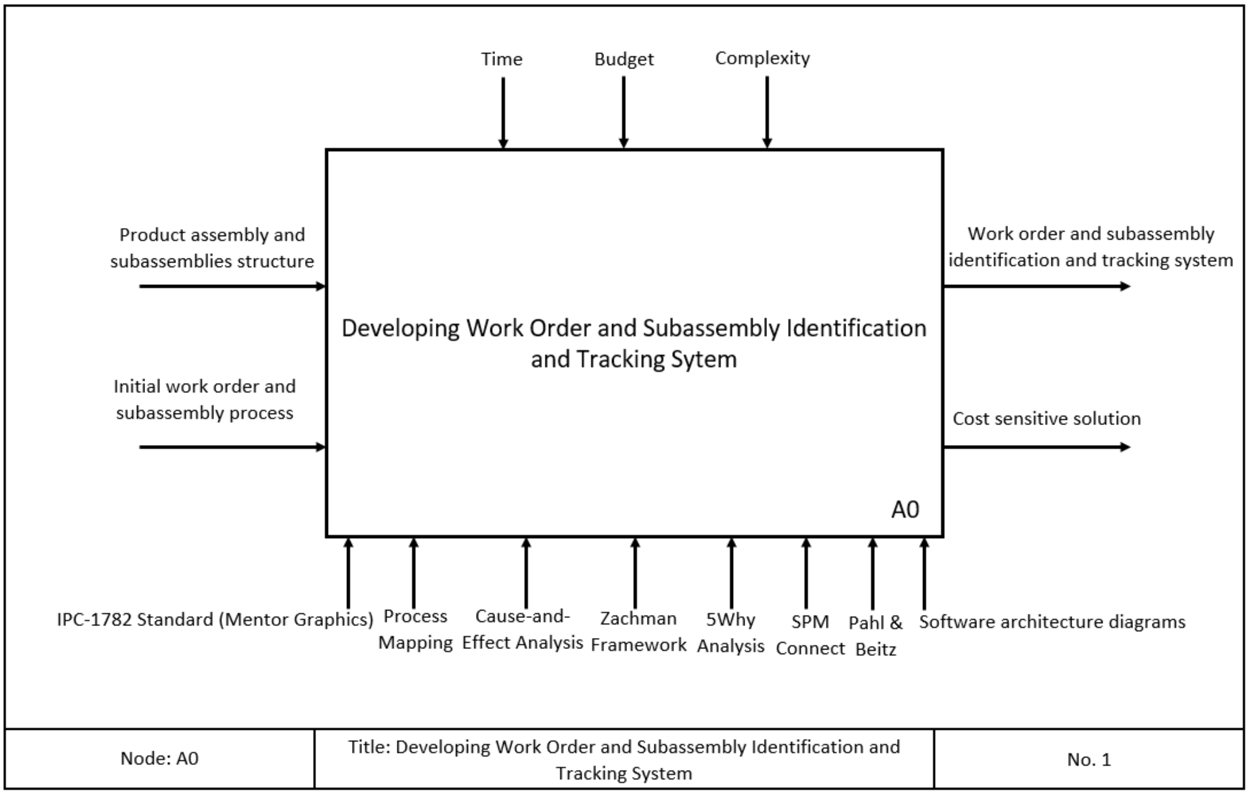


Figure 7 - IDEF Diagram A0 No.1

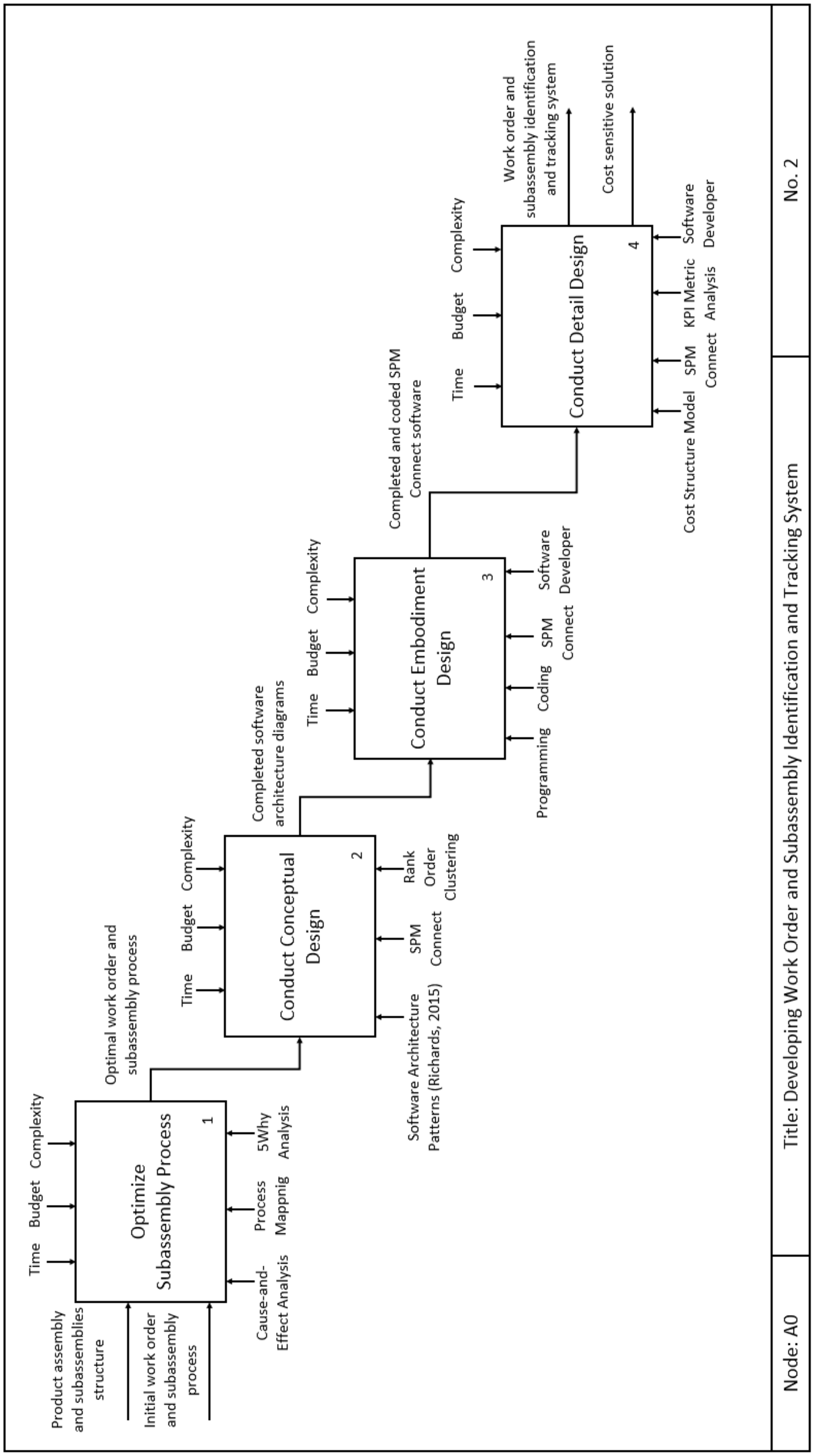


Figure 8 - IDEF Diagram A0 No.2

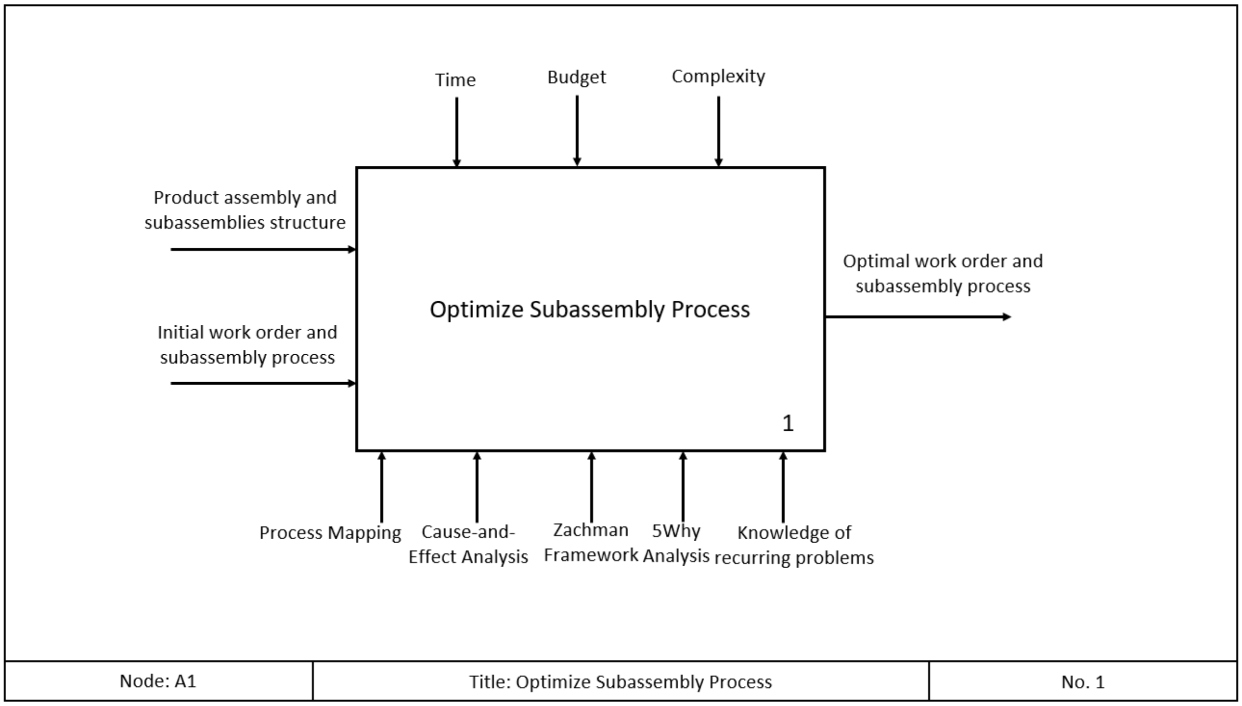


Figure 9 - IDEF Diagram A1

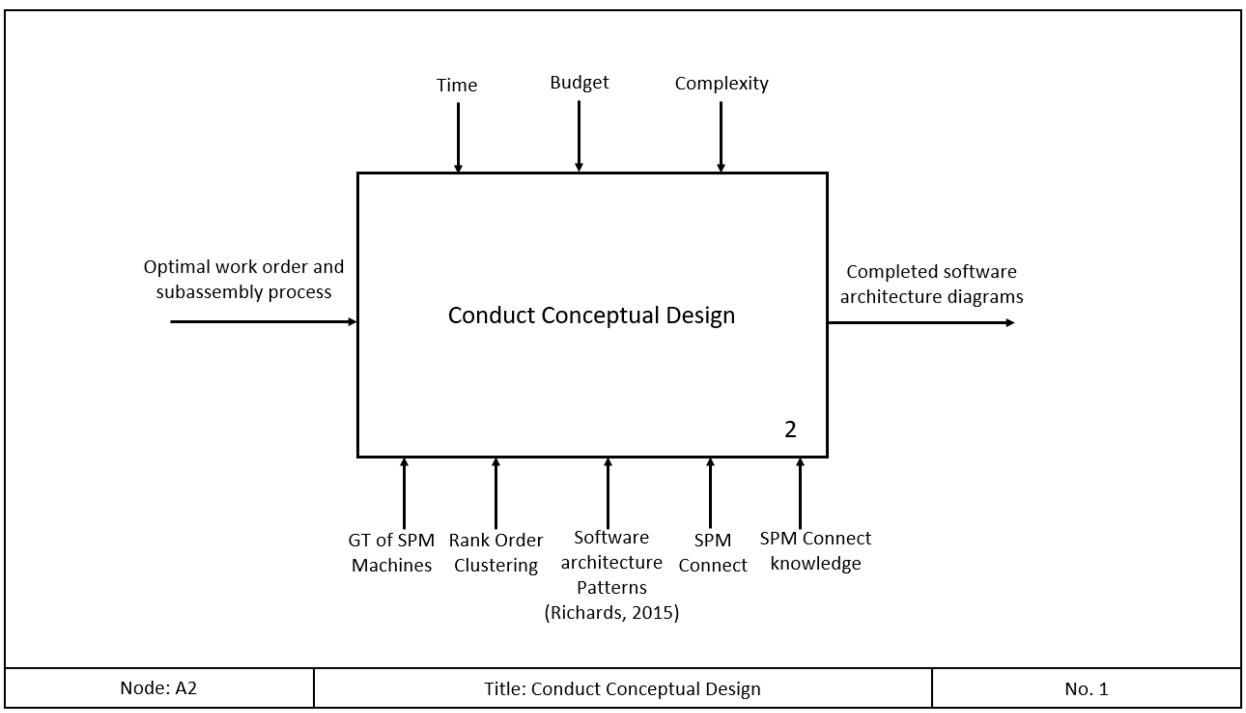


Figure 10 - IDEF Diagram A2

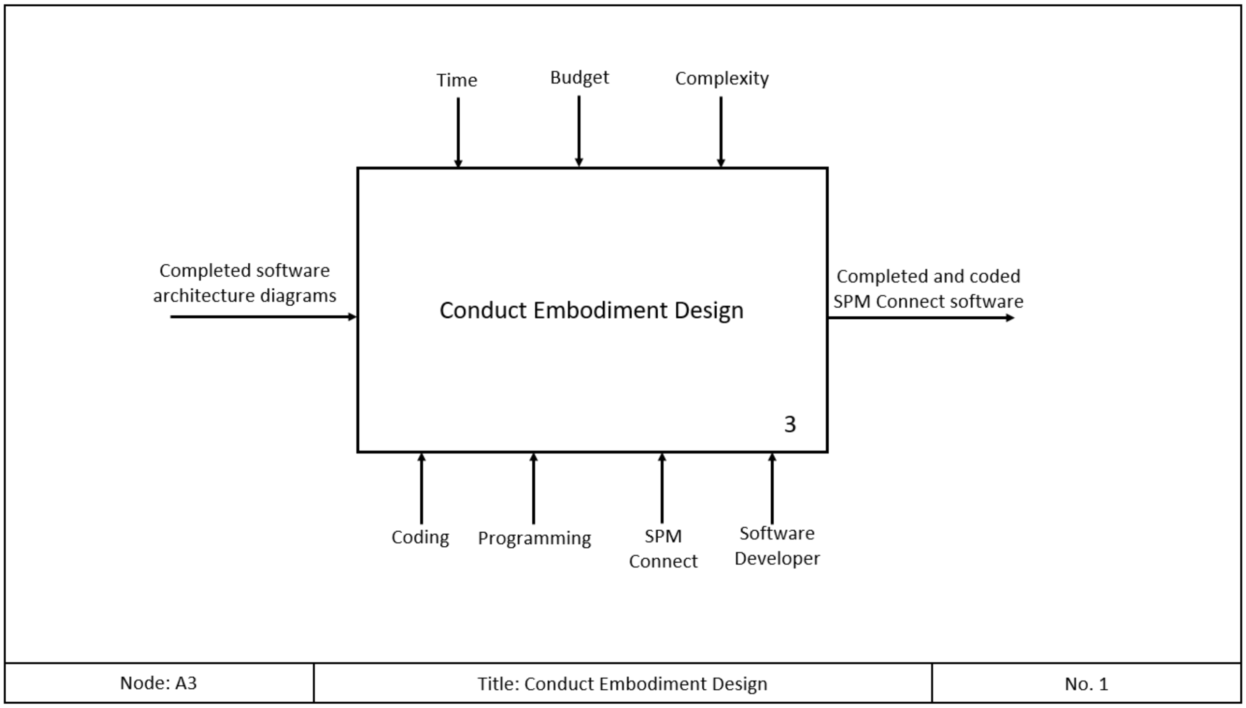


Figure 11 - IDEF Diagram A3

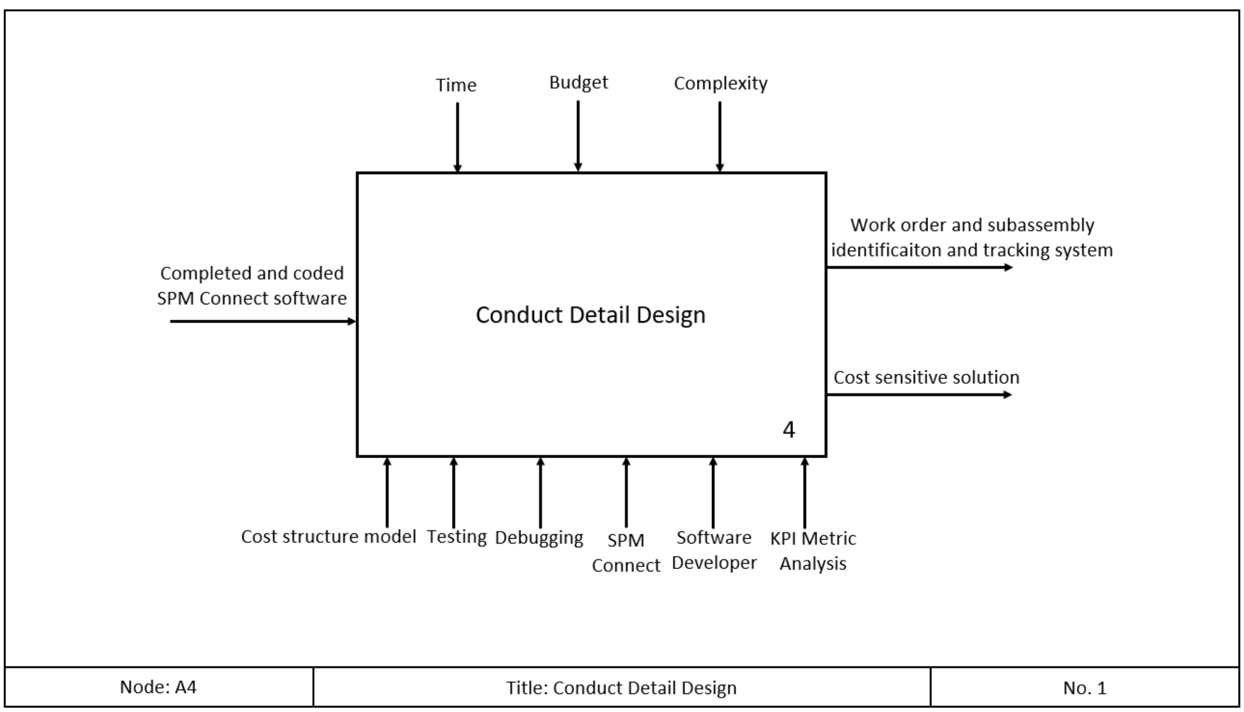


Figure 12 - IDEF Diagram A4

3.3 Systematic Design Process (Pahl & Beitz)

Figure 13 illustrates Pahl & Beitz, a systematic design methodology, adapted from (Wright, 2005). The sections used within this research are task clarification, conceptual design, embodiment design, and detail design. The breakdown of each section is explained below.

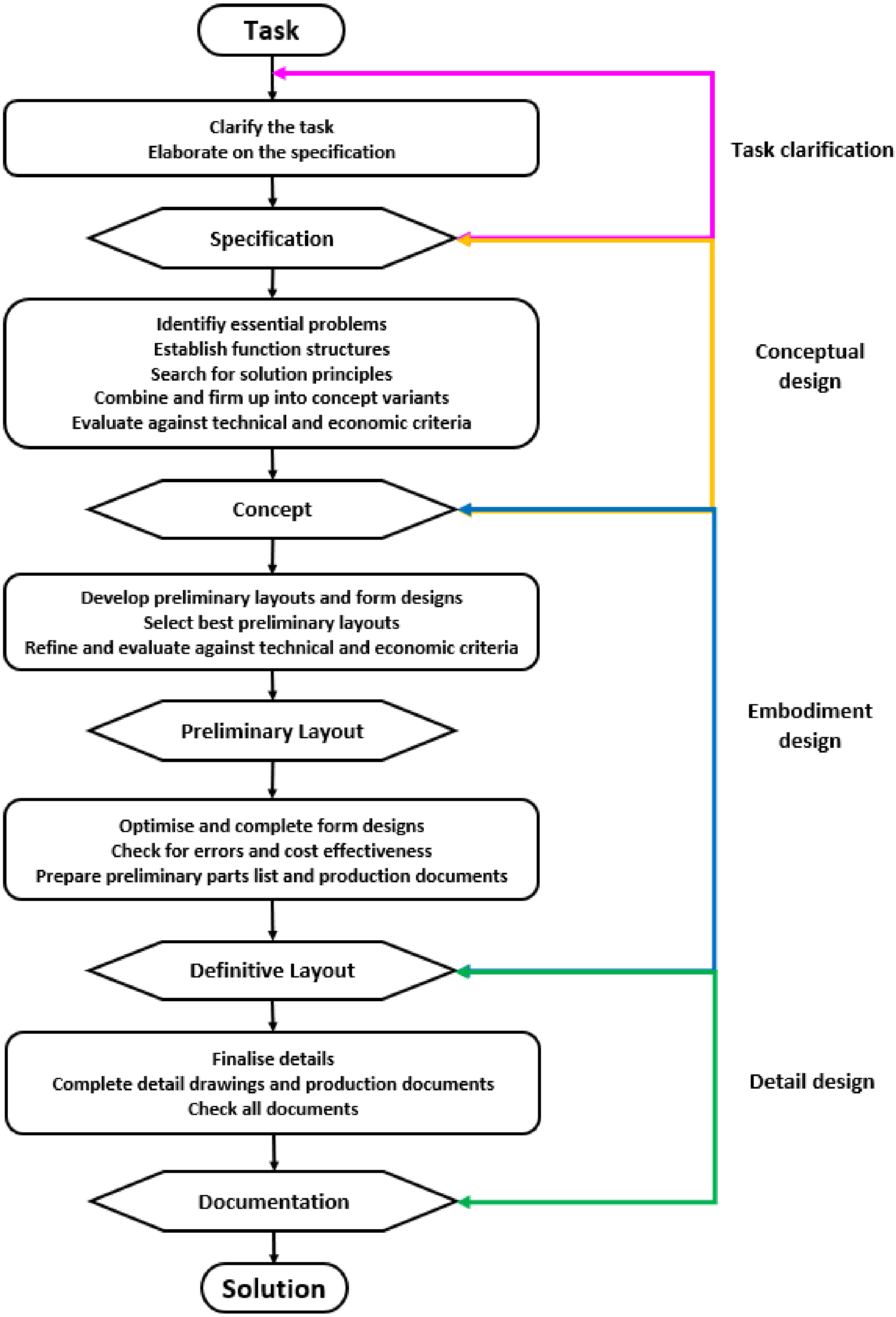


Figure 13 - Pahl & Beitz, adapted from (Wright, 2005)

3.3.1 Task Clarification

The task clarification outlines the problem statements and overall objectives of the problem that is being investigated. They are as follows:

- Excess inventory resulting in storage issues and unnecessary costs
- No tracking and process flow for work orders and subassemblies
- Identification and tracking of work orders and tangible and conventional subassemblies for efficient retrieval, tracing, and handling
- Develop software architecture to implement via software to minimize costs and time while increasing efficiency

3.3.2. Conceptual Design

The conceptual design consists of an overview of the potential solution and how it will be implemented. It is the blueprint of the entire problem. This includes brainstorming and methodologies like Zachman Framework, Rank Order Clustering, Process Mapping and Group Technology of SPM Machines. It also consists of creating the software architecture diagrams for the optimal work order and subassembly process that will be integrated into the software system. This will form the basis of how the process will function and track work orders and subassemblies throughout their entire cycle, from beginning to end.

3.3.3 Embodiment Design

The embodiment design is the beginning of the actual design process that will incorporate the conceptual design. This section includes the coding and programming of the SPM Connect software. The software architecture diagrams depict the flow within the software, meaning the coding and programming are heavily dependant on them. The software must be easy to use and understand, as employees will be accessing it to retrieve specific information about subassemblies.

3.3.4 Detail Design

The detail design is the final part of the design process. This includes the actual testing of the conceptual and embodiment designs. The software architecture diagrams are implemented within the software and tested to ensure it is easily accessible, understandable, and efficient for all users at the facility. Once testing was complete, the data was analyzed to construct a detailed discussion on the findings. The testing is explained in Chapter 4, and the results and discussion are presented in Chapter 5.

3.4 Zachman Framework

Figure 14 below is the Zachman Framework model, which outlines the overall concept of this research. The three main models consist of conceptual, logical, and physical.

