Aalto University
School of Business

Simulation Modeling for Designing and Evaluating a New Flexible Manufacturing System. Case Study: Cylinder Gas Industry

MSc program in Information and Service Management

Master's thesis

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Department of Information and Service Economy
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Abstract of master's thesis

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Abstract

The production utilization and costs reduction are critical factors to be considered in a highly competitive environment, especially when the demand of variety of products has been increasing gradually. Flexible Manufacturing System (FMS) is designed to attain the key of cost effective production because it is a good combination between variety and productivity. FMS is defined as an integrated, computer controlled complex of automated material handling devices. Correspondingly, the cost for constructing the FMS is positively correlated with its flexibility. For that reason, the design of FMS requires an intensive work on designing, planning and operating.

The objective of this thesis is to study and evaluate the Flexible Manufacturing System (FMS) by simulation modeling. Furthermore, the experiment and analysis of production performance measures which are inclusive of cost, machine utilizations, production rates, and inventory levels, help the company studying the system and avoiding a potential future problem before implementing a new system.

The methodology used in this study is simulation modelling which is presented as a tool that can capture the complexities of the FMS. The auxiliary use of the advanced simulation tool available in the ARENA software allows mimicking the designed system as well as providing an environment in which experiment of the system can be performed. By analysing various possibilities, the simulation model is able to lead to a high performing "Advanced planning and Scheduling" instrument, which attempts to provide for all contingencies of production system's rate. Excessively, simulation can help to find the optimal solution so that the production costs are minimized and the service level rate is ensured to be respected.

As a result, the utilization of the system with different operation strategies are presented as well as the service level and the holding cost under each scenario. The potential bottlenecks of the system are analysed from the simulation reports. In addition, the optimal solution for the buffer stock level is given based on the current demand rate.

Last but not least, another significant contribution of the study is to interpret the simulation and simulation optimization technique that will enable the management to make better decisions.

Keywords Simulation, FMS, ARENA Simulation, Cylinder Gas

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Abbreviations

AMSs	Advanced Manufacture Systems
AGVs	Automated Guided Vehicles
CLT	Central Limit Theorem
FMSs	Flexible Manufacturing Systems
SKUs	Stock Keeping Units
SL	Service Level
SS	Safety Stock

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1 Introduction

The main idea in operation strategies is to find the optimal solution for the production process in order to reach a high customer service level; likewise, satisfy customer's demand in both quantity and quality. The optimal solution is when the company is able to utilize resources effectively and the cost is minimized. As stated by Heizer and Render (2011, p. 34), 'the facility contributes to the efficient movement of people and material with the necessary controls to ensure that proper portions are served'.

Managing the operations focuses on evaluating new tools and technologies, adjusting the production process to raise the level of productivity and efficiency, improving the quality, implementing advanced planning and scheduling, forecasting sales and materials, and staffing required. Operations management is the set of activities that creates value in the form of goods and services by transforming inputs to outputs (Heizer & Render, 2011). Shi (2004) cites Williams (1988) when emphasizing the dynamics and optimized action in manufacturing– 'Manufacturing systems approaches seek to optimize the initial design to commercial product time, the design lead time and factory door-to-door time, the manufacturing lead time by considering the whole factory as a system and simplifying and optimizing the performance of this complete system'.

From an operational standpoint, production planning is one of the logical steps in managing the whole manufacturing system and supply chain, from making an individual product to delivering it to a customer. Looking at the aggregate level of supply chain, Advanced Planning and Scheduling (APS) is 'an instrument able to take into account the contingencies that deviates the rhythm of production from production plan' (Caputo et al., 2009, p. 352). Forecasting and planning manufacturing output in accordance with market demand analysis, company goals, and constraints plays an important role in contributing to the company's profitability.

At the same time, many companies try to aim to lean manufacturing in supply chain, apparently to avoid the unnecessary expenses and cost of shortages. The business of manufacturing and production has been extensively addressed in the literature over the decades. There have been magnificent developments in the philosophy of flexibility in manufacturing where they can attain a cost effective production. The terms flexible manufacturing system, advanced manufacture system, computer integrated manufacturing, and computerized manufacturing system have been used interchangeably in the literature, to name that flexibility in manufacturing.