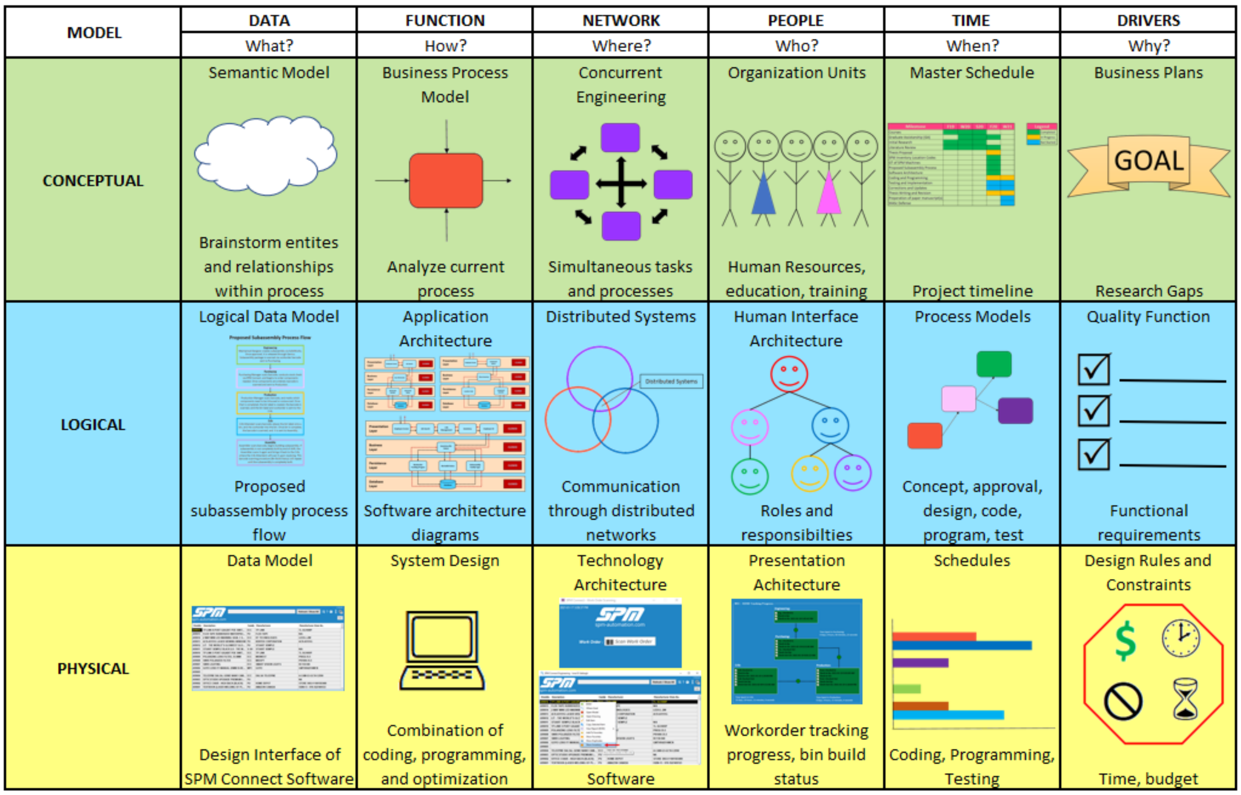


Figure 14 - Zachman Framework

3.5 Group Technology of SPM Machines: Subassembly Commonalities

Group Technology (GT) is a method that identifies commonalities between parts, subassemblies, assemblies, or processes. It has a wide range of applications and can be used within various industries. Examples of Industries that can apply GT are automotive, agriculture, healthcare, retail, construction, etc. Some benefits of GT include an increase in productivity and quality and a decrease in design variety (Engineering Notes, n.d.).

SPM creates various machines, and within each machine are many subassemblies. Currently, there are two main types of SPM machines: Gen Machines and Ultrasonic Machines. Gen Machines consists of the Gen 1, Gen 2, and Gen 3 machine. Ultrasonic Machines consist of the DT Wheel Flare (Front and Rear) Welders, P42J Winglet Welder, P558 Front Flair Welder, and T1 IP Cluster Hoods (MTC, SOFT, HUD). The Bills of Manufacturing from SPM Connect for each machine and the common subassemblies are shown in Figures 15-20 below.

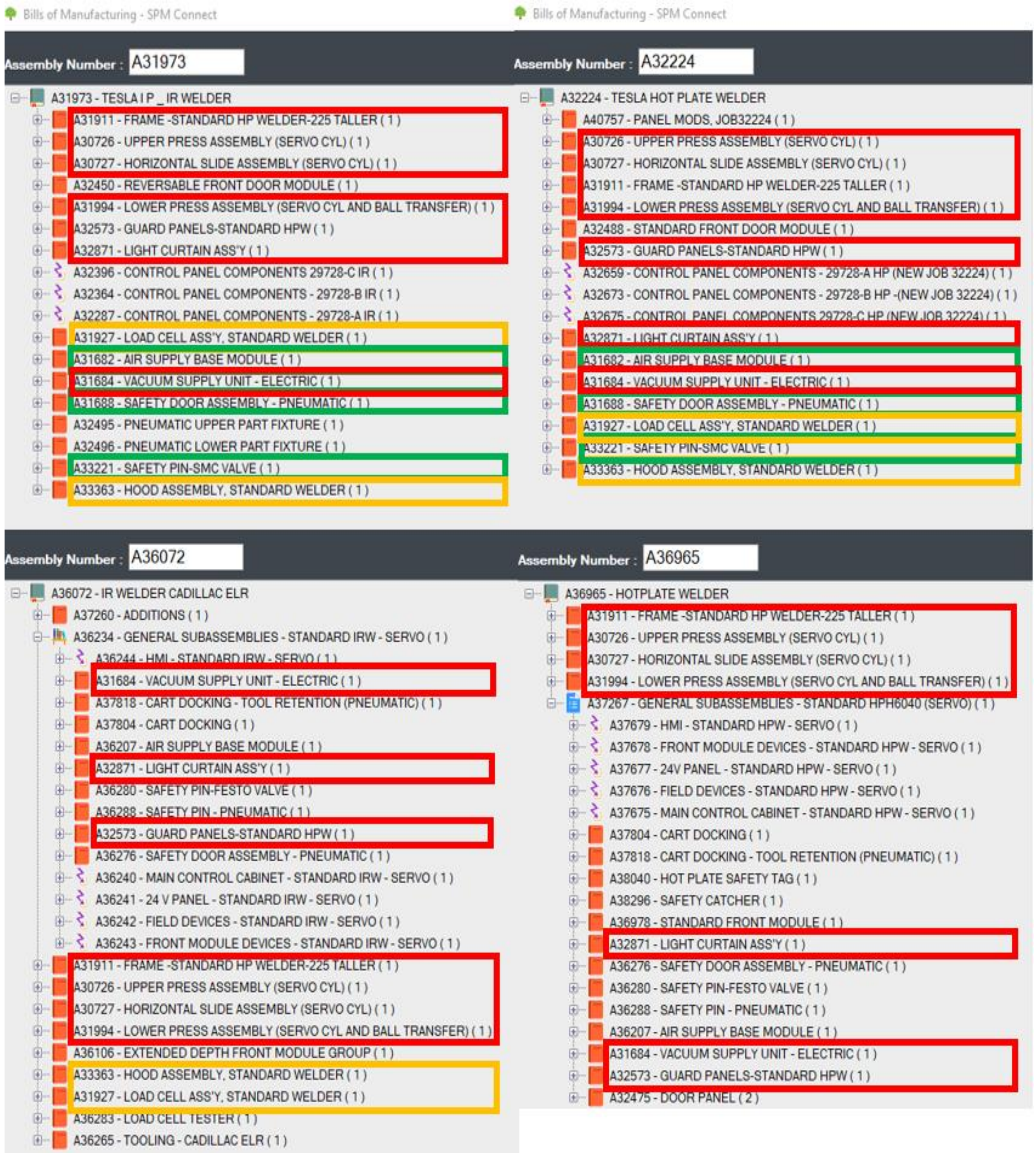


Figure 15 - Gen 1 Machines

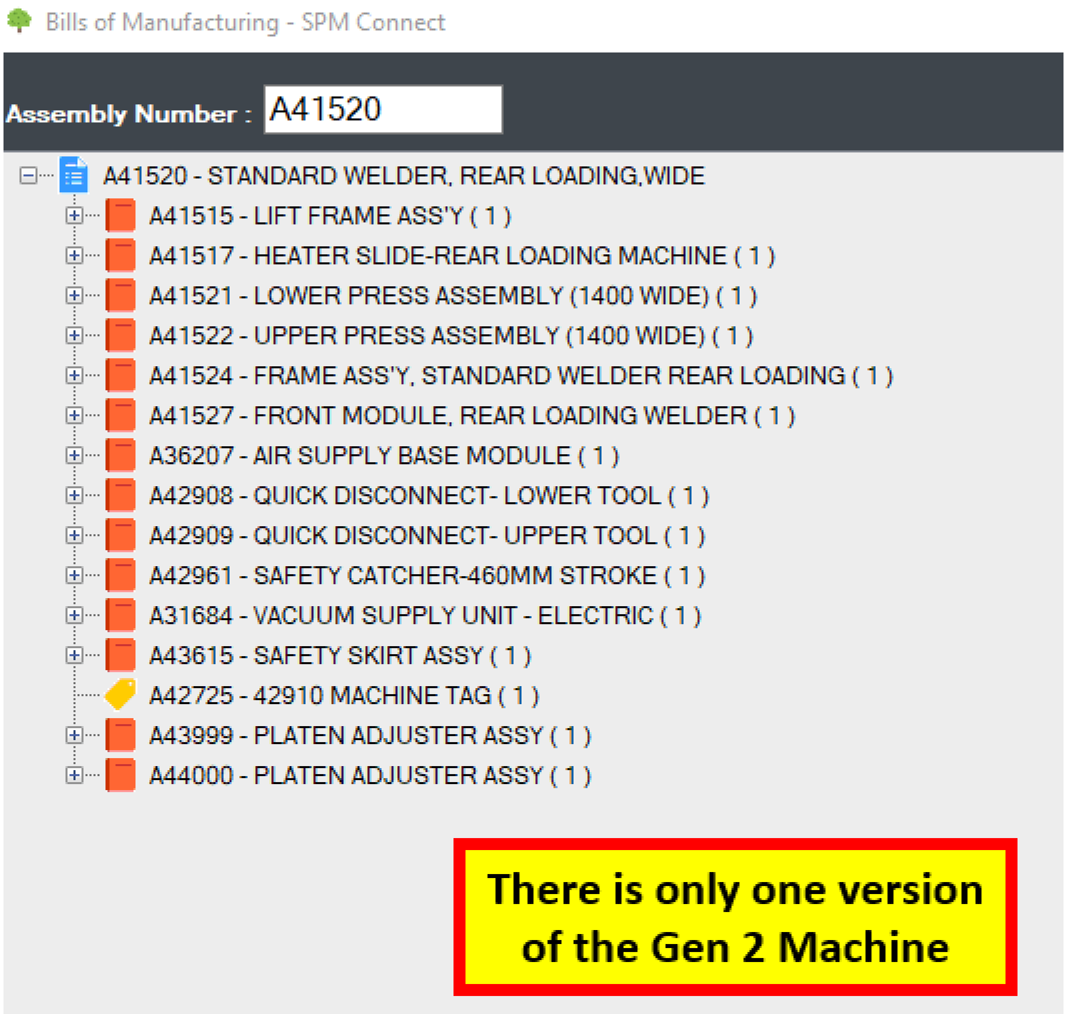


Figure 16 - Gen 2 Machine

Figure 17 - Gen 3 Machines

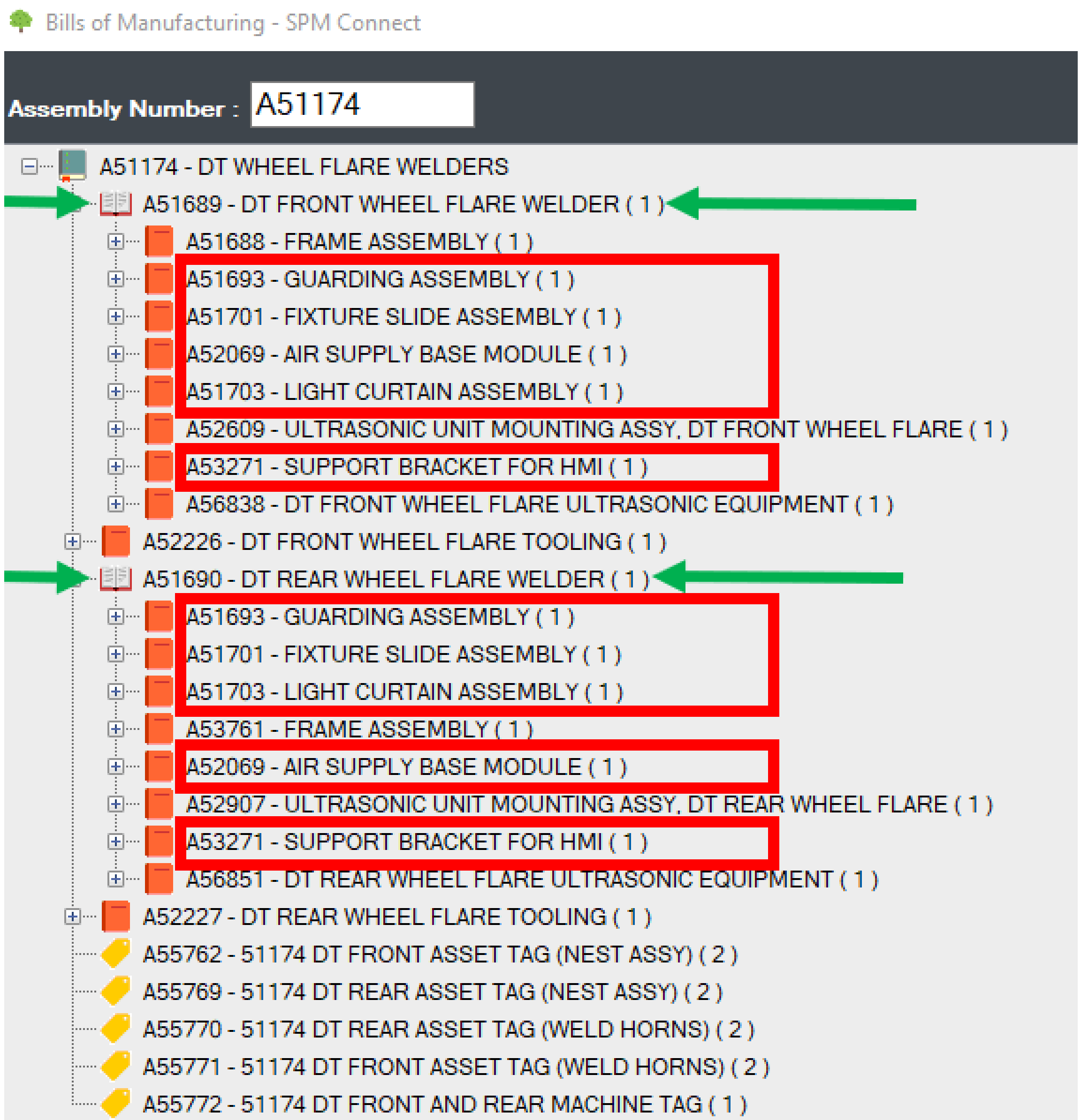


Figure 18 - DT Wheel Flare Machines

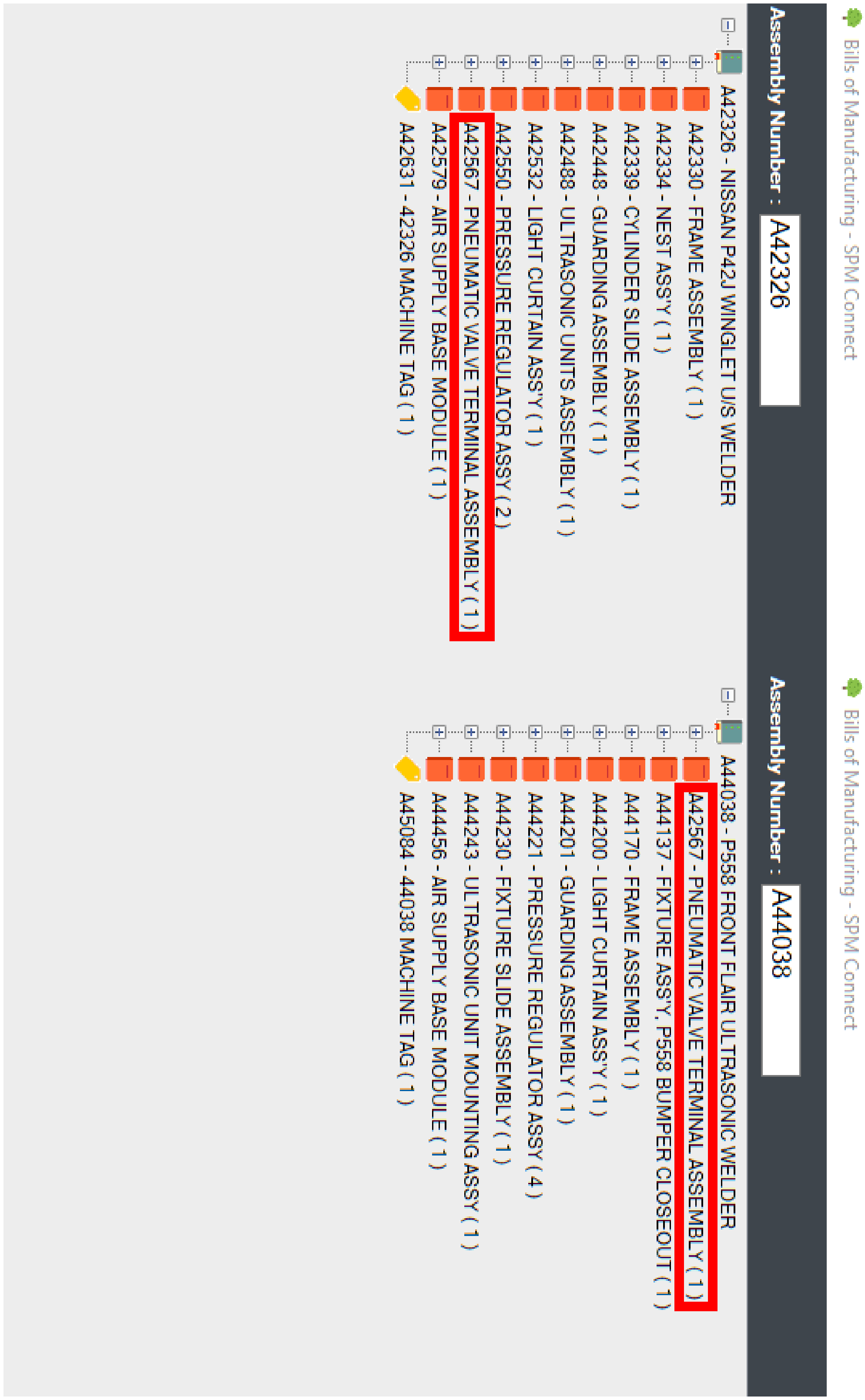


Figure 19 - Ultrasonic Welder Machines

Figure 20 - Cluster Hood Machines

Figures 21 and 22 below illustrate the information into tree graphs for further analysis.

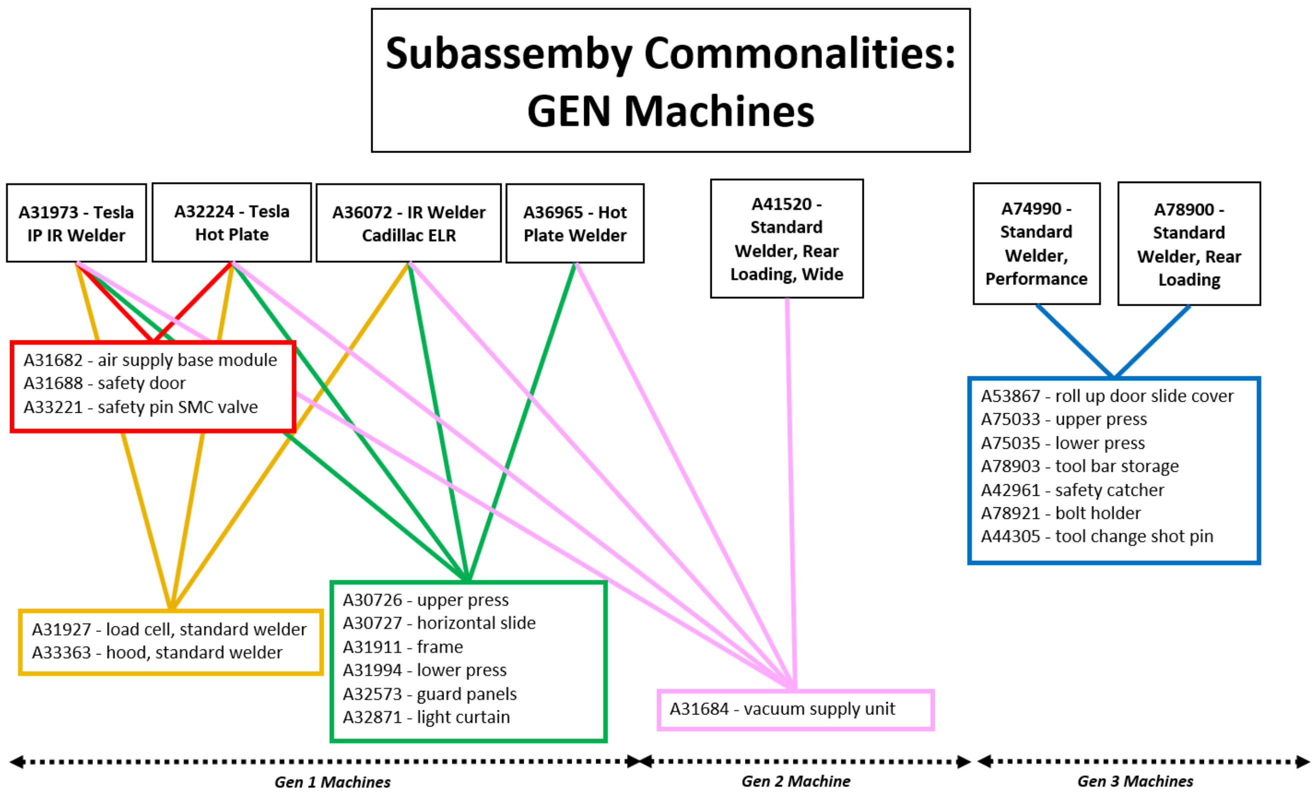


Figure 21 - Subassembly Commonalities: Gen Machines

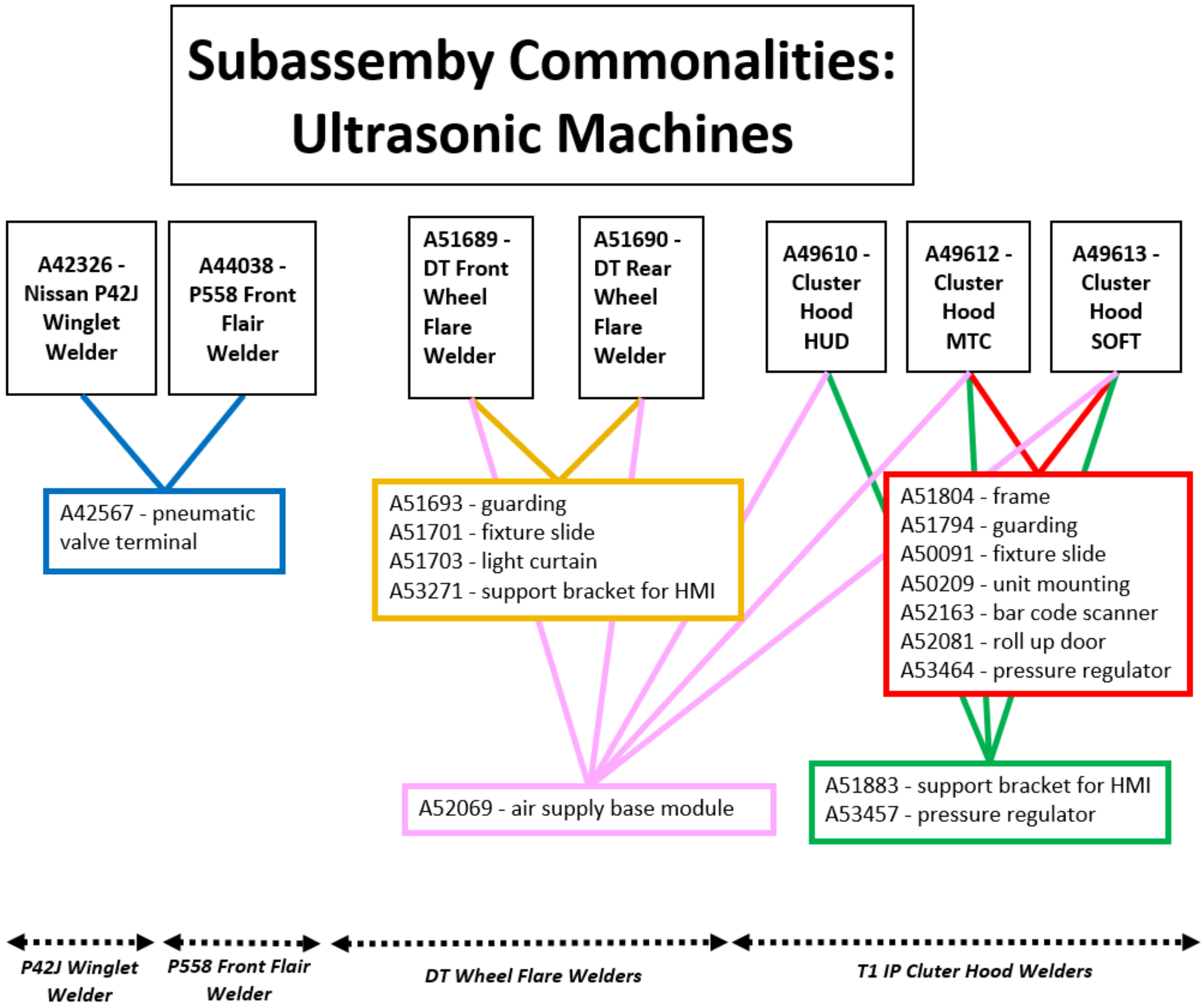


Figure 22 - Subassembly Commonalities: Ultrasonic Machines

It is evident there are many common subassemblies between machine types, and identifying these commonalities improves productivity. The machines and subassemblies above were inputted into a matrix to apply the Rank Order Clustering Methodology. This method determines the part families associated with machines and parts. However, for this research, the method will be used with machines and subassemblies. Tables 4-8 below give the legend of the machine and subassembly numbers, as well as the matrices and subassembly families.

Table 4- Machine and Subassembly Legend

#	Machine	#	Subassembly	#	Subassembly	#	Subassembly
1	A31973	1	A31682	15	A75035	29	A51794
2	A32224	2	A31688	16	A78903	30	A50091
3	A36072	3	A33221	17	A42961	31	A50209
4	A36965	4	A31927	18	A78921	32	A52163
5	A41520	5	A33363	19	A44305	33	A52081
6	A74990	6	A30726	20	A42567	34	A53484
7	A78900	7	A30727	21	A51693		
8	A42326	8	A31911	22	A51701		
9	A44038	9	A31994	23	A52069		
10	A51689	10	A32573	24	A51703		
11	A51690	11	A32871	25	A53271		
12	A49610	12	A31684	26	A51883		
13	A49612	13	A53867	27	A53457		
14	A49613	14	A75033	28	A51804		

Table 5- Rank Order Clustering Screenshot #1

Machines	2^{33}	2^{32}	2^{31}	2^{30}	2^{29}	2^{28}	2^{27}	2^{26}	2^{25}	2^{24}	2^{23}	2^{22}
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
2^{13} **1**	1	1	1	1	1	1	1	1	1	1	1	1
2^{12} **2**	1	1	1	1	1	1	1	1	1	1	1	1
2^{11} **3**				1	1	1	1	1	1	1	1	1
2^{10} **4**						1	1	1	1	1	1	1
2^{9} **5**												1
2^{8} **6**												
2^{7} **7**												
2^{6} **8**												
2^{5} **9**												
2^{4} **10**												
2^{3} **11**												
2^{2} **12**												
2^{1} **13**												
2^{0} **14**												
Decimal Equivalent	12288	12288	12288	14336	14336	15360	15360	15360	15360	15360	15360	15872
Rank	4	4	4	3	3	2	2	2	2	2	2	1

Machines	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1			
4	1	1	1	1	1	1	1					
5	1											
6												
7												
8												
9												
10												
11												
12												
13												
14												

Table 6- Rank Order Clustering Screenshot #2

2^{21}	2^{20}	2^{19}	2^{18}	2^{17}	2^{16}	2^{15}	2^{14}	2^{13}	2^{12}	2^{11}	2^{10}	2^{9}
Subassemblies												
13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
1	1	1	1	1	1	1						
1	1	1	1	1	1	1						
							1					
							1					
								1	1	1	1	1
								1	1	1	1	1
										1		
										1		
										1		
384	384	384	384	384	384	384	96	24	24	31	24	24
5	5	5	5	5	5	5	6	8	8	7	8	8

Subassemblies												
13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**23**	**21**	**22**	**24**	**25**
1	1	1	1	1	1	1						
1	1	1	1	1	1	1						
							1					
							1					
								1	1	1	1	1
								1	1	1	1	1
								1				
								1				
								1				

Table 7- Rank Order Clustering Screenshot #3

2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0	Decimal Equivalent	Rank
26	27	28	29	30	31	32	33	34		
									1.718E+10	1
									1.718E+10	1
									2.143E+09	2
									532676608	3
									4194304	4
									4096000	5
									4161536	5
									16384	6
									16384	6
									15872	7
									15872	7
1	1	1	1	1	1	1	1	1	2559	8
1	1	1	1	1	1	1	1	1	2559	8
1	1	1	1	1	1	1	1	1	2559	8
7	7	7	7	7	7	7	7	7		
9	9	9	9	9	9	9	9	9		

26	27	28	29	30	31	32	33	34
1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1

Table 8- Subassembly Families

	Family				
	1	2	3	4	5
Subassmeblies	1-12	13-19	20	21-25	26-34
Machines	1-5	6,7	8,9	10-14	12-14

3.6 Initial Work Order and Subassembly Process

The initial work order and subassembly process is illustrated using the Process Mapping Methodology in the figure below. It all starts in the Engineering Department. The Mechanical Designer creates a subassembly on SolidWorks, and once the Engineering Manager approves it, it is released through Genius, the Enterprise Resource Planning (ERP) system at the facility. A copy of the subassembly package, which includes the work order, is sent down to the Production Manager. The Production Manager manually conducts a stock check on all the items on the work order. This is done in the Crib – they physically look for items that are already in stock. They also mark which components need to be made in-house or outsourced. This is dependent on capacity, complexity, quantity, etc. The in-house/outsource operations consist of lathe, milling, boring, and CNC (3-axis and 5-axis).

Once the stock check is complete, the Production Manager gives the work order to the Purchasing Manager. The Purchasing Manager begins to order the components needed. Once the components are ordered, the Purchasing Manager gives the work order back to the Production Manager. The Production Manager creates a bin label containing the work order number and gives the work order and bin label to the Crib Attendant. The Crib Attendant then places the bin label onto the bin and the work order into the bin. They manually track the bin completion status, as they are responsible for ensuring the bin is filled with the correct items and quantities on the work order.

Once the bin is complete, the Crib Attendant gives the bin to the assembler to begin building the subassembly. If the subassembly is not entirely built by the end of the assembler's shift, it is sent back to the Crib and taken out of the Crib the following shift. This bin build process will repeat until the subassembly is entirely built.

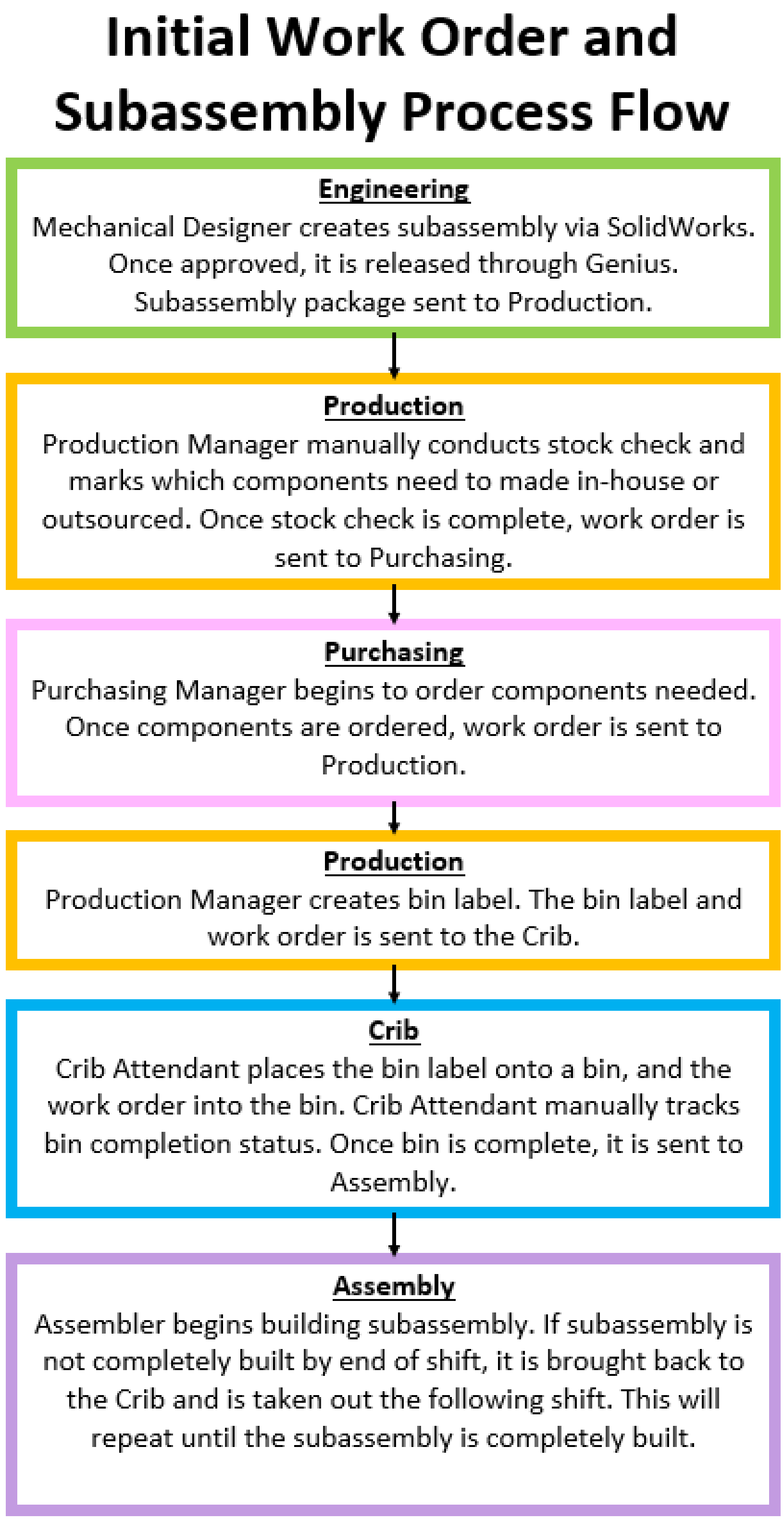


Figure 23 - Initial Work Order and Subassembly Process Flow

Figure 24–26 below illustrates the Cause-and-Effect Diagrams that determine some of the recurring problems in the initial work order and subassembly process.

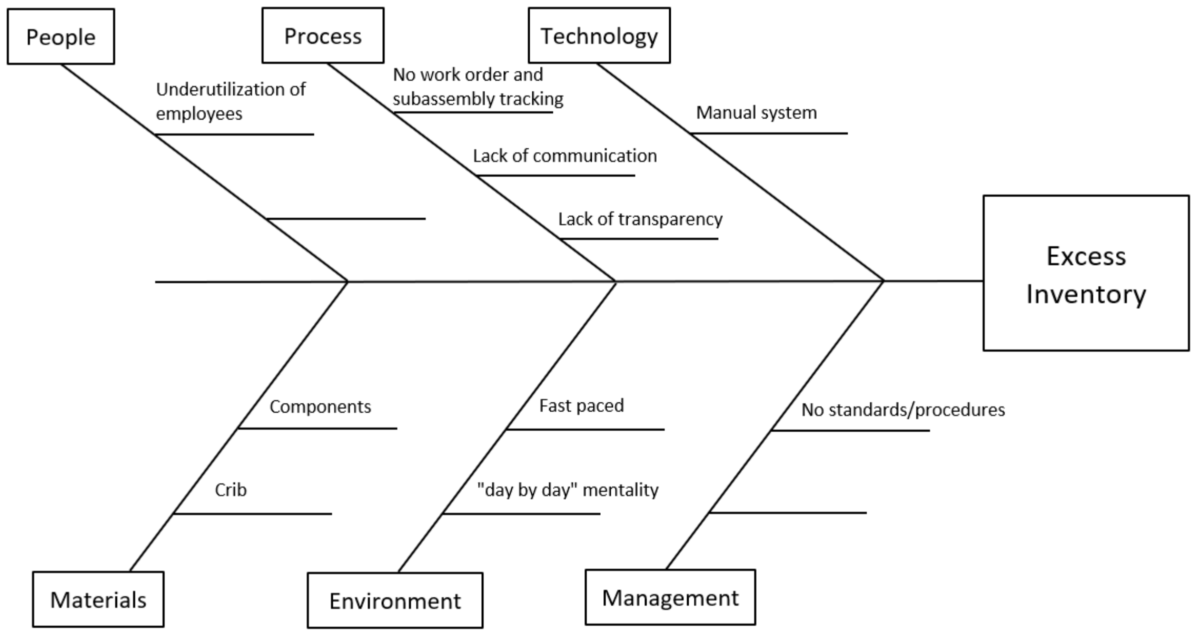


Figure 24- Excess Inventory Cause-and-Effect Diagram

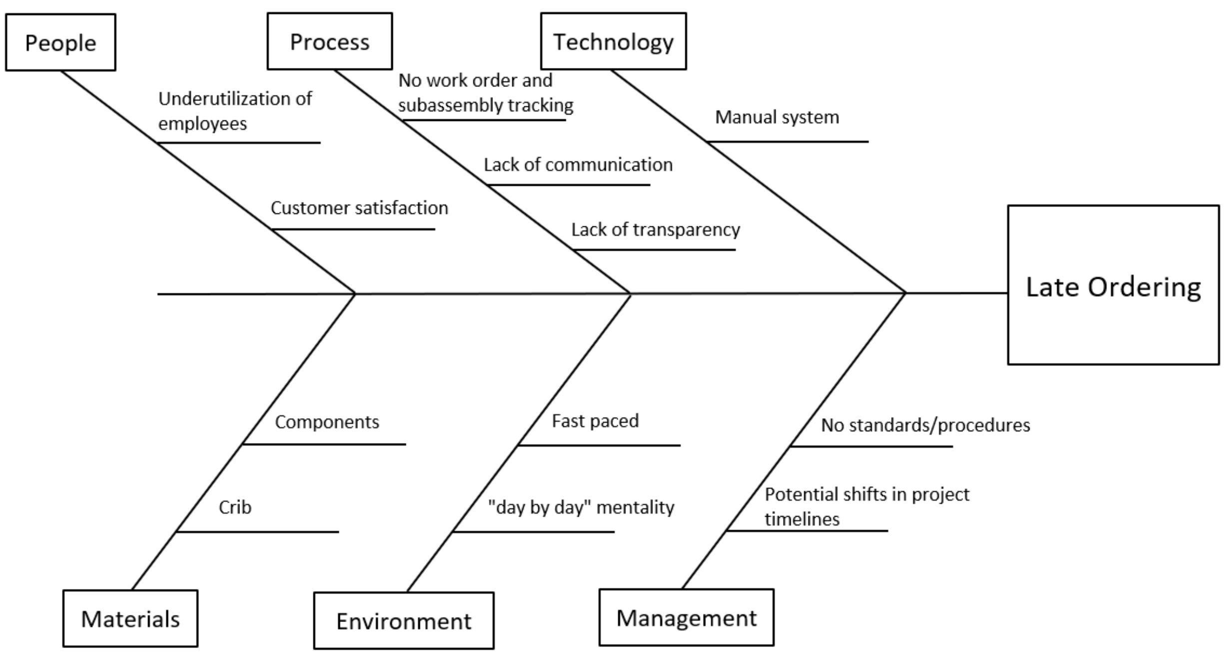


Figure 25- Late Ordering Cause-and-Effect Diagram

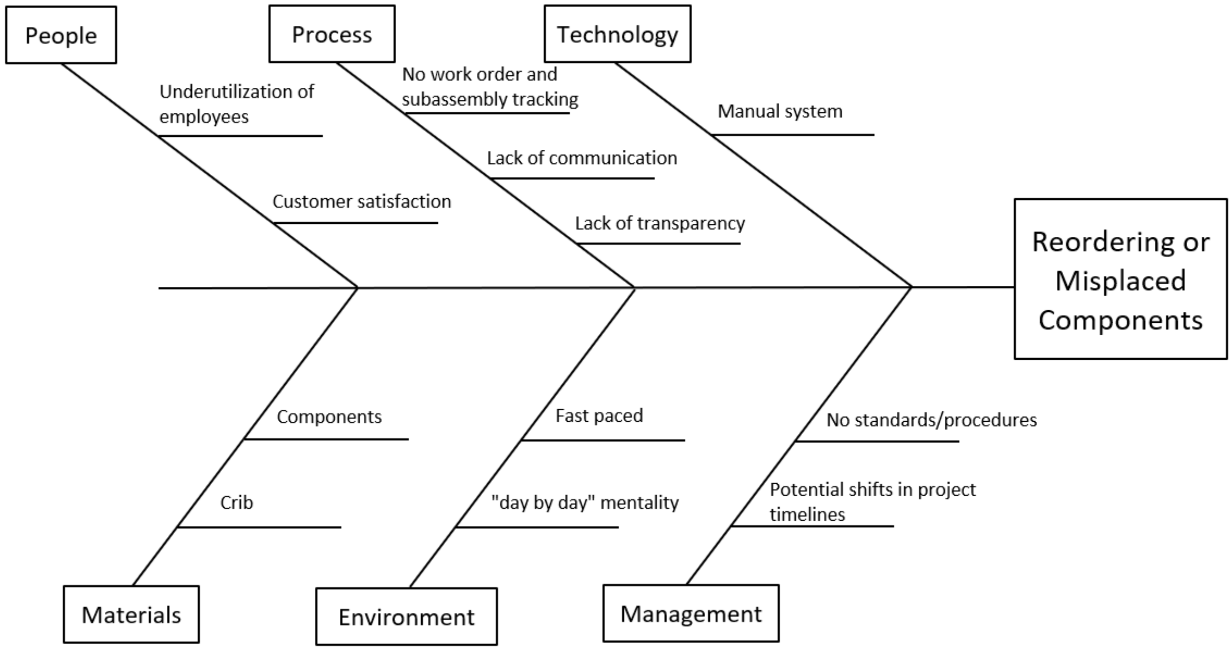


Figure 26- Reordering or Misplaced Components Cause-and-Effect Diagram

Based on the Cause-and-Effect diagrams above, three critical recurring problems arise from this process. They are excess inventory, late ordering, and reordering or misplaced components.

1. Excess inventory – since stock checks are done manually, there is a higher probability of human error. Sometimes, components are missed on the stock check, leading to ordering components already in the crib.
2. Late ordering – forgetting to order components leads to shifts in project timelines. If long-lead items are not ordered within the scheduled ordering time frame, it can significantly affect the timeline and customer satisfaction. Due to the manual process in place, work orders are misplaced or lost, leading to late ordering.
3. Reordering or misplaced components – since tracking the bin completion status in the Crib is done manually, there is a high probability of human error. Sometimes, the work orders in subassembly bins are not updated correctly, resulting in reordering or misplaced parts.

One can see how solving these problems can positively affect the company's overall performance, productivity, efficiency, and costs.

To solve any problem, it is crucial to identify why the problem is continuously reoccurring, in other words, the causes pertaining to the problem. The following list includes the reasons involved in the reoccurrence of the issues presented above:

1. No Work Order and Subassembly Tracking – there was no information to explain where the work order or subassembly is and who has it.
2. Lack of Communication / Transparency – human error can cause subassembly bins to go out to Assembly while missing components. Sometimes, the Assembler would grab an item they need from another subassembly bin to complete the bin they were working on. This was done without informing the Crib Attendant. Examples of these components are pneumatic cylinders, clamps, and pins.
3. Underutilization of Employees – due to the initial process being heavily human-dependent, employees were manually conducting stock checks and tracking components and bins. Automating the system allows employees to do productive work and focus on other tasks that greatly benefit the company.
4. Manual system – the initial process was completed manually, meaning it was heavily human-dependent, which almost always results in human errors being made. This was consuming time and resources. By automating the process using the company's SPM Connect software, stock checks are done efficiently and effectively.

The causes are illustrated in the 5Why Analysis in Figure 27 below.

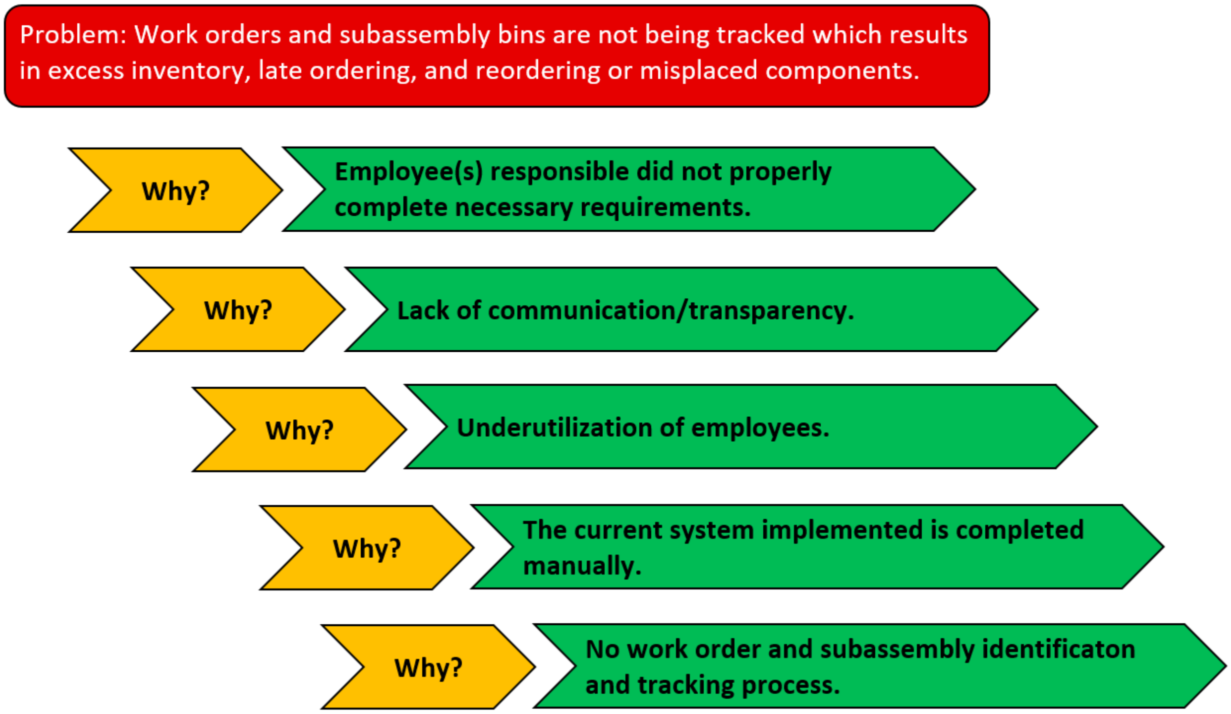


Figure 27 - 5Why Analysis

3.7 Optimal Work Order and Subassembly Process

After multiple discussions and brainstorming sessions with the Engineering Manager and Mechanical Designer / Software Developer, it was agreed that the Engineering Department releases the subassembly package to Purchasing instead of Production. Moreover, Purchasing would be responsible for stock checks, and it will be automated. The stock checks will be done on SPM Connect. Releasing the work order to Purchasing allows the Purchasing Manager to stock check the items on the work order and order what is necessary. Once items have been ordered, the work order is given to the Production Manager. The Production Manager will mark which items need to be made in-house or outsourced and creates the bin label. Both the bin label and work order are given to the Crib Attendant.

All employees with access to SPM Connect will be able to search the work order tracking progress. The whole process will be tracked with barcode scanning. The work orders will have to be scanned by the department that has them. For example, the Engineering

Department will scan the barcode on the work order when leaving Engineering. The Purchasing Department will then scan the barcode, showing that it has been received and is currently in that department. When Purchasing is done with the work order, they will scan the barcode and give it to Production and so on.

Moreover, all work orders will be available on SPM Connect. This automated improvement will give the Crib Attendant access to any work order online, rather than a piece of paper. This will prevent the misplacement of work orders.

Furthermore, access to the crib will be restricted to only the Crib Attendant. This will eliminate any potential situations where Assemblers take items from other subassembly bins. This will be enforced by applying an RFID keypad lock system on the entrance of the Crib. In case of urgent inquiries, the additional employees with access to key cards are the President, Purchasing Manager, Production Manager, and Engineering Coordinator.

All these improvements minimize or eliminate the problems stated above. Having a process flow that is automated and tracked by barcode scanning improves transparency and provides employees with information on which department has the work order. Also, highly automated systems minimize human error and underutilization of employees. This decreases late ordering, reordering, misplaced parts, and excess inventory. Lastly, restricting the Crib to having only one person in charge of the bins eliminates the lack of communication. The optimal subassembly process is illustrated in the figure below.

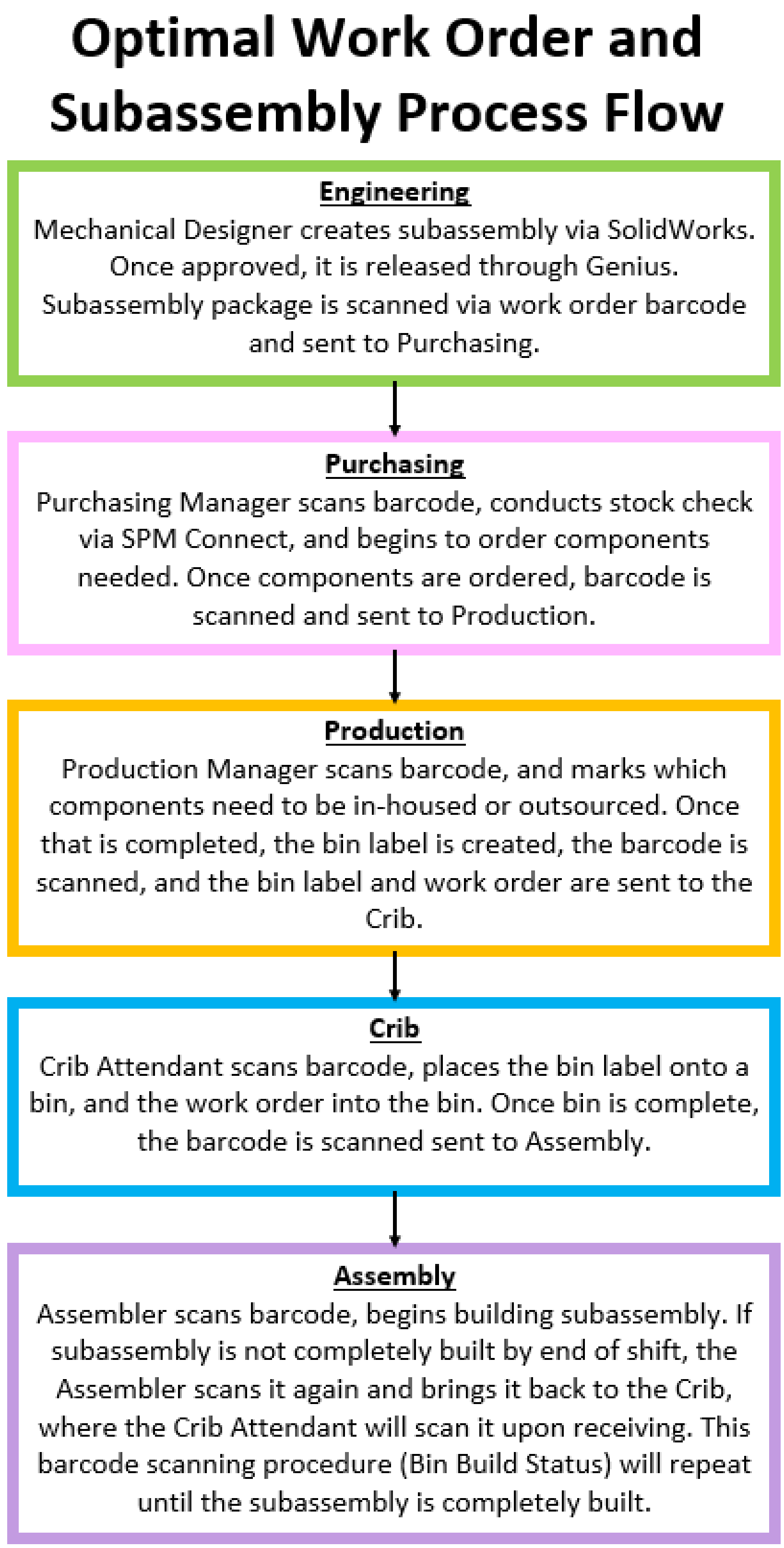


Figure 28 - Optimal Work Order and Subassembly Process Flow

3.8 Software Architecture

Techopedia defines software architecture as “a structured framework used to conceptualize software elements, relationships and properties. This term also references software architecture documentation, which facilitates stakeholder communication while documenting early and high-level decisions regarding design and design component and pattern reuse for different projects” (Techopedia, n.d.).