Nowadays, with modern technology, the production technology has been gradually changing into a more automated system. In the present market, the companies are always adapting to change in a rapidly changing business environment. Wherein, the diversified demand in products and services is growing. Thus, it is very important for a manufacturing system to accommodate these changes to maintain a competitive edge. Flexible Manufacturing System (FMS) is a highly integrated manufacturing system and is 'a good combination between variety and productivity' (Abdulziz et al., 2011, p. 115). Kuula (1993) emphasizes that these manufacturing technologies are based on advanced information technologies in product design, production planning, shop floor control, and logistics. He states that important characteristics of these technologies are flexibility, integration, and capital intensiveness (ibid).

The complexities of these systems basically result from their flexibility (Geral et al., 1994). The experiment and analysis of production performance measures, which include cost, machine utilizations, production rates, inventory levels, etc., is required when the company wants to fix the current problem or to avoid a potential future problem while designing a new system. The second case will be studied in this thesis. Simulation modeling can help tremendously in mimicking the designed FMS and testing whether the system will perform as predicted before construction.

1.1 Motivation and Objective

The production plan plays an important role and affects the whole logistics service and company's business in general. The level of logistics service greatly influences customer satisfaction which in turn has a major impact on revenues (Ghiana et al., 2004). In the global market with high competitiveness, poor relationships with suppliers and customers inevitably lead to company failure (Chang & Matkatsoris, 2001). Also, it is evident that companies offering superior customer service remain competitive and profitable (Larsen & Thornstenson, 2007).

However, it is a big challenge to optimize the production plan due to the complexity of the production process and uncertainty factors such as demand or lead time in the real world. For instance, when the demand is highly seasonal or erratic, it is difficult to make an accurate forecast. As a result, the production plan would be unreliable and cause over or under estimated stocks. With the aim of trying to model the impact of uncertainties on manufacturing, the development of appropriate planning tools for each particular scenario in production and inventory management is always an interesting and important topic.

There are several determining factors for the production process to be considered in managerial work. Demand Planning, Speed of production, Machine time allocation over planning horizon, and Queuing time, Cost, and Quality of Products are standards to evaluate. In this research, Multi Products Single Machine System economic production quantity model with stochastic demand within constrains of machine capacity and space is studied. Moreover, a proper calculation of buffer stocks based on historical sales data and demand forecast would help to assure delivery on time and not losing customers to the competitors. At the same time, the inventory holding and operational cost is trade off with service level. Thus, determining a suitable amount of buffer stock for each product is essential.

This thesis focuses on studying a new flexible manufacturing system's productive capacity in Cylinder Gas Industry. The decisions for performance measures in cost, production rates, machine utilization and inventory levels or buffer stock are suggested. Excessively, the simulation helps find optimal solutions so that the production costs are minimized and the service level rate is ensured to be respected, as well as, the flexibility in the system is improved.

1.2 Outlines

My thesis is organized as follows. Chapter 2 reviews relevant literature. Chapter 3 describes the methodology and how I approach the research study. Next, the real case company is presented in Chapter 4. Chapter 5 demonstrates the model development in simulation software Arena. Chapter 6 presents the results and analysis of the case study. Chapter 7 concludes the case, including the contribution in practice and theory of simulation modeling. The thesis finishes with suggestions for further research opportunities in Chapter 8.

2 Literature Review

As mentioned above, there are several terms used in different research papers when discussing about the flexible manufacturing system. Here, I would like to use FMS as an expression for the manufacturing system which I discuss about in this thesis.

2.1 Flexible Manufacturing System (FMS)

Herald and Nof (1978) used the term Advanced Manufacture Systems (AMSs) and expressed that those are systems composing of manufacture parts with the material handling equipment, processing machines, and devices controlled by a computer. Kathryn (1983) used the term Flexible Manufacturing System (FMS) and it was defined as an integrated, computer controlled complex of automated material handling devices and numerically controlled machine tools that can simultaneously process medium-sized volumes of a variety of part types. The AMSs or FMSs have been designed to attain the key of cost effective production. Correspondingly, the efficiency of well-balanced and machine paced transfer lines are achieved while utilizing the flexibility that job shops have to process multiple part types simultaneously (Browne et al., 1984). They said that flexibility and automation are the key conceptual requirements of FMSs (ibid).