Software Architects use software architecture to illustrate and relay their designs. This can be shown in several methods. These methods are called software architecture patterns.

There are five types of software architecture patterns. They are layered architecture, event-driven architecture, microkernel architecture, microservices architecture, and space-based architecture. (Richards, 2015). The software architecture pattern used in this research is the layered architecture. It is also called the n-tier architecture pattern.

The layered architecture pattern is frequently used within various technical applications, as it is very compatible with conventional IT communication and structures within various companies and organizations. The name of this pattern explains its overall design concept. Layers are designed horizontally, with components in each layer. Each layer conducts a separate, specific task. The combination of all tasks results in the development and function of an application. The number of layers varies, depending on the Software Architect’s preference and the size and functions of the application. On average, there are four layers. They are as follows: presentation, business, persistence, and database. The presentation layer handles the user interface and displaying the program. The business layer applies specific rules depending on the request received. The request is the main problem that is trying to be solved. The persistence accesses the data and information requested by the business layer from the database layer. This requires a programming language and logic.

Matt Pfeil wrote an article on data persistence and defined persistence as "the continuance of an effect after its cause is removed.” This means that the persistence of data is the continuation of the data being in the system, even after the specific request has been completed (Pfeil, 2010). For example, suppose the system is asking for a particular outcome, like the number of customers enrolled in a specific training, the persistence layer will retrieve that information from the database. Once the information has been relayed to the presentation layer, it will be brought back into the database and stored again, but not be deleted. Therefore, data persistence ensures all data is enclosed in a database and is kept indefinitely.

The database stores and handles all data and information. The figure below illustrates the four layers.

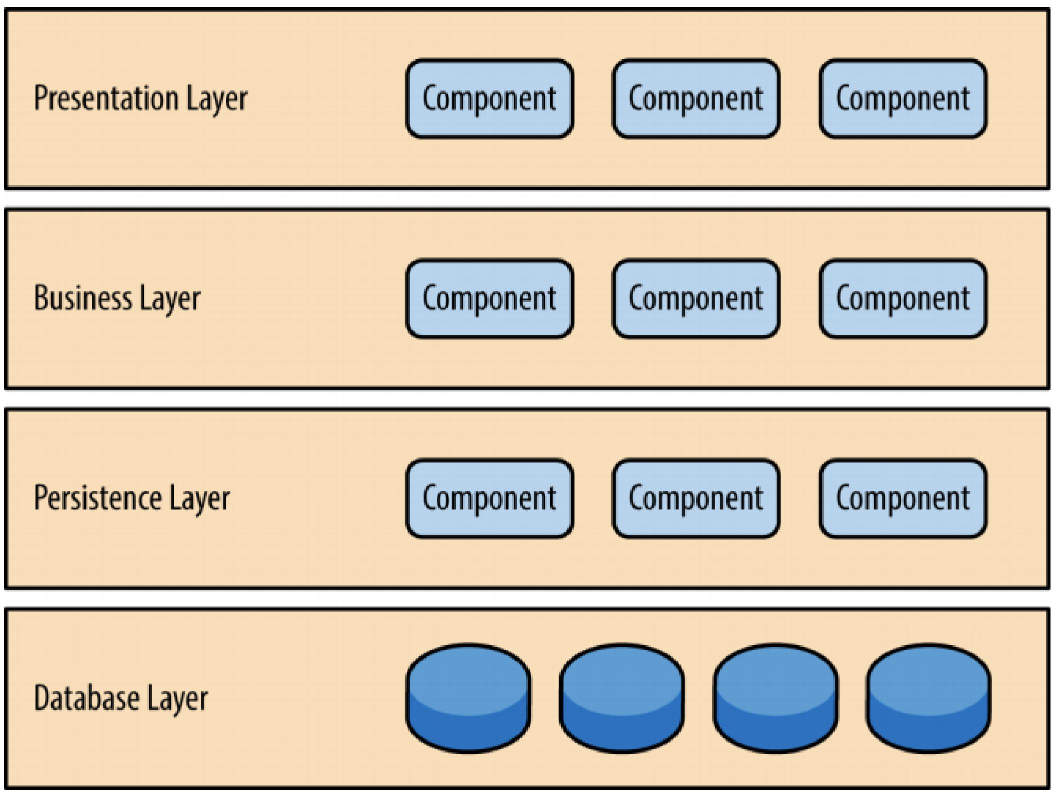


Figure 29 - Software Architecture Layers (Richards, 2015)

When designing the data architecture, there is the option of making the layers open or closed. Having all closed layers means layers cannot be skipped. The layer on top must go to the layer directly below it and so on. For example, the business layer must go through the persistence layer to get to the database layer. Closed layers separate each layer individually, making it easier to alter or edit a layer, if necessary. This is called the Layers of Isolation Concept.

There is also the option to keep some layers open while having some closed. This will allow a layer that is above an open layer to skip it and go to the layer under the open layer. If layers are open or closed, they will be labelled with an “open” or “closed” box on the far right in each layer. There are two types of arrows following into and out of these diagrams. The black arrows indicate the user input, while the red arrows indicate the system output (Richards, 2015).

3.8.1. SPM Software Architecture

There are three software architecture diagrams for this research. The first diagram is the work order barcode scanning. The second diagram is the architecture pertaining to the automated stock check. The last diagram is the computerized retrieval and tracking of work orders and subassemblies. The primary programming language used for SPM Connect is SQL SERVER. All the diagrams in this research are closed layers.

3.8.1.1 Work Order Barcode Scanning

Scanning work orders in and out of an automated system is essential in tracking their location and progress. Therefore, the purpose of this process is to ensure proper tracking of work orders throughout their respective project timelines. This also allows users to see a work order’s status. The software architecture diagram for this process is shown below.

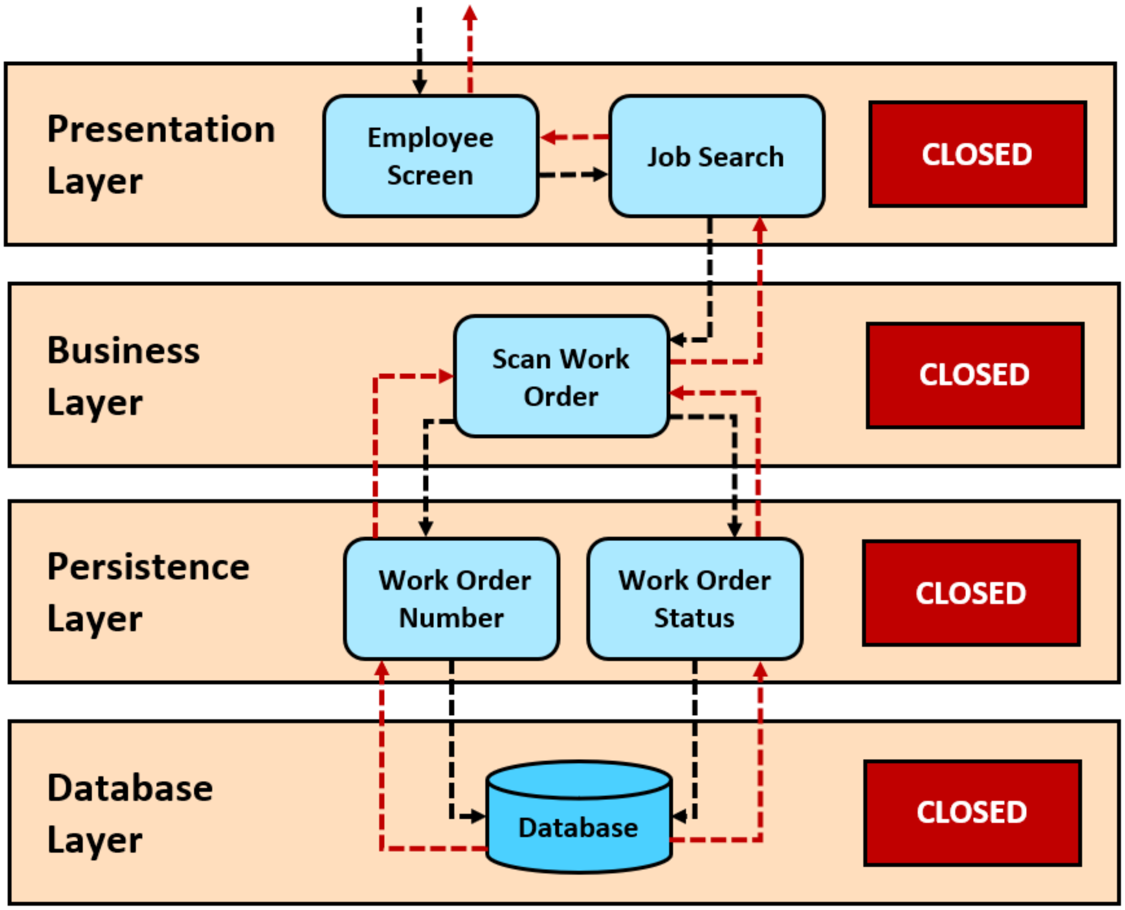


Figure 30 - Work Order Barcode Scanning Software Architecture Diagram

3.8.1.2 Stock Check

For the stock check at SPM to become automated, all inventories must be inputted into a software system. Therefore, an inventory cleanup was conducted, and all inventory components were counted and given a location code. This was done using the 5S Methodology: Sort, Set, Shine, Standardize, and Sustain. Once the items were sorted, set, and shined, they were standardized by giving them location codes. The use of the location codes would result in the sustaining of the items in the crib. The location code is a combination of the row, section, and shelf of where the component is in the Crib. The inventory in the Crib is from rows 7-16. The section varies from A-Q, depending on the row. The shelf number also varies from 1-4, depending on the row and section. The figure below illustrates an example for the generation of a component's location code.

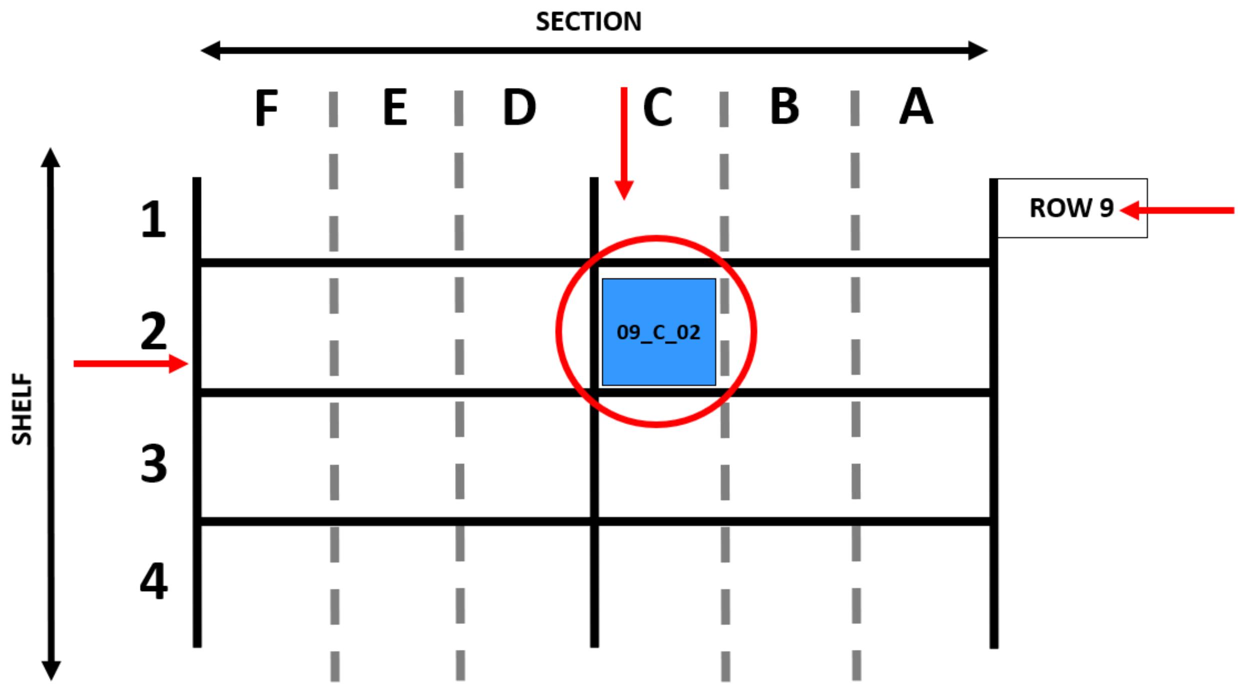


Figure 31 - SPM Location Code Example #1

Sometimes, when components are on the shelf, they are placed into bins. These components' location code contains an additional section outlining the bin number. Therefore, the code would be the row, section, shelf, and bin number. The figure below illustrates an example of this code variation.

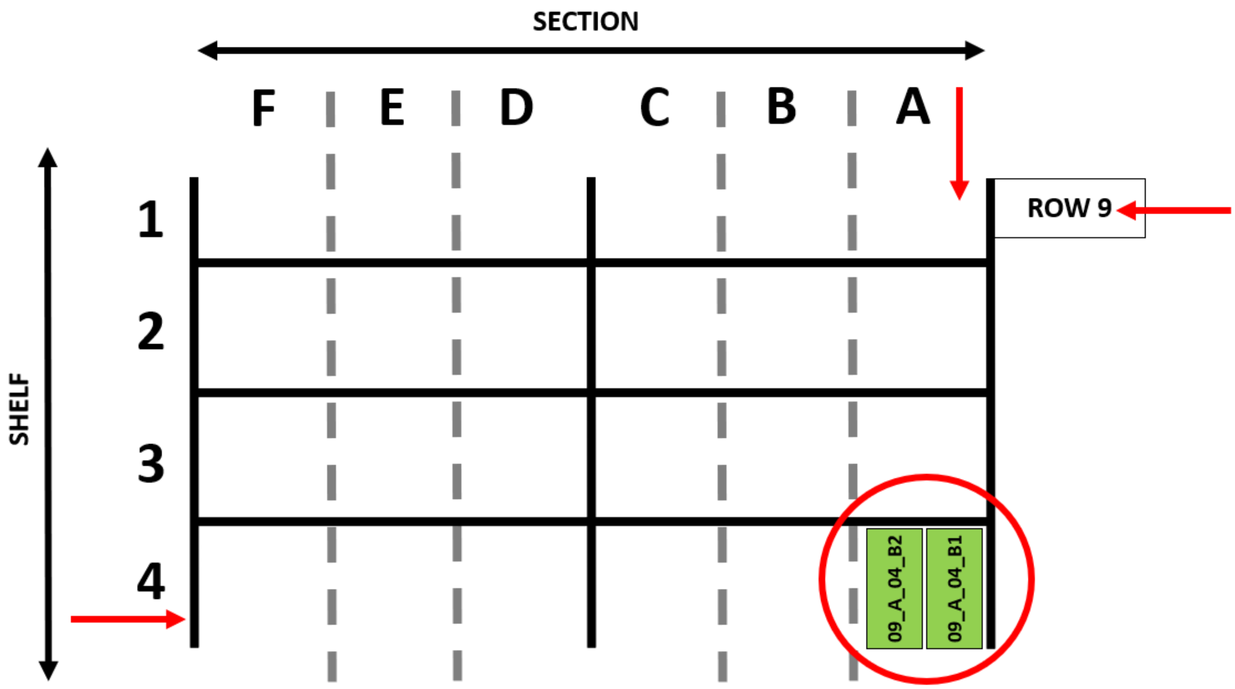


Figure 32 - SPM Location Code Example #2

Once the location codes were all created, they were imported in Genius and, from there, were inputted into SPM Connect. The Purchasing Manager can now look up components for stock checks and see the location codes, as well as their respective quantities. The software architecture diagram of this process is shown in the figure below.

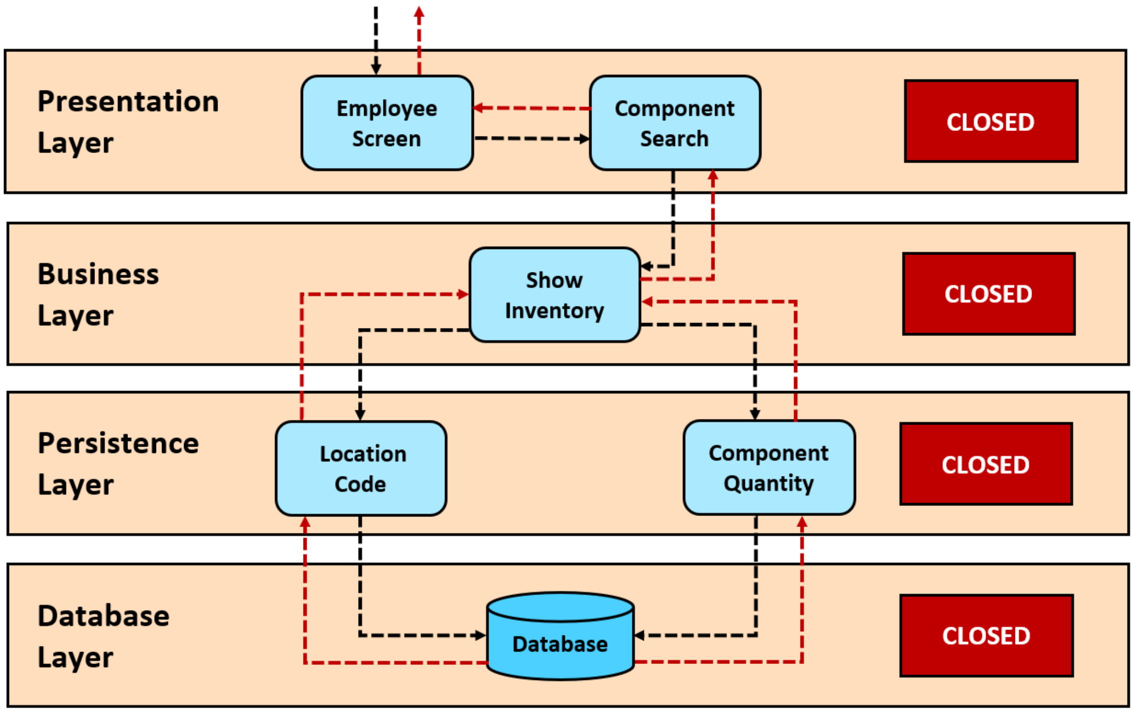


Figure 33 - Stock Check Process Software Architecture Diagram

3.8.1.3 Work Order and Subassembly Identification and Tracking

This process ensures all SPM Connect users can track and retrieve information about any work order or subassembly. The work order tracking progress consists of the location (which department it is in), who has it (last employee to scan the work order), and the check-in/out time. This allows users to see a work order's current location, the name of the last person that scanned it, and the time it was scanned. It also shows the bin build status. Lastly, the users can see which subassembly family any work order belongs to. These subassembly families are discussed in Section 3.5 above. The software architecture diagram is shown in the figure below.

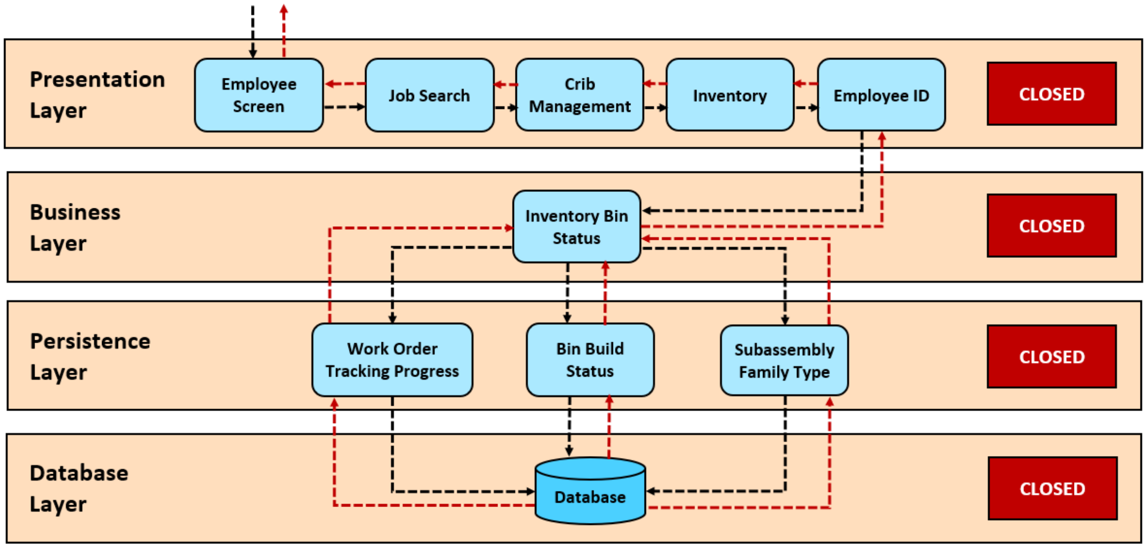


Figure 34 - Work Order and Subassembly Identification and Tracking

3.8.2 Coding and Programming

The coding and programming of the SPM Connect software was completed by Mr. Shailkumar Patel, the former Mechanical Designer / Software Developer at SPM.

3.9 Summary

Various tools and methodologies were used to brainstorm and determine subassembly families. These include IDEF Methodology, Systematic Design (Pahl & Beitz), Zachman Framework, Group Technology, and Rank Ordering Clustering Methodology. Moreover, the optimal work order and subassembly process flow was determined by using Process Mapping, Cause-and-Effect Diagrams, and 5Why Analysis. Other tools like 5S Methodology and Software Architecture Diagrams were used to establish the functionality of the developed software system. The following chapter explains the testing of the SPM Connect software, as well as procedures on how to navigate each section of the software. There are three sections discussed, each directly related to the software architecture diagrams above.

CHAPTER 4: WORK ORDER AND SUBASSEMBLY TRACKING MODEL TESTING

4.1 Overview

The testing of this research was held within SPM's facility. It consisted of five main departments. They are Engineering, Purchasing, Production, Crib, and Assembly. There were five work orders tested using the optimal work order and subassembly process.

4.2 Equipment

The equipment needed for this case study include the SPM Connect software and one barcode scanner. If the company chooses to implement the developed software system, five barcode scanners would be needed – one for each department involved. The figure below illustrates the work centers involved.