According to Kuula (1993, p. 2), the flexibility can be classified in three major classes: product mix flexibility, production volume flexibility and time flexibility. The product mix flexibility describes the possibility to produce various different products by using the same machines and tools; or possibility to produce multi products simultaneously by different machines. Secondly, the production volume flexibility characterizes the potentiality to change the production levels, for instance, by increasing the batch sizes of production. Thirdly, the time flexibility depicts the capability to have short lead times and to cope with different delivery times. As Gerald (1994) referred to the association of complexities and the modeling of AMSs, I would like to explore resource flexibility additionally. Therein, flexibility is also an interaction of different resources in order for the system to operate efficiently and to attain the possible highest level of utilization. Typically, in the FMSs, different types of parts may be processed by different stations and be transferred by different routes. Scheduling parts and arranging the resources must be analyzed and decided. Overall, FMS must possess three capabilities in order to be flexible: i) 'the ability to identify and distinguish among different incoming parts or product styles processed by the system'; ii) 'quick changeover of operating instructions'; iii) 'quick changeover of physical setup' (Abdulziz et al., 2011, p. 118).

The production systems controlled by computer were explored since the 20th century. However, the automation system couldn't be achieved completely. In that early automation, it was fixed, rigid, and tailored to each specific product (Shnits & Sinreich, 2006). At the end of 20th, there were more papers addressing the issues of designing, controlling dynamic scheduling in the literature (Research papers of Rachamadugu and Stecke (1994), Balogun and Popplewell (1999), or Chan et al. (2002)). Bring it into the 21st century when the technology is growing strongly, the FMS is more empirical to help the business reach their targets in production cost and effectiveness.

Nevertheless, the cost for constructing the FMS is positively correlated with its flexibility. For that reason, the design of FMS requires an intensive work on designing, planning and operating.

2.1.1 Characteristics of a Manufacturing System

Each production system itself has special features that should be defined in the design phase. Kuula (1993) emphasizes the importance of the integration of product design, production planning, scheduling, and manufacture when designing the FMS. The flexibility does not come from the abilities of machine but it results from a combination of physical characteristics, operating decisions, information integration and management practice (Gupta & Buzacott, 1989). In design and operation of FMS, the decision should be made including the types of products to be produced, the types and numbers of resources as machines or material handling equipment in the system. Then, a layout of the system, potential routes for each independent components and entities, sequencing rules, buffer location and capacity, production process time and production schedules should be thoroughly discussed and planned in advance because these considerations might influence the cost and efficiency of the production system.

Manufacturing system is often designed for a long term plan. The designs of each component in a system are required to be coherent and together contribute to reach the defined purpose of that production system. Generally, the FMS consists of five fundamental characteristics (Heilala, 1999, p. 5) as listed in the Table 1 below:

Table 1: Charateristic of Manufacturing System

Manufacturing System	Parameters
Physical Layout	Product Bill of Materials Product Flow, Routes, and Resources.
Labor	Production Schedules: Shift Schedules Make to Stock or Make to Order
Machines	Production Control: Capacity, Failure Rates. Assigning Jobs, Routing, Sequencing Rules,
Work Stations	Processing, Assembly line Packing and Shipping Storage
Handling Equipment	Conveyors Transporter: Automated Guided Vehicle, Robots…

There are many ways to study and evaluate the FMS. The complexity of FMS is interdependencies and variability. The system performance metrics when evaluate FMS should be customized based on the purpose of the designed system. The metrics can be the flow time of the products, the utilization of resource, the value added time and waiting, the flow rate, productivity or the inventory level. Those are minimized or maximized when the best combination of decision variables is found. One of useful system analysis techniques is simulation, which is going to be discussed in the next section.