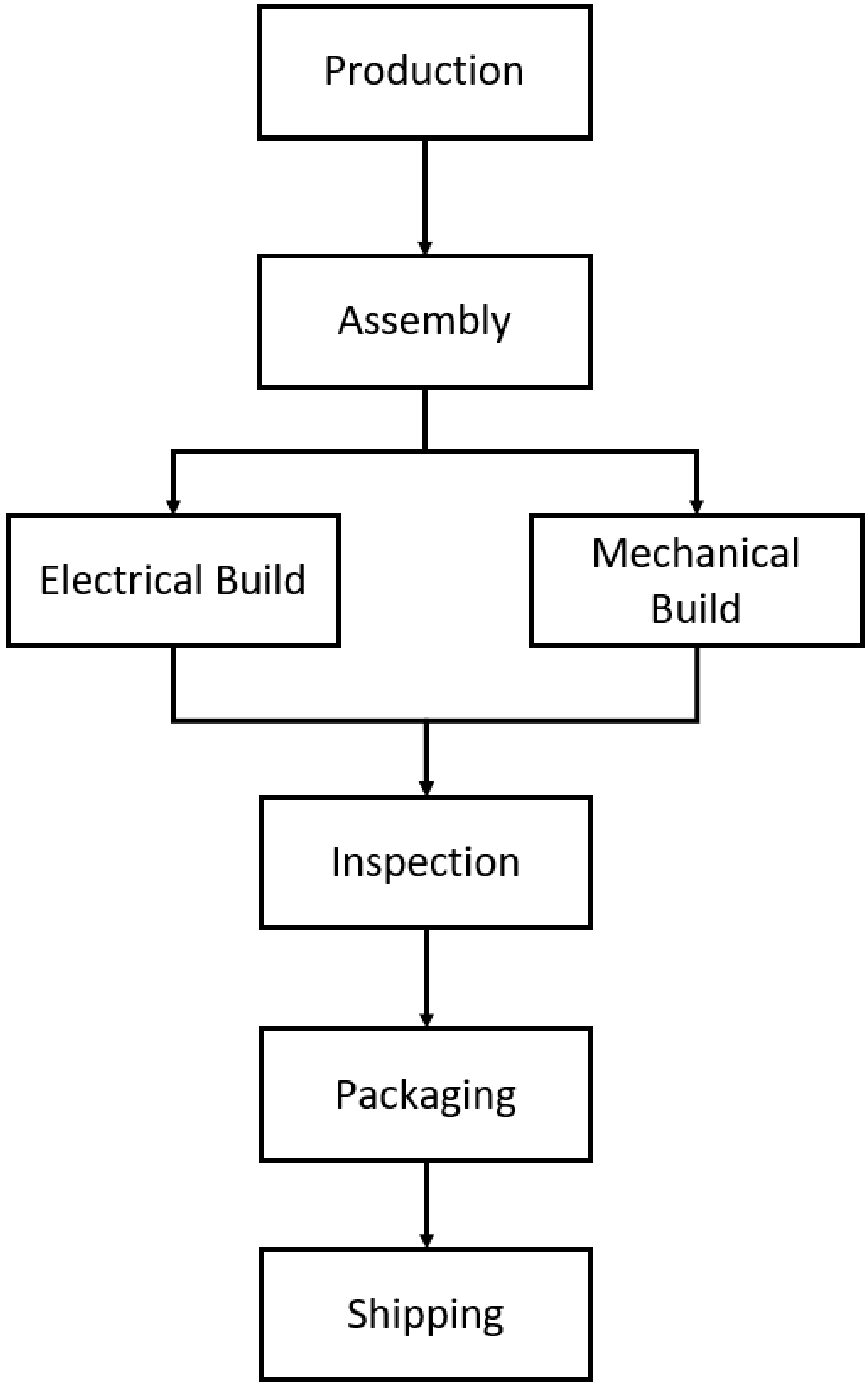


Figure 35- Work Centers

4.3 Procedure

The procedure is identical to the optimal work order and subassembly process flow, illustrated in Chapter 3. The figure below illustrates the overall developed software system, along with the connections between each procedure. All procedures start at the SPM Connect main interface screen.

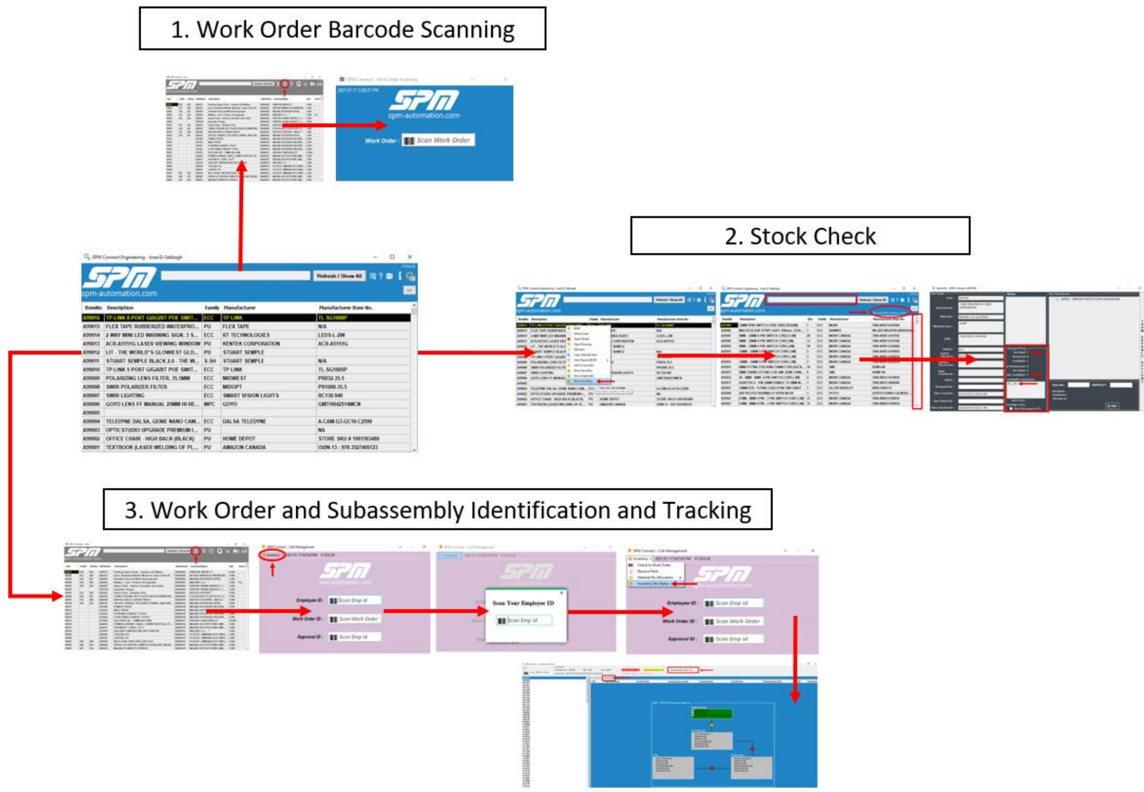


Figure 36- Overall Developed Software System

4.3.1 Work Order Barcode Scanning

Whenever a department receives a work order, they need to scan it into SPM Connect. To do this, the user opens SPM Connect and clicks on "Job Numbers." A new screen pops up with the list of all jobs at SPM. The user then clicks "Scan Work Order." A new screen will appear where the user will then scan the work order number. This is done when it is being checked in and out of a department. Figures 37-39 below illustrate the barcode scanning procedure.

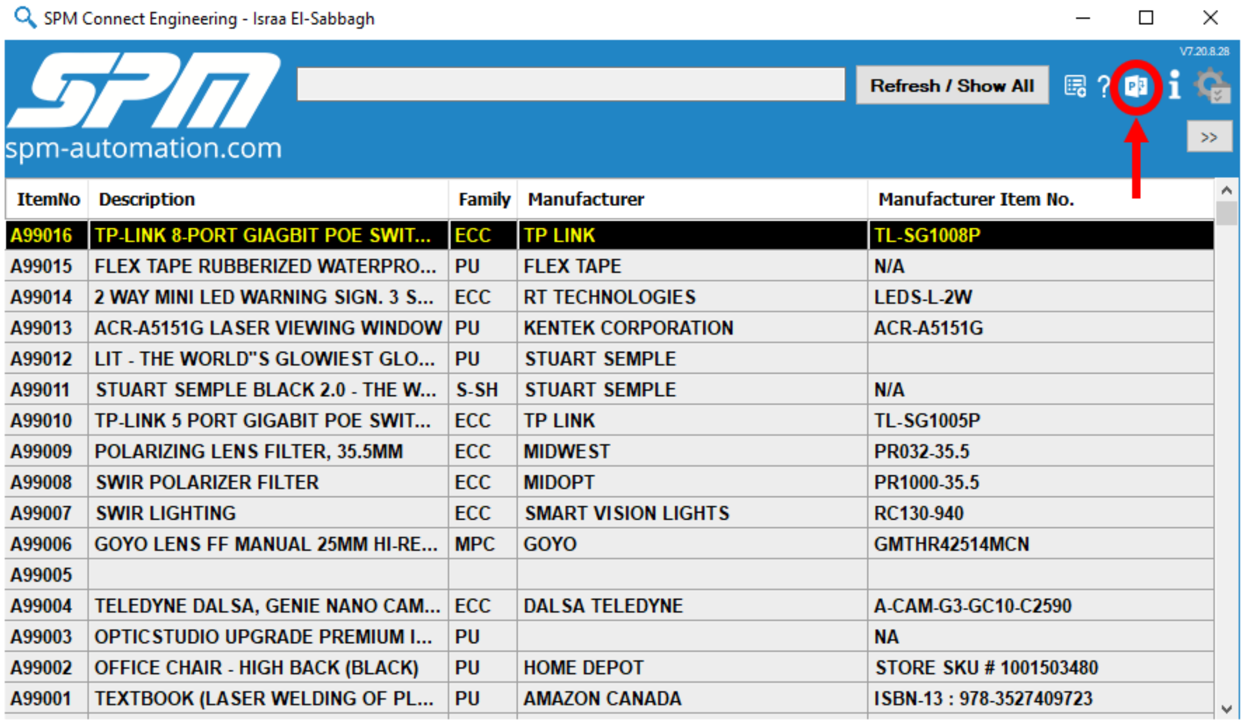
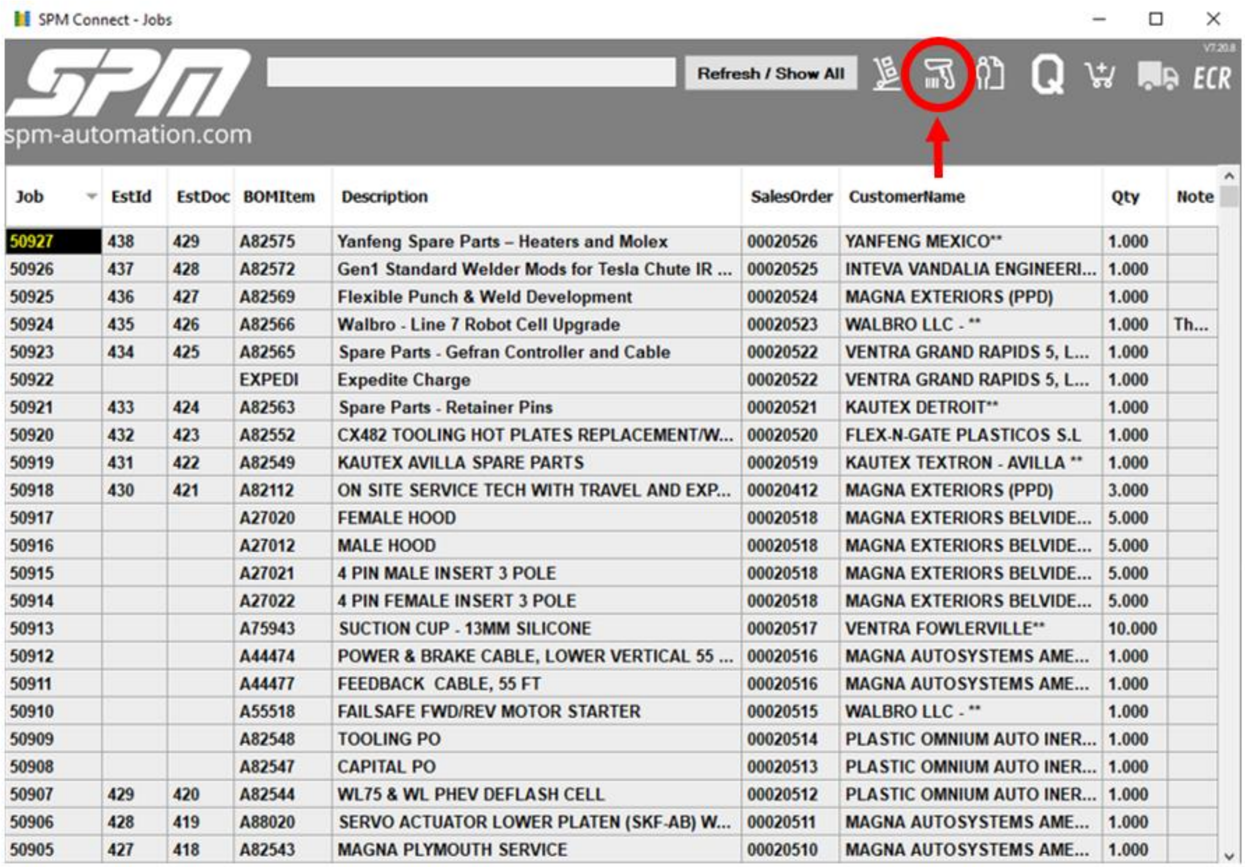


Figure 37 - Barcode Scanning Procedure Step #1



Job	EstId	EstDoc	BOMItem	Description	SalesOrder	CustomerName	Qty	Note
50927	438	429	A82575	Yanfeng Spare Parts – Heaters and Molex	00020526	YANFENG MEXICO**	1.000	
50926	437	428	A82572	Gen1 Standard Welder Mods for Tesla Chute IR ...	00020525	INTEVA VANDALIA ENGINEERI...	1.000	
50925	436	427	A82569	Flexible Punch & Weld Development	00020524	MAGNA EXTERIORS (PPD)	1.000	
50924	435	426	A82566	Walbro - Line 7 Robot Cell Upgrade	00020523	WALBRO LLC - **	1.000	Th...
50923	434	425	A82565	Spare Parts - Gefran Controller and Cable	00020522	VENTRA GRAND RAPIDS 5, L...	1.000	
50922			EXPEDI	Expedite Charge	00020522	VENTRA GRAND RAPIDS 5, L...	1.000	
50921	433	424	A82563	Spare Parts - Retainer Pins	00020521	KAUTEX DETROIT**	1.000	
50920	432	423	A82552	CX482 TOOLING HOT PLATES REPLACEMENT/W...	00020520	FLEX-N-GATE PLASTICOS S.L	1.000	
50919	431	422	A82549	KAUTEX AVILLA SPARE PARTS	00020519	KAUTEX TEXTRON - AVILLA **	1.000	
50918	430	421	A82112	ON SITE SERVICE TECH WITH TRAVEL AND EXP...	00020412	MAGNA EXTERIORS (PPD)	3.000	
50917			A27020	FEMALE HOOD	00020518	MAGNA EXTERIORS BELVIDE...	5.000	
50916			A27012	MALE HOOD	00020518	MAGNA EXTERIORS BELVIDE...	5.000	
50915			A27021	4 PIN MALE INSERT 3 POLE	00020518	MAGNA EXTERIORS BELVIDE...	5.000	
50914			A27022	4 PIN FEMALE INSERT 3 POLE	00020518	MAGNA EXTERIORS BELVIDE...	5.000	
50913			A75943	SUCTION CUP - 13MM SILICONE	00020517	VENTRA FOWLERVILLE**	10.000	
50912			A44474	POWER & BRAKE CABLE, LOWER VERTICAL 55 ...	00020516	MAGNA AUTOSYSTEMS AME...	1.000	
50911			A44477	FEEDBACK CABLE, 55 FT	00020516	MAGNA AUTOSYSTEMS AME...	1.000	
50910			A55518	FAILSAFE FWD/REV MOTOR STARTER	00020515	WALBRO LLC - **	1.000	
50909			A82548	TOOLING PO	00020514	PLASTIC OMNIUM AUTO INER...	1.000	
50908			A82547	CAPITAL PO	00020513	PLASTIC OMNIUM AUTO INER...	1.000	
50907	429	420	A82544	WL75 & WL PHEV DEFLASH CELL	00020512	PLASTIC OMNIUM AUTO INER...	1.000	
50906	428	419	A88020	SERVO ACTUATOR LOWER PLATEN (SKF-AB) W...	00020511	MAGNA AUTOSYSTEMS AME...	1.000	
50905	427	418	A82543	MAGNA PLYMOUTH SERVICE	00020510	MAGNA AUTOSYSTEMS AME...	1.000	

Figure 38 - Barcode Scanning Procedure Step #2

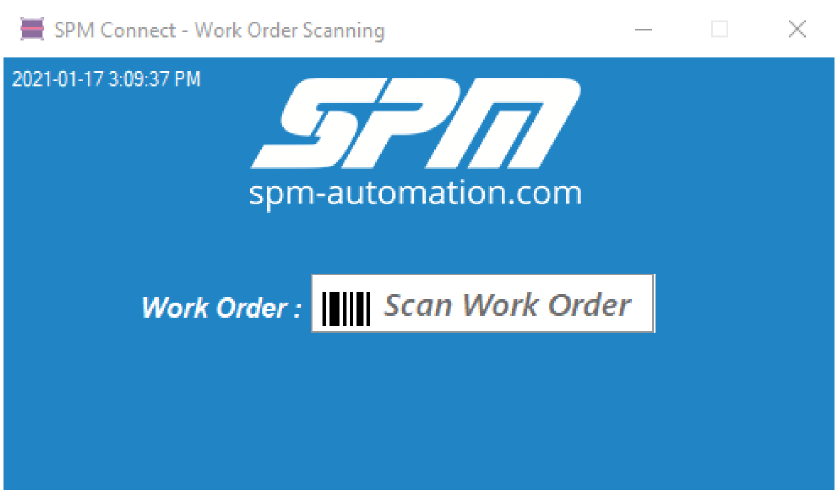


Figure 39 - Barcode Scanning Procedure Step #3

If the work order is already in the system, meaning Engineering has released it, a note will pop up stating so. This note will pop up for every department, except Engineering. After clicking “OK,” a summary of its status is shown. An example is shown in Figure 40 below.

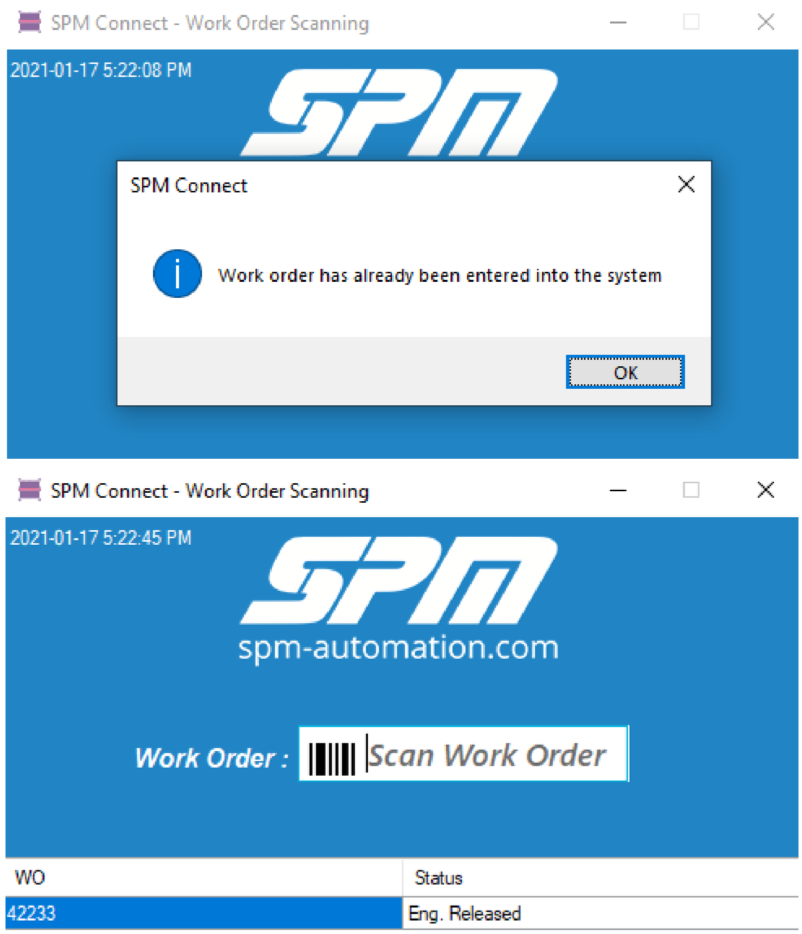


Figure 40 - Barcode Scanning Procedure Status Summary Example

4.3.2 Stock Check

This procedure is specifically for the Purchasing Manager, as they are the ones to complete the stock checks in the optimal process flow. The user opens SPM Connect, right clicks any item on the screen, and clicks "Show Inventory." Another screen will appear, listing all the inventory in the Crib. The user can type in the component they are looking for or scroll through the list. Once the component is found, the user double clicks on it and a new window will appear that consists of the location code and quantity. Figures 41-43 below illustrate an example of the stock check procedure.

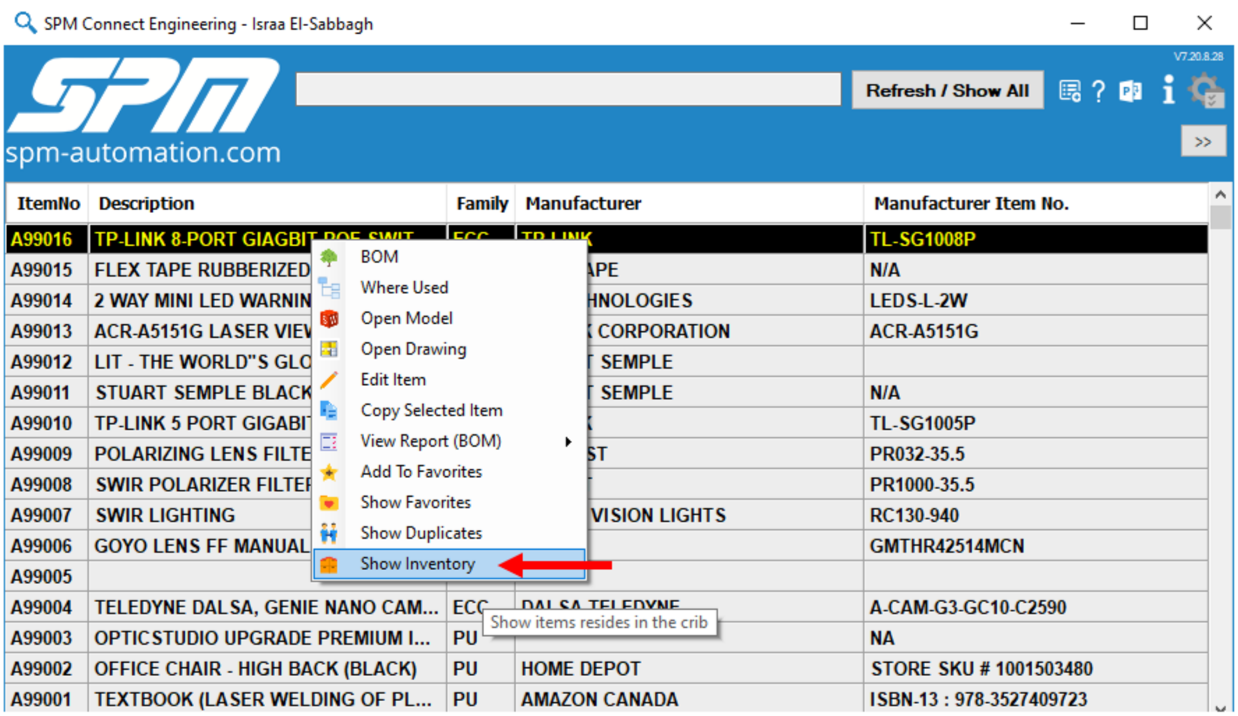


Figure 41 - Stock Check Procedure Step #1

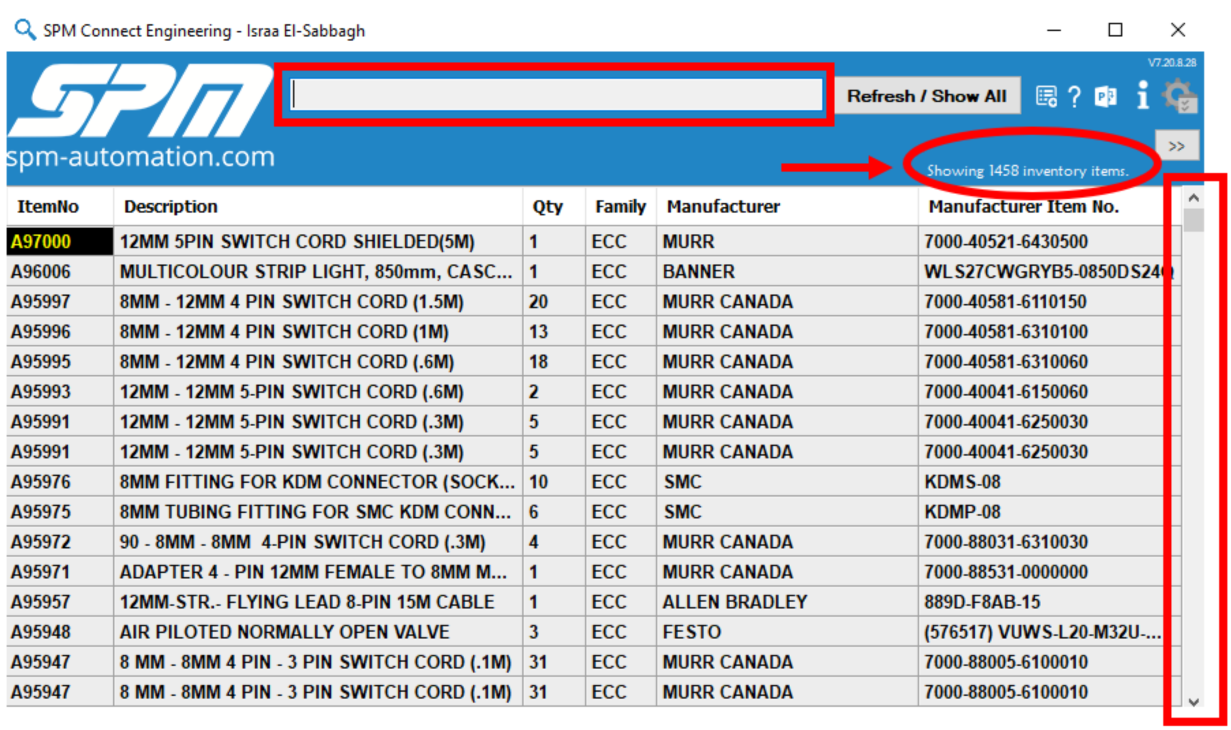


Figure 42 - Stock Check Procedure Step #2

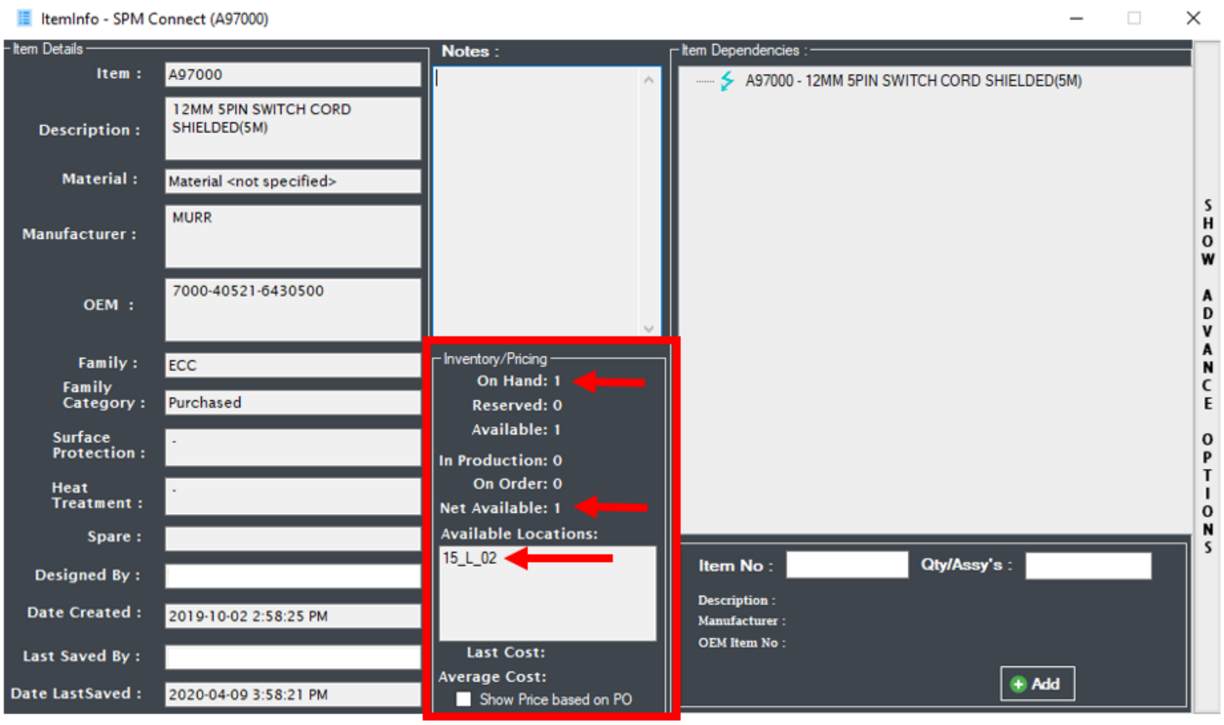
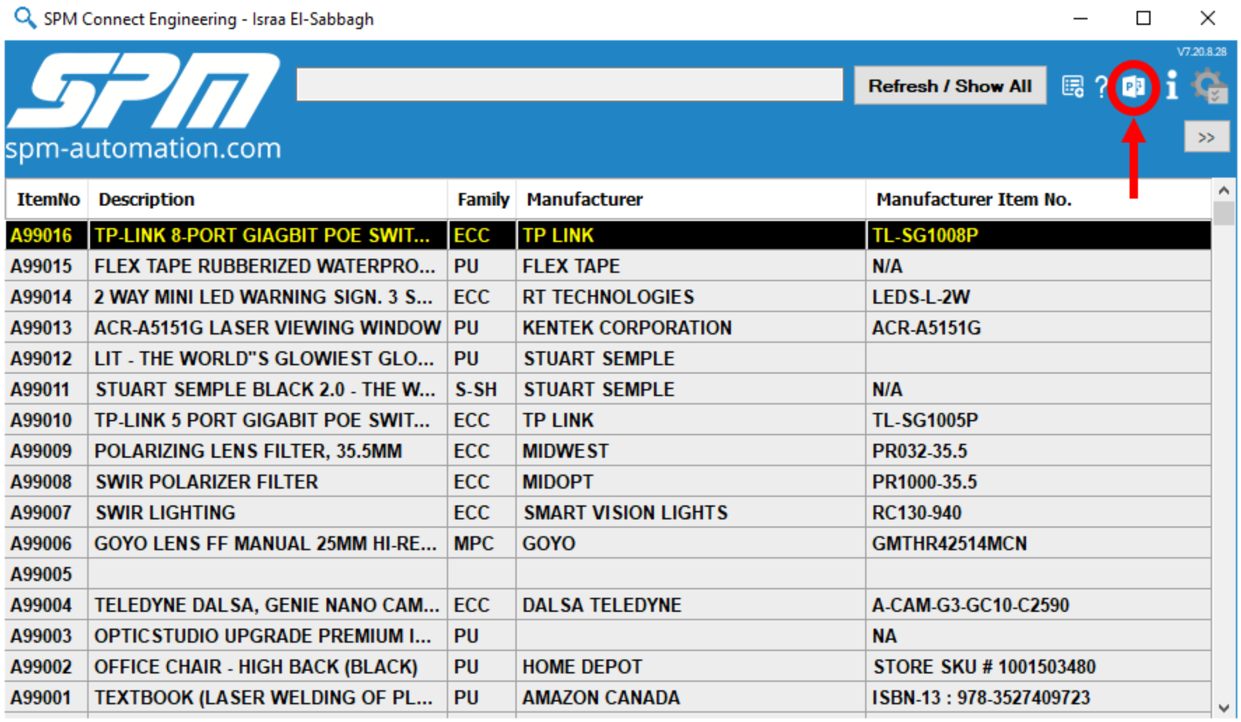


Figure 43 - Stock Check Procedure Step #3

4.3.3 Work Order and Subassembly Identification and Tracking

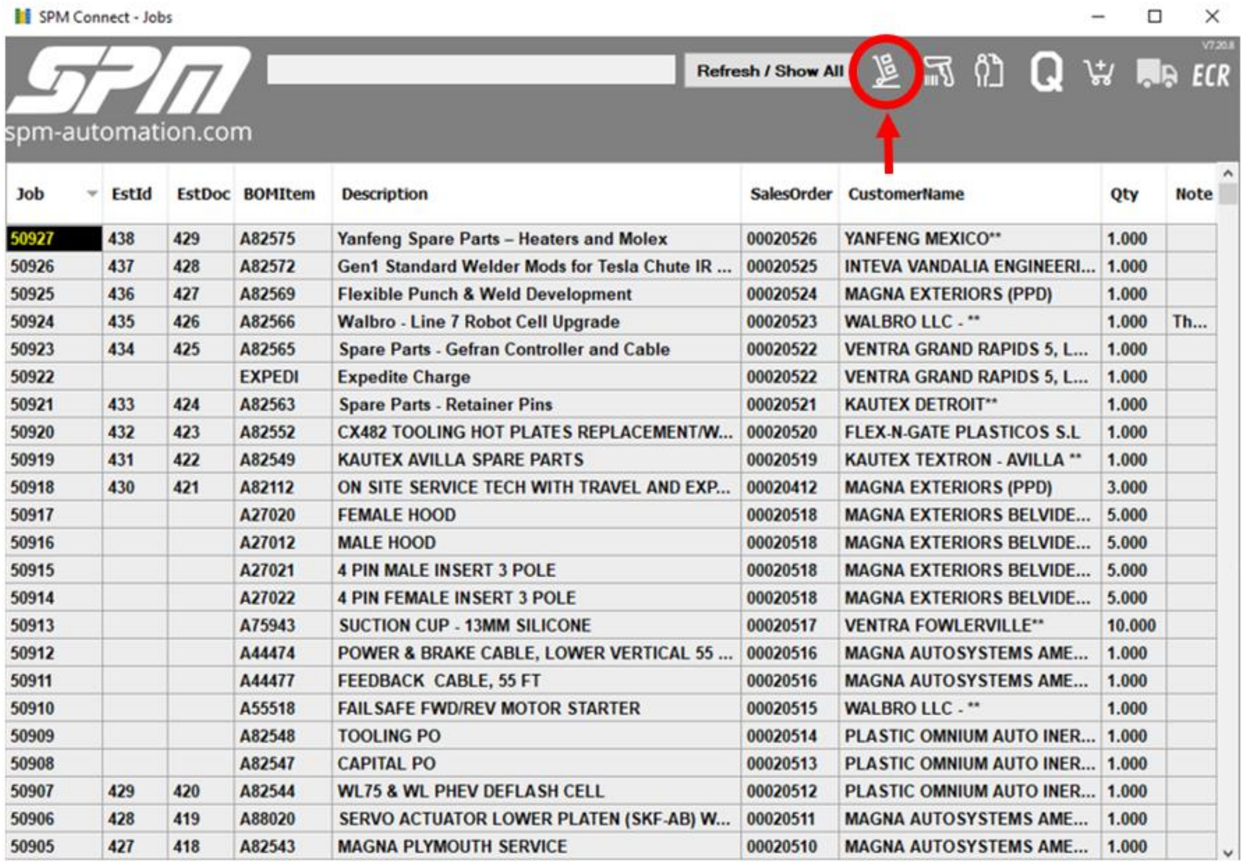
SPM Connect users can look up any work order to see its overall status, as well as the bin build status. The bin build status is the logging in and out of the subassembly bin. This tracks how long Assemblers are taking when building subassemblies. It also shows how many times the bin was returned to the Crib.

To access either of these, the user opens SPM Connect and clicks the "Job Numbers." A new screen pops up with the list of all jobs at SPM. The user then clicks "Crib Management." A new screen will appear where the user will click the "Inventory" drop-down button on the top left of the screen. This will prompt a new screen to pop up asking for the Employee's ID. Once the Employee ID is scanned or typed in, the user clicks the "Inventory" drop-down button again and clicks "Inventory Bin Status." This will open a new screen that displays all work orders in the system, their bin build status, and overall work order status. The user can scan a work order in the search bar or scroll through the list. Figures 44-51 illustrate an example of this procedure.



ItemNo	Description	Family	Manufacturer	Manufacturer Item No.
A99016	TP-LINK 8-PORT GIAGBIT POE SWIT...	ECC	TP LINK	TL-SG1008P
A99015	FLEX TAPE RUBBERIZED WATERPRO...	PU	FLEX TAPE	N/A
A99014	2 WAY MINI LED WARNING SIGN. 3 S...	ECC	RT TECHNOLOGIES	LEDS-L-2W
A99013	ACR-A5151G LASER VIEWING WINDOW	PU	KENTEK CORPORATION	ACR-A5151G
A99012	LIT - THE WORLD"S GLOWIEST GLO...	PU	STUART SEMPLE	
A99011	STUART SEMPLE BLACK 2.0 - THE W...	S-SH	STUART SEMPLE	N/A
A99010	TP-LINK 5 PORT GIGABIT POE SWIT...	ECC	TP LINK	TL-SG1005P
A99009	POLARIZING LENS FILTER, 35.5MM	ECC	MIDWEST	PR032-35.5
A99008	SWIR POLARIZER FILTER	ECC	MIDOPT	PR1000-35.5
A99007	SWIR LIGHTING	ECC	SMART VISION LIGHTS	RC130-940
A99006	GOYO LENS FF MANUAL 25MM HI-RE...	MPC	GOYO	GMTHR42514MCN
A99005				
A99004	TELEDYNE DALSA, GENIE NANO CAM...	ECC	DALSA TELEDYNE	A-CAM-G3-GC10-C2590
A99003	OPTICSTUDIO UPGRADE PREMIUM I...	PU		NA
A99002	OFFICE CHAIR - HIGH BACK (BLACK)	PU	HOME DEPOT	STORE SKU # 1001503480
A99001	TEXTBOOK (LASER WELDING OF PL...	PU	AMAZON CANADA	ISBN-13 : 978-3527409723

Figure 44 - Work Order and Subassembly Tracking Procedure Step #1



Job	EstId	EstDoc	BOMItem	Description	SalesOrder	CustomerName	Qty	Note
50927	438	429	A82575	Yanfeng Spare Parts – Heaters and Molex	00020526	YANFENG MEXICO**	1.000	
50926	437	428	A82572	Gen1 Standard Welder Mods for Tesla Chute IR ...	00020525	INTEVA VANDALIA ENGINEERI...	1.000	
50925	436	427	A82569	Flexible Punch & Weld Development	00020524	MAGNA EXTERIORS (PPD)	1.000	
50924	435	426	A82566	Walbro - Line 7 Robot Cell Upgrade	00020523	WALBRO LLC - **	1.000	Th...
50923	434	425	A82565	Spare Parts - Gefran Controller and Cable	00020522	VENTRA GRAND RAPIDS 5, L...	1.000	
50922			EXPEDI	Expedite Charge	00020522	VENTRA GRAND RAPIDS 5, L...	1.000	
50921	433	424	A82563	Spare Parts - Retainer Pins	00020521	KAUTEX DETROIT**	1.000	
50920	432	423	A82552	CX482 TOOLING HOT PLATES REPLACEMENT/W...	00020520	FLEX-N-GATE PLASTICOS S.L	1.000	
50919	431	422	A82549	KAUTEX AVILLA SPARE PARTS	00020519	KAUTEX TEXTRON - AVILLA **	1.000	
50918	430	421	A82112	ON SITE SERVICE TECH WITH TRAVEL AND EXP...	00020412	MAGNA EXTERIORS (PPD)	3.000	
50917			A27020	FEMALE HOOD	00020518	MAGNA EXTERIORS BELVIDE...	5.000	
50916			A27012	MALE HOOD	00020518	MAGNA EXTERIORS BELVIDE...	5.000	
50915			A27021	4 PIN MALE INSERT 3 POLE	00020518	MAGNA EXTERIORS BELVIDE...	5.000	
50914			A27022	4 PIN FEMALE INSERT 3 POLE	00020518	MAGNA EXTERIORS BELVIDE...	5.000	
50913			A75943	SUCTION CUP - 13MM SILICONE	00020517	VENTRA FOWLERVILLE**	10.000	
50912			A44474	POWER & BRAKE CABLE, LOWER VERTICAL 55 ...	00020516	MAGNA AUTOSYSTEMS AME...	1.000	
50911			A44477	FEEDBACK CABLE, 55 FT	00020516	MAGNA AUTOSYSTEMS AME...	1.000	
50910			A55518	FAILSAFE FWD/REV MOTOR STARTER	00020515	WALBRO LLC - **	1.000	
50909			A82548	TOOLING PO	00020514	PLASTIC OMNIUM AUTO INER...	1.000	
50908			A82547	CAPITAL PO	00020513	PLASTIC OMNIUM AUTO INER...	1.000	
50907	429	420	A82544	WL75 & WL PHEV DEFLASH CELL	00020512	PLASTIC OMNIUM AUTO INER...	1.000	
50906	428	419	A88020	SERVO ACTUATOR LOWER PLATEN (SKF-AB) W...	00020511	MAGNA AUTOSYSTEMS AME...	1.000	
50905	427	418	A82543	MAGNA PLYMOUTH SERVICE	00020510	MAGNA AUTOSYSTEMS AME...	1.000	

Figure 45 - Work Order and Subassembly Tracking Procedure Step #2

Figure 46 - Work Order and Subassembly Tracking Procedure Step #3

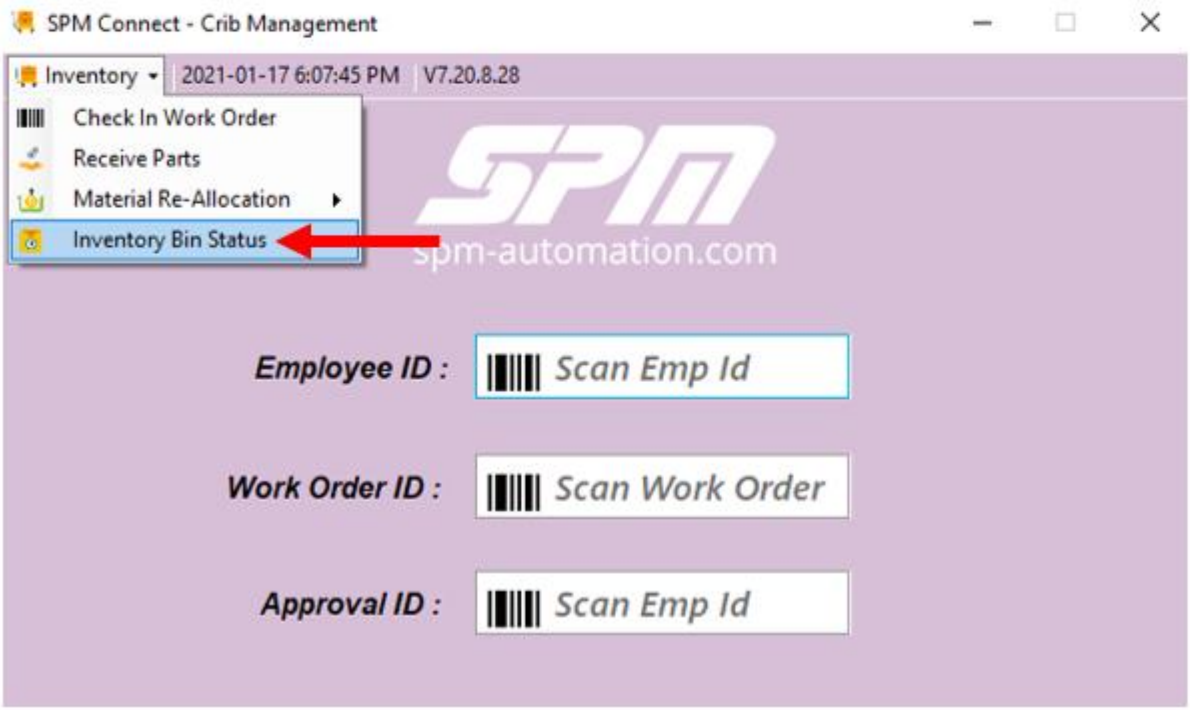


Figure 47 - Work Order and Subassembly Tracking Procedure Step #4

The “Bin Build Status” tab shows the checking in/out of the subassembly bin. This interaction is between the Crib Attendant and Assembler. This tab consists of the work order number, employee checking out the bin, check out time, employee approving the checkout, time it was approved for check out, employee checking in the bin, check-in time, employee approving the check-in, time approved for check-in, inbuilt status, and completed status. The inbuilt column is regarding the subassembly’s assembly. The completed column is regarding the bin being empty upon arrival to the crib. If the inbuilt and completed columns are yes, the subassembly has been built, and the Assembler is returning the empty bin back to the Crib. If they are both no, it means the Assembler is returning the bin with the unfinished subassembly to the crib. The only employee that will be approving the check-in/out of bins is the Crib Attendant.

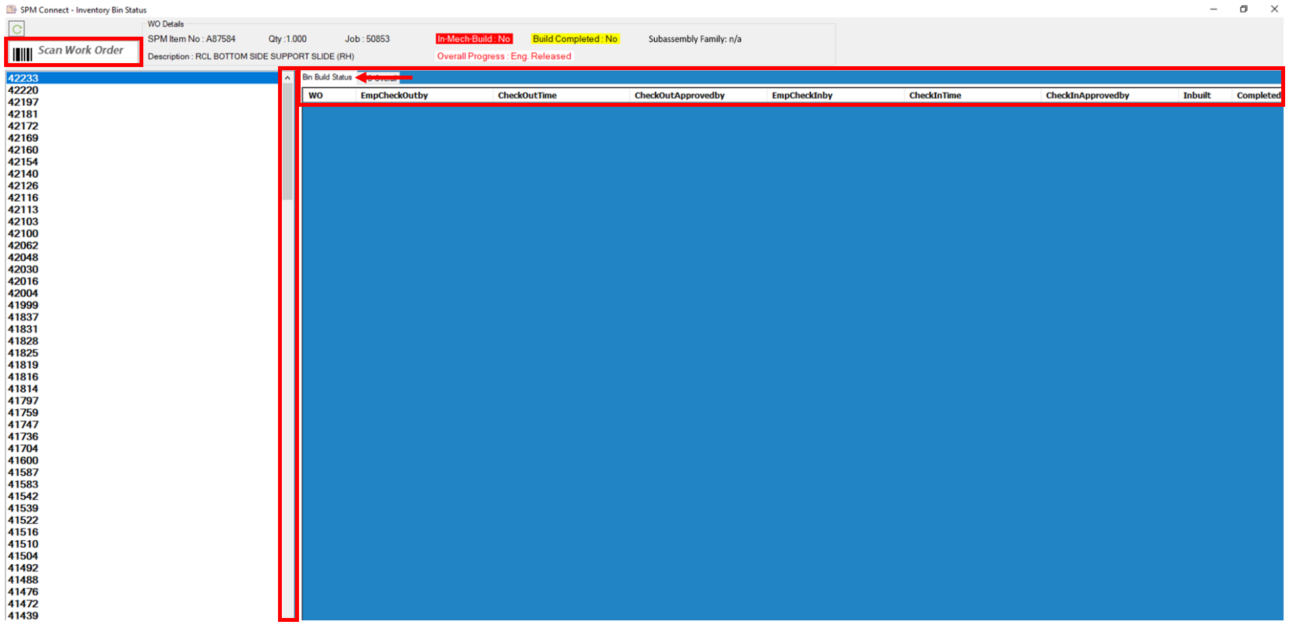


Figure 48- Work Order and Subassembly Tracking Procedure Step #5

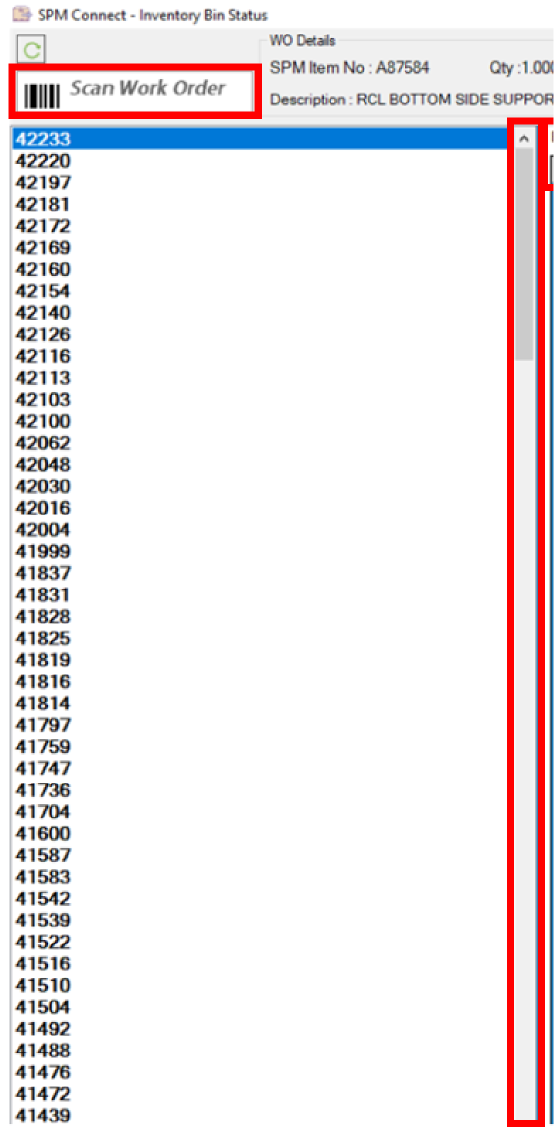


Figure 49- Work Order and Subassembly Tracking Procedure Step #5 Scroll Bar

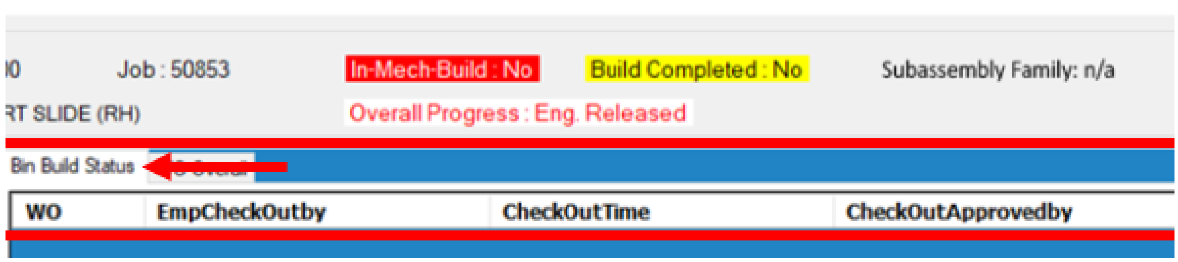


Figure 50- Work Order and Subassembly Tracking Procedure Step #5 Headings (First Half)

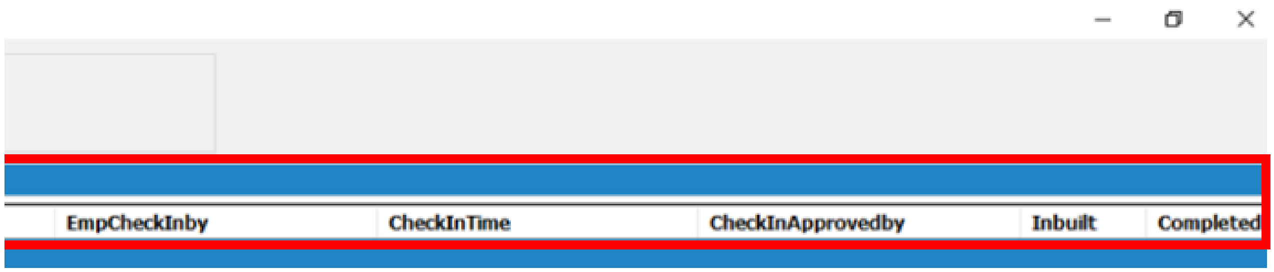


Figure 51- Work Order and Subassembly Tracking Procedure Step #5 Headings (Second Half)

The “WO Overall” tab shows the tracking of the work order. This includes which department has the work order, who it was checked in/out by, and what time it was checked in/out. The boxes of each department change colours, depending on the progress within each department. The colour grey indicates the department has not received the work order. Orange indicates the department has received the work order, and it is currently working on it. Green indicates the department has received the work order, completed the necessary requirements, and has checked out the work order from the department. The circles in between each department also change colour to indicate the process of the work order. If the circle is orange, that means the department prior has completed their work and is waiting for the following department to check in the work order. If it is green, then the work order has been checked in by the latter department. If it is red, the department prior has not checked out the work order.