2.2 Simulation Modeling

Computer simulation has been used to solve many business problems from production to logistics, which leads to optimize profitability, as well as, minimize costs. Simulation is a process that mimics a process. In another way, it reproduces behavior of a system, which helps us observing, understanding and defining the bottlenecks of the system in order to have adjustments in time. It provides fast analysis of the schedule. Using simulation for testing a schedule is economical. Simulation can be used for an actual or planned production.

A simulation model is an alternative when the analytical model is too complex for solving the real problem of manufacturing systems. However, the analytical approach would give more accurate results as these are obtained by proven algorithms or mathematical models. Whereas the simulation model yields approximate solution as it works on logical manipulation. In simulation, the values of parameters in the model must be specified. The accuracy of the simulation model's result can be increased by determining the run length and number of replication of the simulation.

2.2.1 Simulation in Manufacturing System

Nowadays, simulation is more developed and has been used in manufacturing system management by a large number of industrial organizations. Computer simulation models enable fast and effective testing of alternative manufacturing possibilities and analysis of key manufacturing decisions, in which the complex practical production problems relating to material required management, inventory, production schedules, and other daily operations would be solved.

There have been many research publications about the use of simulation in manufacturing. Dargi et al. (2011) have outlined that the company use simulation for the purpose of strategic capacity planning, automation systems design, manufacturing process validation, and evaluation of various manufacturing execution scenarios. Badri (1993) has developed the simulation decision support system for inventory control management with consideration of variations in demand, re-order point, stock-control level and lead time. Hlupic and Paul (1994) have presented simulation models which focused on flexible manufacturing systems and used the software tool to analyze and obtain the results. In the later years, the use of simulation technique in optimization of production productivity has been rising. Altinkilic

(2004) has looked into the shop flow production and presented the use of simulation in Arena simulation software to evaluate and compare the performances of an existing system and a developed one. As a result, the simulation analysis could help the analyzers to point out few bottlenecks and recommendations for the mentioned job shop production. In another case, Thoews at al. (2008) have developed a flow simulation model to identify production bottlenecks and determine the improvements in sawmill productivity.

Caputo et al. (2009, p. 352) have stated that 'the simulation technique allows the checking with better precision of the use of resources with variation of the ties'. In the survey on the use of simulation for manufacturing system design and operation by Smith (2003), it has been reported that simulation is considered a useful tool in order to study and optimize production processes. Especially, simulation modeling offers the most compliant approach for modeling flexible manufacturing systems as Smith (2003) showed an evidence of references for applying simulation in flexible manufacturing system design and operations planning and scheduling. Several authors agree on simulation potentialities in the analysis of the dynamic and stochastic behavior of manufacturing system (Battista et al., 2011). They also predict its operational performance and point out its critical factors (ibid).

2.2.2 Simulation and Optimization

The optimization of simulation model deals with the situation in which the analyst would like to find which of possibly many sets of model specifications which are input parameters or structural assumptions, lead to optimal performance (April et al., 2003). According to Law and Kelton (1991), a simulation can be considered as a 'mechanism that turns input parameters into output performance measures'.

Mentioned in the research by Fu (2002), there are four classical approaches for optimizing simulation: stochastic approximation (gradient-based approaches); (sequential) response surface methodology; random search; sample path optimization (stochastic counterpart). Nevertheless, these four main classical approaches have not been used in practical application (April et al., 2003, p. 72) because of the substantial requirement from high technical issue and computer time to solve the problem (Andradóttir, 1998 cited in April et al., 2003, p. 72). Since the metaheuristic optimization is advanced where optimization procedure does not depend on type of problem or system to be optimized, there is an integration of simulation and optimization (Glover et al., 1999). Figure 1 represents the coordination between optimization and simulation.