The top right of the interface includes the “Subassembly Family” section. This will indicate which subassembly family a work order belongs to, based on the subassembly families in Section 3.5 of Chapter 3. If the subassembly family is n/a, it means that the work order does not belong to any of the common subassemblies listed within the numbering legend in Chapter 3. The figures below are an example of a work order in the tracking system.

<u>Note</u>: Employee names have been removed for confidentiality and privacy reasons.

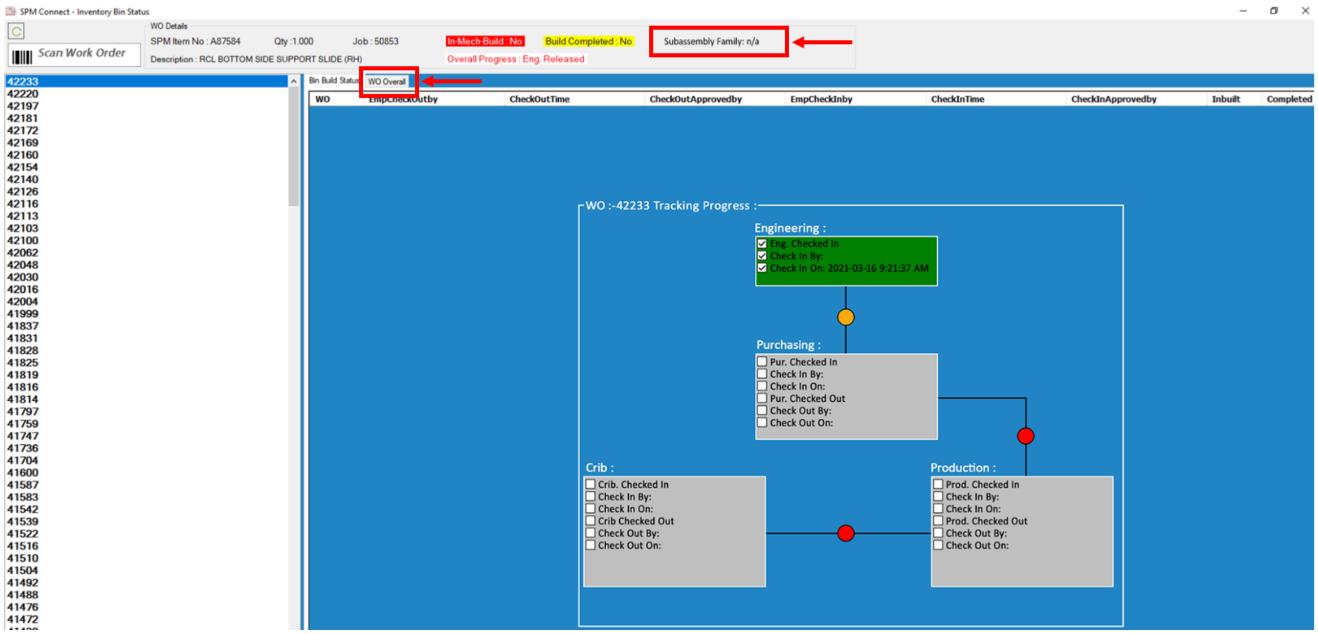


Figure 52- Work Order and Subassembly Tracking Example #1

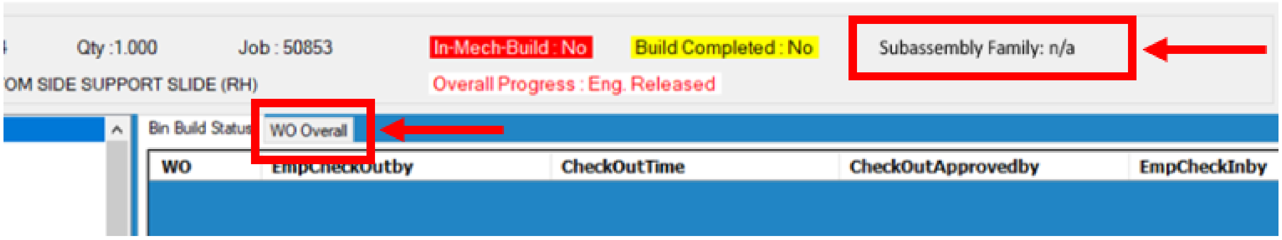


Figure 53 - Work Order and Subassembly Tracking Example #1 Headings

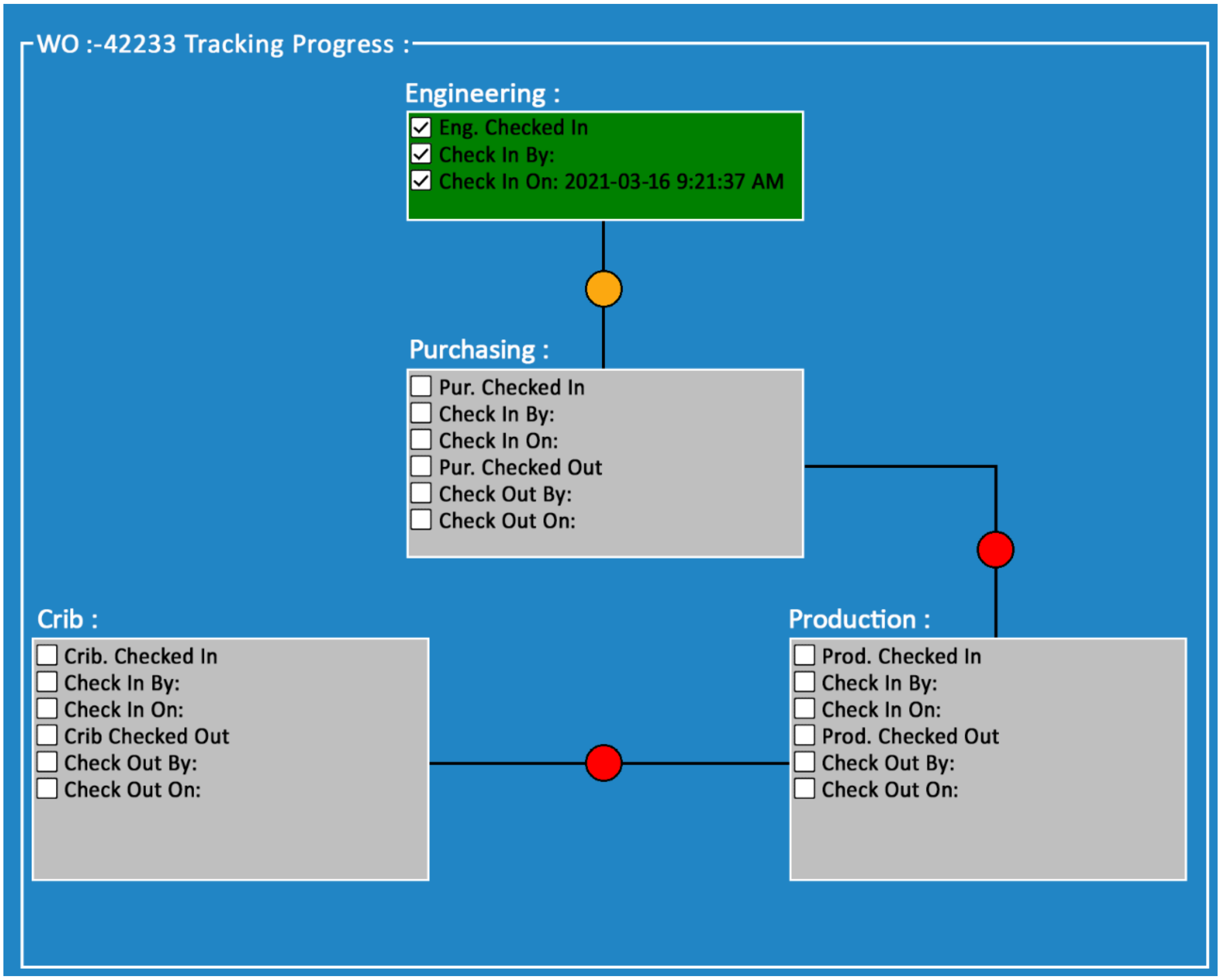


Figure 54 - Work Order and Subassembly Tracking Example #1 WO 42233

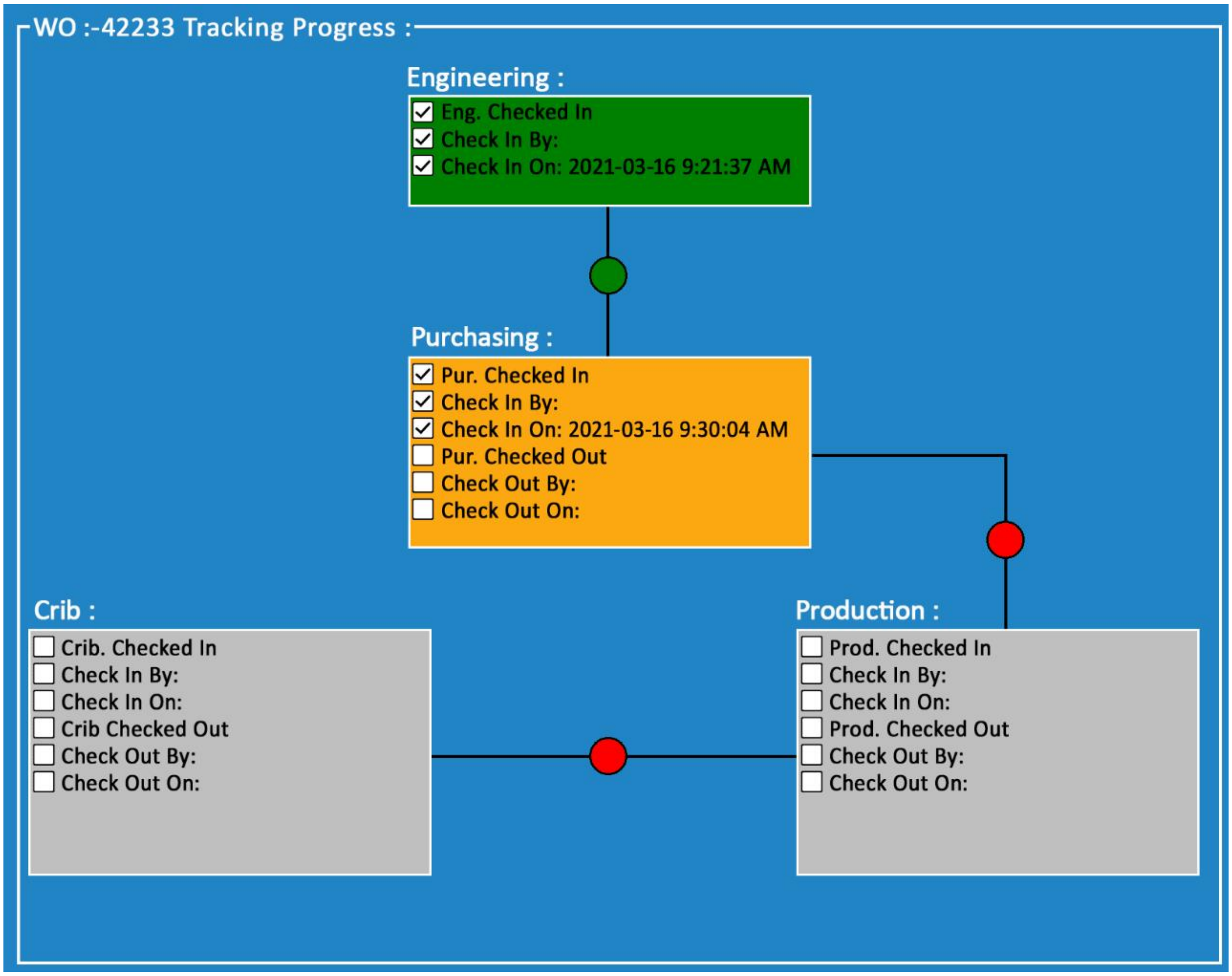


Figure 55 - Work Order and Subassembly Tracking Example #2 WO 42233

4.4 Testing

The system was tested on SPM Job 50853 - C1UC MCM RCL Laser Welding Tooling. The job consists of the following five work orders, listed in numerical order:

- 42181 – Upper Tool Base (C1UC – MCM RCL) Laser Weld
- 42197 – C1UC RCL Lower Tool Assembly (RH)
- 42220 – RCL Inboard Support Slide (Lower RH Tool)
- 42233 – RCL Bottom Side Support Slide (RH)
- 42248 – C1UC MCM RCL Upper Tool Nest (RH)

4.5 Summary

The testing, equipment, and procedures for each section of the optimal process are discussed and explained in detail, along with screenshots of the SPM Connect software. The following chapter presents the results and discussions of the five workorders that were tested using the developed system. Specific KPI metrics are analyzed, and percentage decreases are calculated for each. A cost structure model is also presented to illustrate the estimated average annual cost savings and time decrease.

CHAPTER 5: RESULTS AND DISCUSSION

5.1 Results

The testing of the optimal work order and subassembly process was conducted using Job 50853 - C1UC MCM RCL Laser Welding Tooling. The following subsections illustrate the results for each work order tracked, along with an explanation of the interface. The subsections are listed in order from which they were first checked in by the Purchasing Department.

Note: The empty sections and columns in the figures of this chapter are supposed to have the employee names but have been removed for confidentiality and privacy reasons.

5.1.1 Work Order 42181 – Upper Tool Base (C1UC – MCM RCL) Laser Weld

The Engineering Department first released the work order on March 15th at 11:56 AM. It was then checked in by the Purchasing Department at 12:30 PM and checked out at 1:02 PM. The Production Department checked in at 1:03 PM and checked out at 2:33 PM. Finally, the Crib checked in at 2:40 PM and checked out on April 5th at 8:55 AM. One can see that the Purchasing Department took approximately 30 minutes to check in the work order. This is due to other tasks the department may be working on at the time. Moreover, the time spent in each department is written within the interface to give the user a better understanding of how long it takes each department to check out the work order. Figure 56 below shows the interface for this work order's overall tracking status.

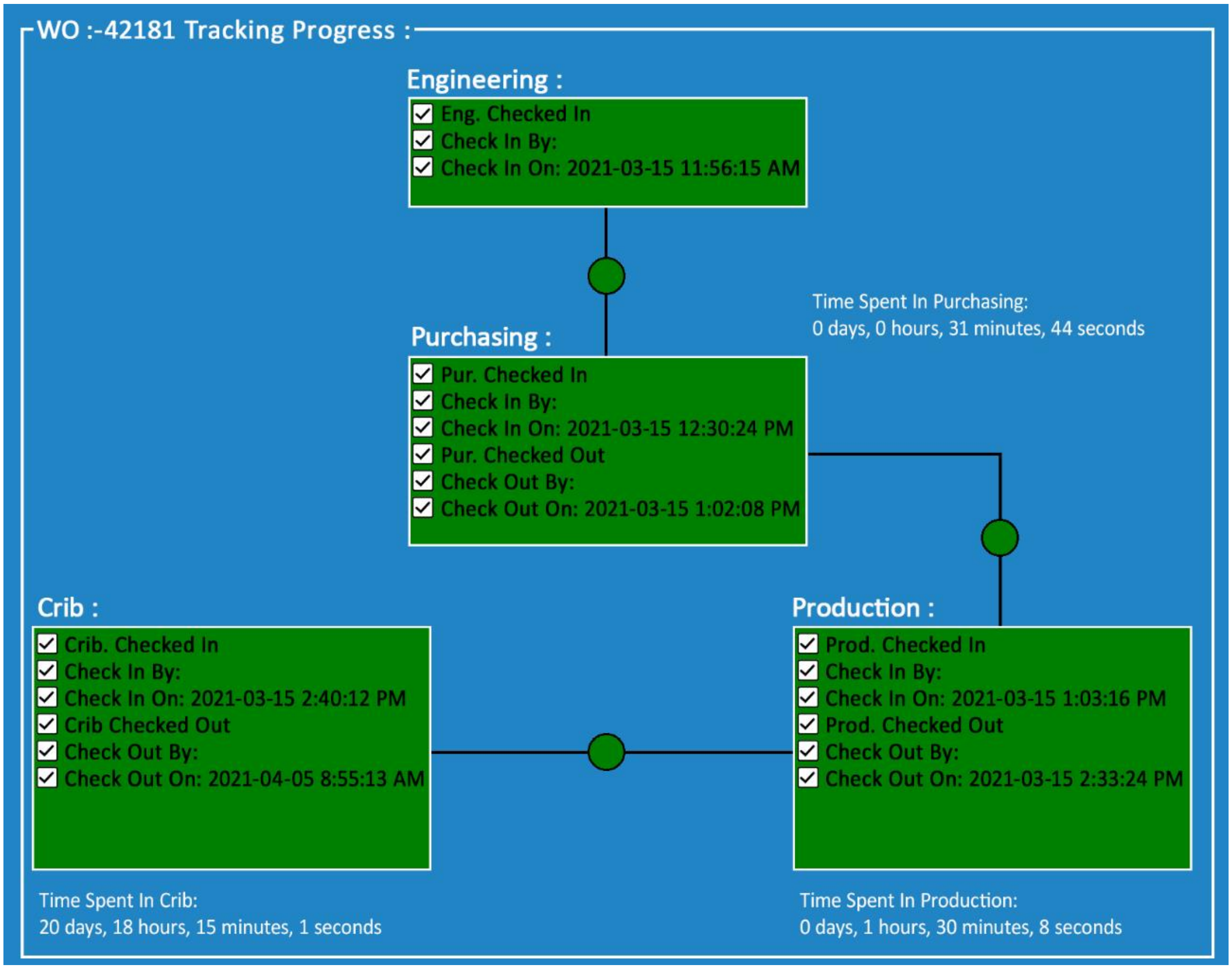


Figure 56 - WO 42181 Tracking Progress

As stated in Chapter 4, the bin build status represents the relationship between the Crib and Assembly. It is an automated log of which Assembler is taking the bin out to Assembly. However, this can only be done when the Crib Attendant approves it. For this work order, the subassembly was completely built within the Assembler's shift. This is shown in the "Inbuilt" and "Complete" columns in Figures 57-58 below. Both columns are marked as "yes," meaning the subassembly has been built, and the empty bin was returned to the crib.

Bin Build Status | WO Overall

WO	EmpCheckOutby	CheckOutTime	CheckOutApprovedby
42181		2021-04-05 8:55 AM	

Figure 57- WO 42181 Bin Build Status First Half

EmpCheckInby	CheckInTime	CheckInApprovedby	Inbuilt	Completed
	2021-04-05 2:30 PM		Yes	Yes

Figure 58 - WO 42181 Bin Build Status Second Half

5.1.2 Work Order 42233 – RCL Bottom Side Support Slide (RH)

The Engineering Department first released the work order on March 16th at 9:21 AM. It was then checked in by the Purchasing Department at 9:30 AM and checked out at 9:58 AM. The Production Department checked in at 10:00 AM and checked out at 11:02 AM. Finally, the Crib checked in at 11:06 AM and checked out April on 6th at 11:21 AM. Figure 59 below shows the interface for this work order's overall tracking status. The bin build status for this work order is in Figures 60-61 below.

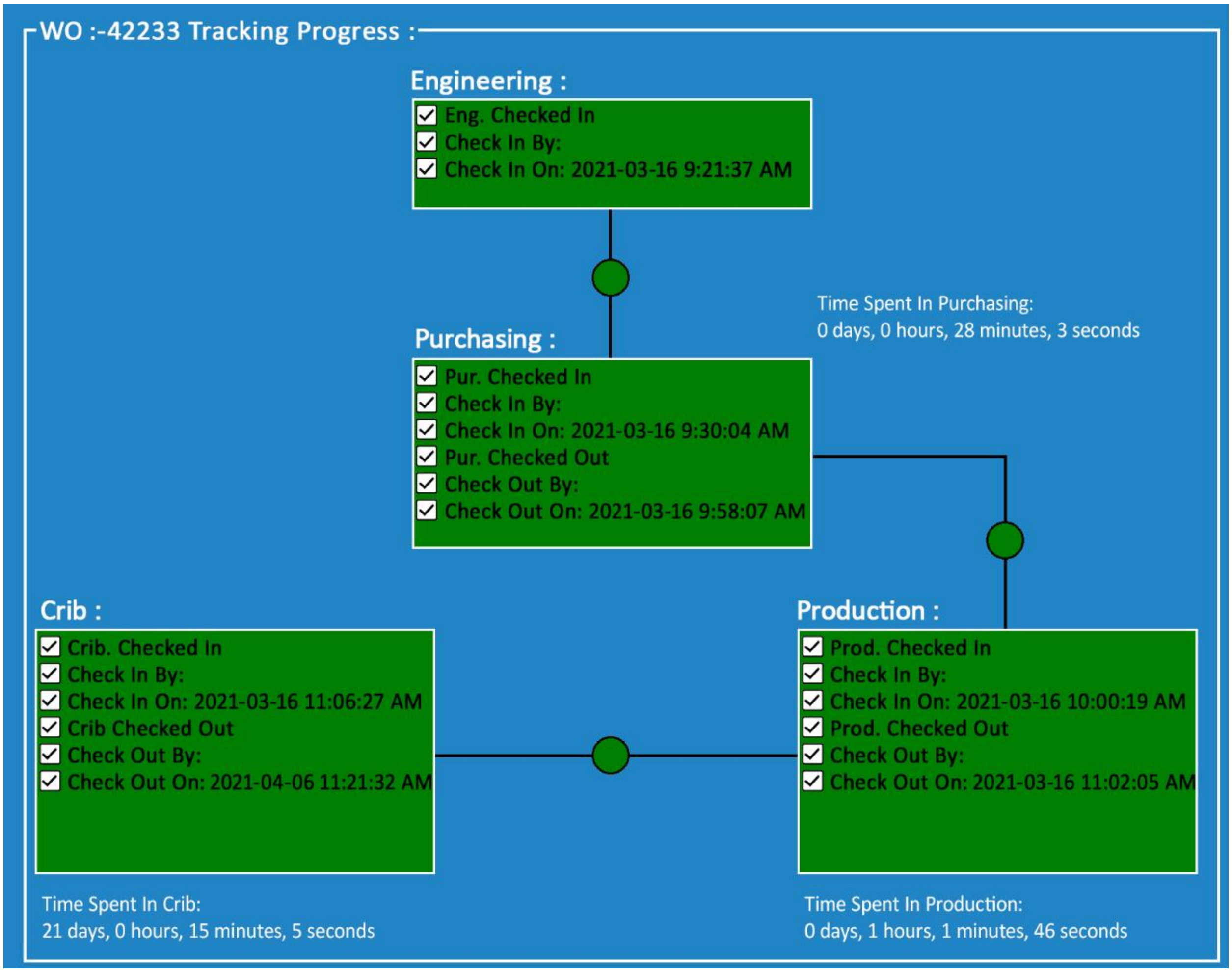


Figure 59 - WO 42233 Tracking Progress

Bin Build Status | WO Overall

WO	EmpCheckOutby	CheckOutTime	CheckOutApprovedby
42233		2021-04-06 11:21 AM	

Figure 60- WO 42233 Bin Build Status First Half

EmpCheckInby	CheckInTime	CheckInApprovedby	Inbuilt	Completed
	2021-04-06 4:30 PM		Yes	Yes

Figure 61 - WO 42233 Bin Build Status Second Half

5.1.3 Work Order 42220 – RCL Inboard Support Slide (Lower RH Tool)

The Engineering Department first released the work order on March 16th at 9:21 AM. It was then checked in by the Purchasing Department at 10:00 AM and checked out at 10:37 AM. The Production Department checked in at 11:15 AM and checked out at 1:15 PM. Finally, the Crib checked in at 1:30 PM and checked out on April 6th at 1:07 PM. Figure 62 below shows the interface for this work order's overall tracking status. The bin build status for this work order is in Figures 63-64 below.

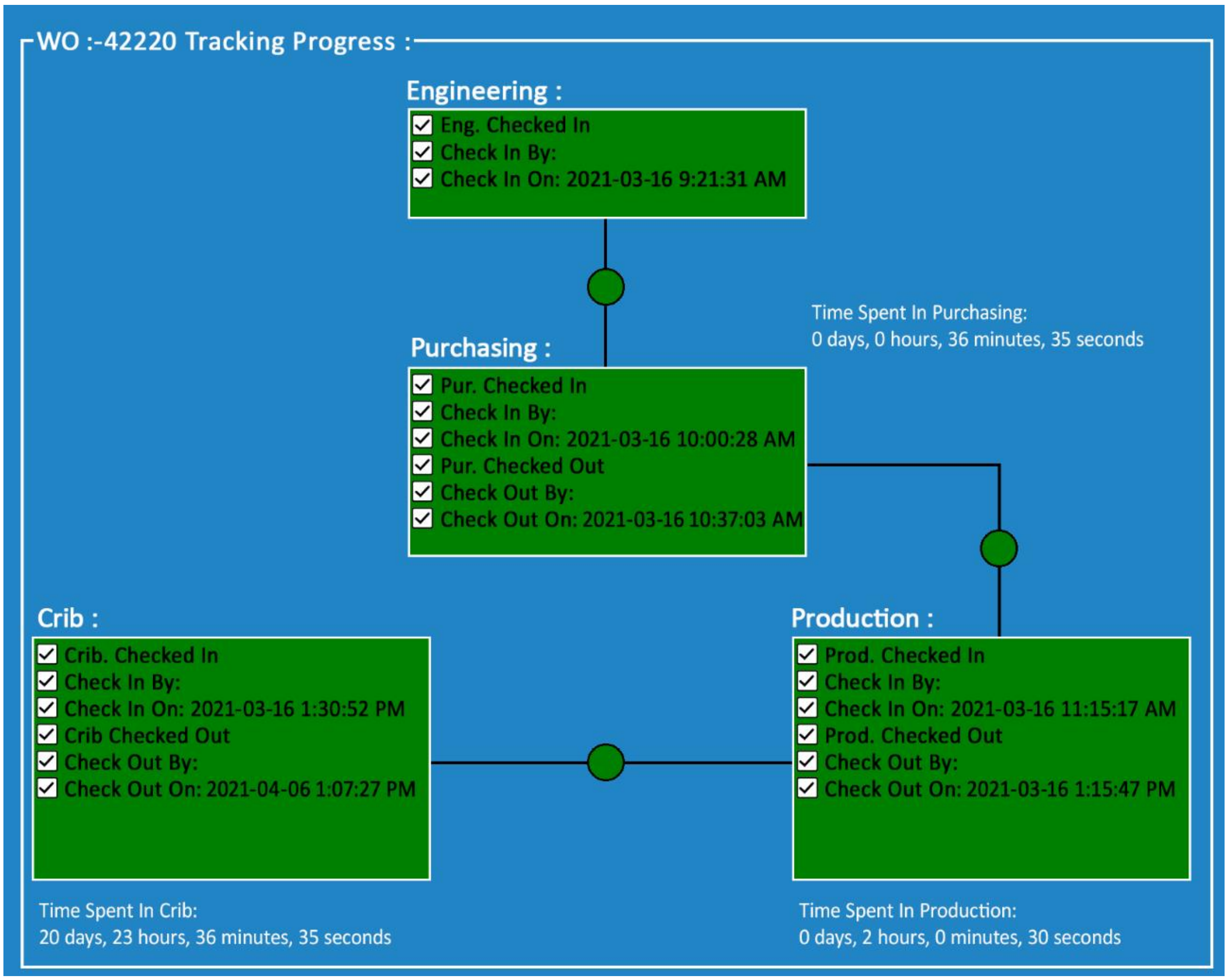


Figure 62 - WO 42220 Tracking Progress

Bin Build Status | WO Overall

WO	EmpCheckOutby	CheckOutTime	CheckOutApprovedby
42220		2021-04-06 1:07 PM	
42220		2021-04-05 1:04 PM	

Figure 63- WO 42220 Bin Build Status First Half

EmpCheckInby	CheckInTime	CheckInApprovedby	Inbuilt	Completed
	2021-04-06 3:31 PM		Yes	Yes
	2021-04-05 3:02 PM		No	No

Figure 64 - WO 42220 Bin Build Status

5.1.4 Work Order 42197 – C1UC RCL Lower Tool Assembly (RH)

The Engineering Department first released the work order on March 16th at 9:21 AM. It was then checked in by the Purchasing Department at 10:40 AM and checked out at 11:20 AM. The Production Department checked in at 1:30 PM and checked out at 5:35 PM. Finally, the Crib checked in on March 18th at 8:30 AM and checked out on April 8th at 2:07 PM. Figure 65 below shows the interface for this work order's overall tracking status. The bin build status for this work order is in Figures 66-67 below.

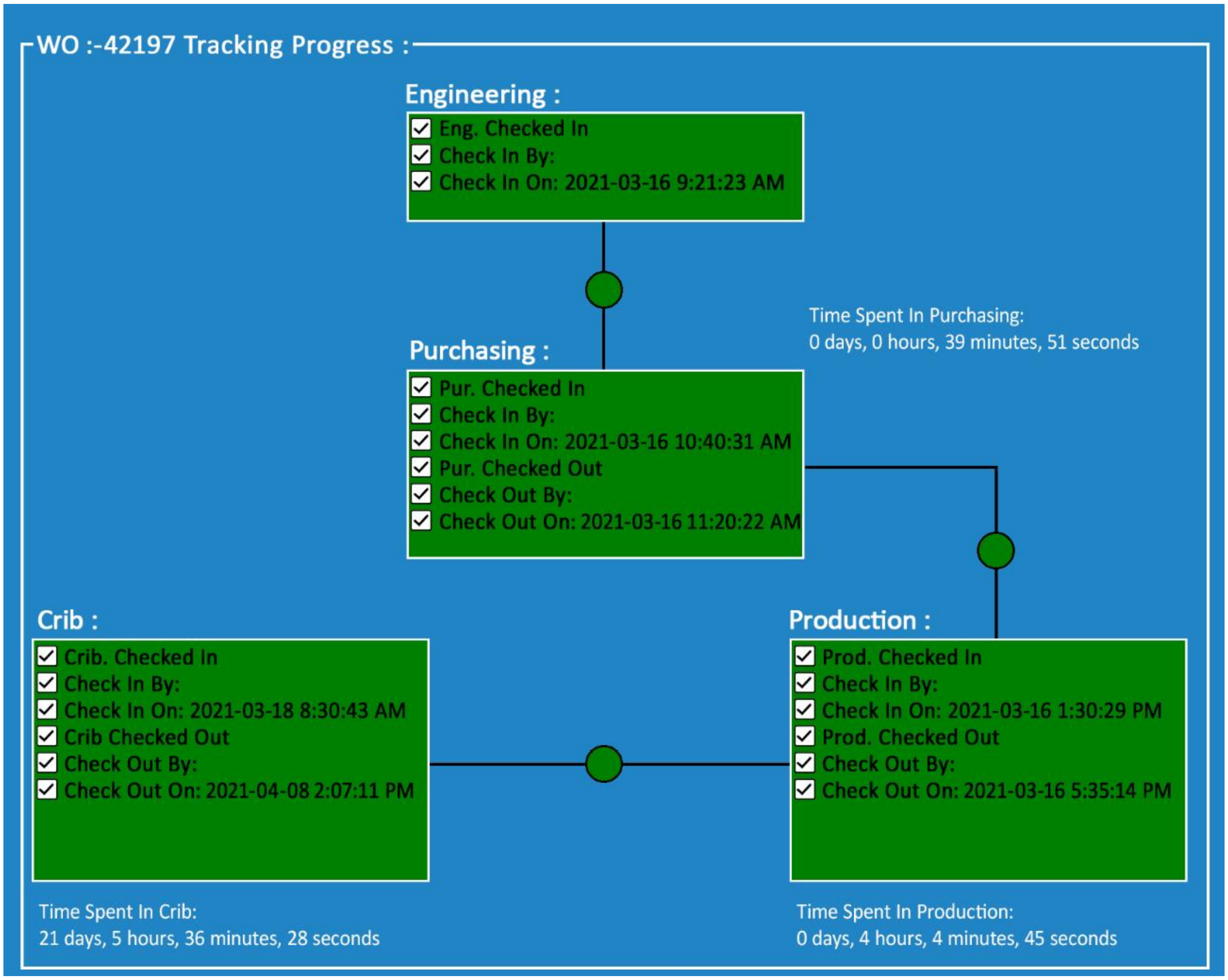


Figure 65 - WO 42197 Tracking Progress

Bin Build Status | WO Overall

WO	EmpCheckOutby	CheckOutTime	CheckOutApprovedby
42197		2021-04-08 2:07 PM	
42197		2021-04-07 11:15 AM	
42197		2021-04-06 1:37 PM	

Figure 66- WO 42197 Bin Build Status First Half

EmpCheckInby	CheckInTime	CheckInApprovedby	Inbuilt	Completed
	2021-04-08 3:45 PM		Yes	Yes
	2021-04-07 3:15 PM		No	No
	2021-04-06 3:00 PM		No	No

Figure 67 - WO 42197 Bin Build Status

5.1.5 Work Order 42248 – C1UC MCM RCL Upper Tool Nest (RH)

The Engineering Department first released the work order on March 18th at 5:05 PM. It was then checked in by the Purchasing Department on March 19th at 8:21 AM and checked out at 9:01 AM. The Production Department checked in at 9:03 AM and checked out at 1:18 PM. Finally, the Crib checked in at 1:20 PM and checked out on April 9th at 9:32 AM. Figure 68 below shows the interface for this work order’s overall tracking status. The bin build status for this work order is in Figures 69-70 below.

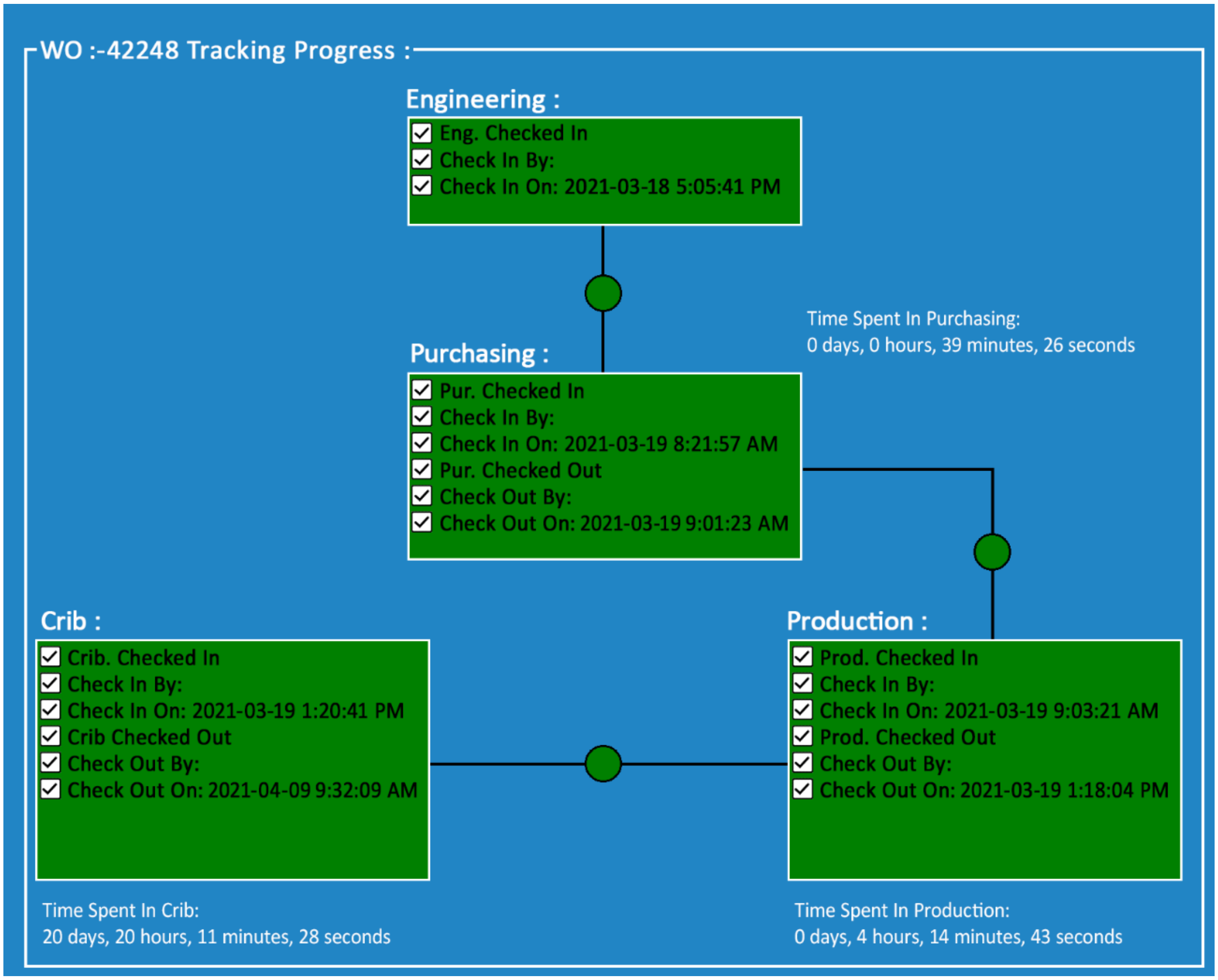


Figure 68 - WO 42248 Tracking Progress

Bin Build Status | WO Overall

WO	EmpCheckOutby	CheckOutTime	CheckOutApprovedby
42248		2021-04-09 9:32 AM	
42248		2021-04-08 12:26 PM	
42248		2021-04-07 1:45 PM	

Figure 69- WO 42248 Bin Build Status First Half

EmpCheckInby	CheckInTime	CheckInApprovedby	Inbuilt	Completed
	2021-04-09 2:38 PM		Yes	Yes
	2021-04-08 4:06 PM		No	No
	2021-04-07 3:19 PM		No	No

Figure 70 - WO 42248 Bin Build Status

5.2 Discussion

Specific Key Performance Indicators (KPIs) were chosen for analysis to quantify the results presented. KPIs are critical in the determination of a process' efficiency and effectiveness. Companies and organizations commonly use them to measure progress and various metrics. Metrics vary depending on the company's objectives or scope and the type of process being evaluated. Different processes require different metrics to be analyzed. Table 9 below shows the test results of Job 50853.

Recall the entire work order and subassembly process was conducted manually in the past, and therefore, there is no quantifiable data to compare the results. However, SPM has a current state of educated approximations based on a previous project (Job 50277 – Magna C1YC MCM RCL Tooling). These educated approximations will be used to compare both Job 50277 and Job 50853. Analyzing the table below shows that incidents of late ordering, reordering, and changes to the project timeline were minimized.

Table 9- Test Results: KPI Comparison between Jobs 50277 and 50853

Test Results: KPI Comparison between Jobs 50277 and 50853									
Key Performance Indicator (KPI)	Unit	50277	Work Order Number					50853	Average
			42181	42197	42220	42233	42248		
Work Order Tracking Completion	Y/N	N	Y	Y	Y	Y	Y	Y	
Bin Build Status Completion	Y/N	N	Y	Y	Y	Y	Y	Y	
Late Ordering	components	3	0	1	0	0	0	1	
Reordering	components	2	0	0	0	1	0	1	
Misplaced Components	components	2	0	0	0	0	0	0	
Changes to Project Timeline	occurences	7	0	1	0	1	0	2	
Time Spent in Purchasing	mins		31	39	36	28	39		35
Time Spent in Production	hrs		1.5	4	2	1	4		3
Time Spent in Assembly (approximation)	hrs		5	7	4.5	5	10.5		6
Number of Times Bin was Checked out Prior to Completion	number		1	3	2	1	3		2

One can see a decrease in components being ordered late, reordered, and misplaced between the two jobs in the figure above. The developed system resulted in no misplaced components while minimizing late ordering, reordering, and changes to the project timeline. Although there were no incidents of misplaced components in the testing of this system, they still have a possibility of occurring, as the bin completion is still conducted manually, which can lead to human error. This is the only part of the developed process done manually, making the overall process approximately 70-80% automated, based on IPC-1782 Standard from Mentor Graphics. Further discussion is included in the Future Research section in Chapter 6.

5.2.1 KPI Percentage Decrease (%)

Equation 5-1 below illustrates the percentage decrease (%) of the four main KPIs: late ordering, reordering, misplaced components, and changes to project timeline.

$$Percentage\ Decrease\ (\%) = \frac{[Job\ 50277\ KPI - Job\ 50853\ KPI]}{Job\ 50277\ KPI} \times 100\% \qquad 5\text{-}1$$

Figure 71 below illustrates the percentage decreases of the KPIs using the equation above. One can see that late ordering decreased by 67%, reordering decreased by 50%, misplaced components decreased by 100%, and changes to project timeline decreased by 71%.

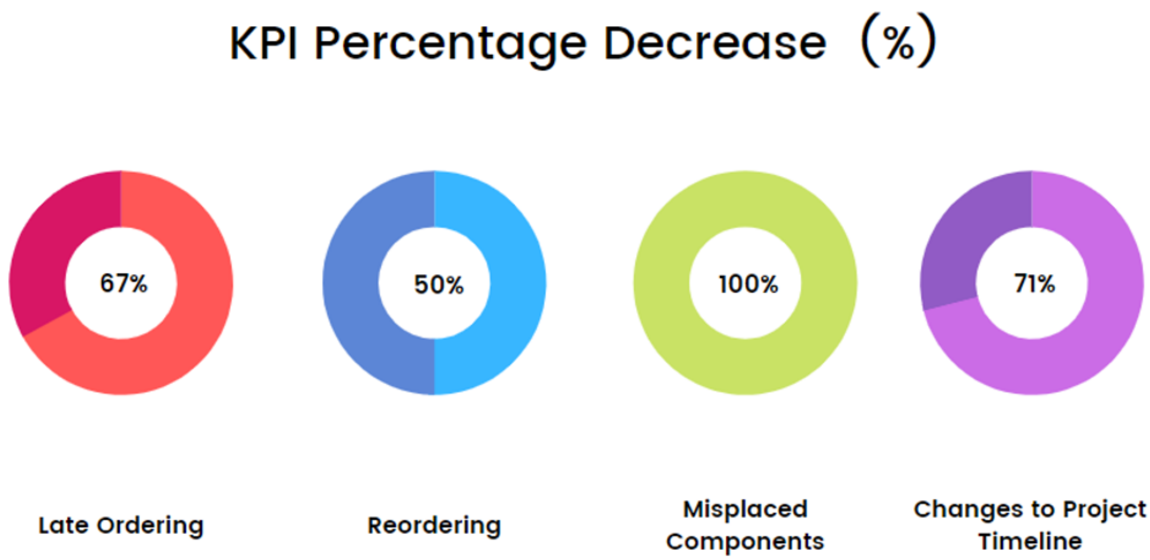


Figure 71 - KPI Percentage Decrease (%)

5.2.2 Cost Structure Model

Having a cost structure model is essential in determining the overall profits and losses the company can gain or lose during the implementation of a new system or process. This model can vary in details and illustrations. The cost structure model used to analyze and determine the cost savings in this research is shown in Table 10.

The cost to train all SPM employees on the developed system totals $1,585.94. This is a one-time cost, as training will be done once before the implementation of the system. Since the system is created in-house, there will be no implementation and software support costs.

The developed work order and subassembly tracking system brings many benefits to SPM. Firstly, it is largely automated system, compared to the current manual system. Secondly, it minimizes critical KPIs, as demonstrated. Moreover, tracking and management of the two jobs, 50277 and 50853, was compared using hourly rates (shop floor rate, admin rate, and design rate). The total costs for each job are presented, and the difference between the two, otherwise known as the total cost savings per job, is shown in the last box in the bottom right in the figure below. To gain a better understanding of the annual savings SPM will achieve, the average number of jobs per year is multiplied by the total cost savings per job, and the one-time cost is subtracted from the total. This resulted in an estimated average annual cost saving of approximately $40,884 and a time decrease of 77.78% for this case study.

Table 10- Cost Structure Model

<table>
<tr><th>Cost</th><th colspan="6">Benefits</th></tr>
<tr><td rowspan="5">SPM Connect Training

= (hrs x number of employees x shop floor rate) + (hrs x number of employees x admin rate) + (hrs x number of employees x design rate)

= (1 x 22 x $28.20) + (1 x 4 x $32.55) + (1 x 22 x $37.97)

= **$1,585.94 one-time cost**

Implementation
$0

Software Support
$0</td><td colspan="3">Automated System
(≈ 70-80%)</td><td colspan="3">KPI Percentage Decrease
• Late Ordering 67%
• Reordering 50%
• Misplaced Components 100%
• Changes to Project Timeline 71%</td></tr>
<tr><td>**KPI Metric**</td><td>**Job 50277**</td><td>**Job 50853**</td><td rowspan="2">**Total Costs**</td><td>**Job 50277**</td><td>**Job 50853**</td></tr>
<tr><td>Late Ordering</td><td>Persons Involved: Purchasing Manager

Time spent: 0.5 hr per component

Rate = (0.5 x $32.55) = $16.28 x 3 components

Total = **$48.84**
Total time spent = 1.5 hrs</td><td>Persons Involved: Purchasing Manager

Time spent: 0.5 hr per component

Rate = $16.28 x 1 component

Total = **$16.28**
Total time spent = 0.5 hr</td><td>= $48.84 + $32.55 + $234.30

= **$315.69**</td><td>= $16.28 + $16.28 + $0

= **$32.56**</td></tr>
<tr><td>Reordering</td><td>Persons Involved: Purchasing Manager

Time spent: 0.5 hr per component

Rate = (0.5 x $32.55) x 2 components

Total = **$32.55**
Total time spent = 1 hr</td><td>Persons Involved: Purchasing Manager

Time spent: 0.5 hr per component

Rate = $16.28 x 1 component

Total = **$16.28**
Total time spent = 0.5 hr</td><td colspan="3" rowspan="2">$315.69 - $32.56 = **$283.13 cost savings**

$283.13 Total Cost Savings per Job

Average Number of Jobs per Year = 150

Average Annual Cost Savings
= $42,469.50 - $1,585.94
≈ $40,884

77.78% Time Decrease</td></tr>
<tr><td>Misplaced Components</td><td>Persons Involved: Materials Coordinator, Electrical Build Lead, Manufacturing Manager, Purchasing Manager

Time spent: 1 hr per component
Rate = $28.20 + 28.20 + $28.20 + $32.55

= $117.15 x 2 components
Total = **$234.30**
Total time spent = 2 hrs</td><td>**$0**</td></tr>
</table>

5.3 Summary

The results presented, discussed, and analyzed using KPI metrics from two SPM jobs were compared (50277 and 50853). Percentage decreases of each KPI were calculated, concluding that late ordering decreased 67%, reordering by 50%, misplaced by 100%, and changes to project timelines by 71%. A cost structure model was presented, indicating an estimate of approximately $40,884 in average annual cost savings and a time decrease of 77.78%. The following chapter discusses the research contribution, significance, conclusions, and future research.

CHAPTER 6: CONCLUSIONS AND FUTURE RESEARCH

6.1 Research Contribution

The research presented in this thesis includes the development of a software system for the identification and tracking of work orders and tangible and conventional subassemblies. Although this software system was created and tested in the Automotive industry, it can be used within any industry that requires the identification and tracking of work orders and subassemblies. By using this software system, work orders and subassemblies are tracked throughout their life cycle, and specific information like work order location and check-in/out times. It also provides the bin build status, which details the log of completion of the subassembly bin.

6.2 Significance

The significance of the research presented in this thesis includes:

- The development of work order and subassembly identification and tracking software system
- Ability to minimize/eliminate recurring problems, such as excess inventory, late ordering, reordering, misplaced components, and number of changes to project timelines
- Creating a system that encompasses both work order and subassembly tracking
- Novel focus on tangible and conventional subassembly tracking, as discussed in Chapter 2
- Potential time and cost savings regarding employee time spent on fixing recurring problems presented

6.3 Conclusions

A work order and subassembly identification and tracking software system was developed to aid SPM employees track work orders and subassemblies efficiently and effectively within the company.

The testing of the software system indicated the developed methodology and software ability to identify and track both work orders and subassemblies minimizes recurring problems, like late ordering, reordering, and changes to project timeline. Moreover, it demonstrated that misplaced components were eliminated with the use of the developed system.

KPI Percentage Decreases were calculated for each KPI. Late ordering decreased by 67%, reordering by 50%, misplaced components by 100%, and changes to project timeline by 71%. These critical KPIs play a significant role in the company's profits. This is shown in the cost structure model in Chapter 5, where the estimated average annual cost savings per year resulted in approximately $40,884 and a time decrease of 77.78%.

These percentages are specific to this case study; however, they demonstrate the type and order of magnitude of achievable improvements in the performance and cost of work order and subassembly tracking and management in typical manufacturing companies.

6.4 Future Research

Future enhancements include developing a fully automated system. This means that the process of ensuring the subassembly bins are filled with the components and quantities on the work orders would be done through SPM Connect, involving barcode scanning. A work order checklist will be automated on SPM Connect, where the Crib Attendant can scan each component in the bin and the designated work order checklist will check off which components are currently available with their respective quantities.

Another method of automating the process includes a robot in the Crib that tracks the bins. I4.0 technological pillars would be used in the development of the robot's functionality. Some of the pillars used would be cyber security, RFID technologies, sensors, and artificial intelligence (AI). Incorporating these pillars would result in the robot replacing the Crib

Attendant, as there would no longer be a need for human personnel in the Crib. Hiring Programmers or Software Engineers would be necessary.

Moreover, research pertaining to Analytical Hierarchical Process (AHP) would be beneficial as it can illustrate all possible outcomes based on specific problems in the work order and subassembly tracking process flow (Passage Technology LLC, 2021). More research on the use of modules vs. assemblies and sub-modules vs. subassemblies would be beneficial for the identification of commonalities and differences between module/sub-module tracking and assembly/subassembly tracking, and better streamlining of the tracking process.

Furthermore, a Subassembly Traceability Standard and tracking system for tangible and returns’ subassemblies should be investigated. A Subassembly Traceability Standard is especially important, as it can create a guideline for tracing subassemblies within manufacturing environments.

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