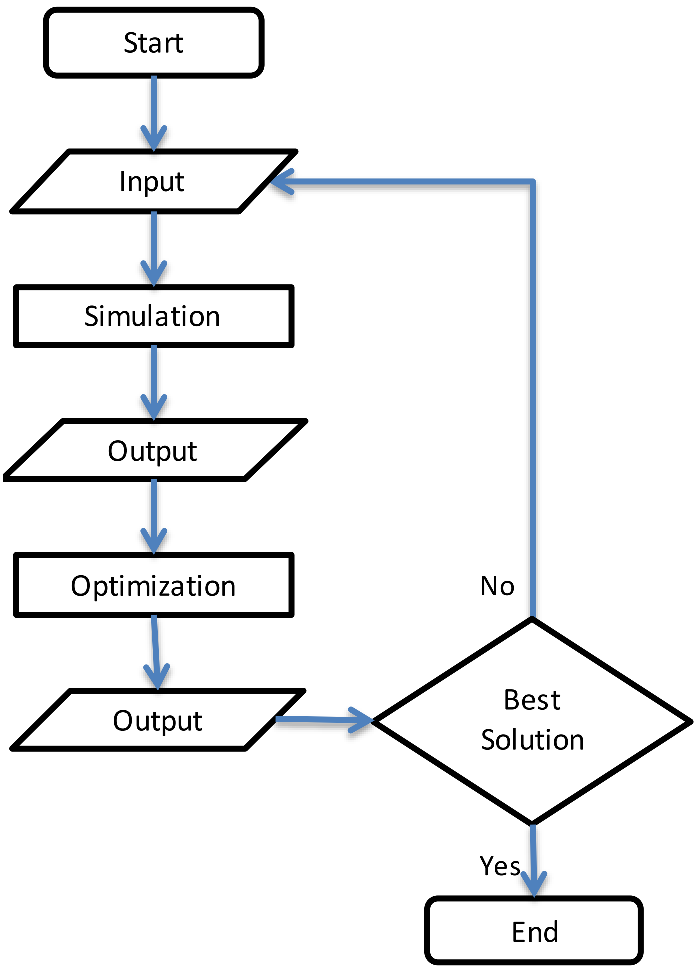


Figure 1: Coordination Between Optimization and Simulation (Glover et al. 1999)

2.3 Inventory Planning

This section reviews the role of inventory management and explains different purposes for keeping inventory. Secondly, Stock-keeping-unit classification is mentioned as one of techniques in inventory management. The final discussion is the connection between a performance measurement - service level alpha, and safety stock or base stock determination. These are the parameters on which I conduct a simulation and provide solutions.

2.3.1 Inventory Management

Inventory includes a company's raw materials, work-in-process, supplies used in operations, and finished goods (Muller, 2003, p. 1). In other words, inventories are materials that are stored, waiting for processing or experiencing processing. Manufacturing managers always consider thoroughly the optimal level of inventory in order to minimize the inventory costs but also provide a high level of service to the customers. Correspondingly, backorder or shortage should not be occurred. Inventory management is a trade-off between the inventory cost and shortage cost. As it is, inventory planning is done in order to minimize the total cost of the plan. The costs include the unit cost of item for which planning is done, the cost of carrying inventory, the cost of ordering and the cost of shortages (Mahadevan, 2009) .

On the contrary, having inventory is also essential despite of its expenses. Some of the more important reasons mentioned by Muller (2003, pp. 3-4) are: i) to have a stable source of input for capacity planning and production scheduling as he said that 'Inventory buffers what you need from what you process'; ii) to keep the production on time or maintain the target service level under a fluctuated demand situation, as well as, unreliability of supply; iii) to reduce costs because of economies of scale as lower ordering cost, quantity discount. Some successful methods in inventory reduction, for example Just-In-Time (JIT) systems, led to the mistaken notion that inventories are of no value and should be completely eliminated; yet well designed, well run production systems including JIT, require some inventories of raw materials, supplies, in-process goods, and final products to operate efficiently (Martinich, 1997, p. 659).

On the other hand, the purpose of having inventory should be understood and defined before calculating the optimal level of stock. Inventories of the same product may look the same physically, but they may be held for different reasons (Martinich, 1997). I would like to quote the types of inventory from Martinich (1997) which are cycling inventories, safety stocks, and speculative inventories. Cycling inventories are held primarily to achieve economic efficiency incurred from ordering or setting up costs. In contrast, safety stocks are for a purpose of protection against uncertainties in demand or lead time. The third type, speculative inventories, is held for short periods on an irregular basis to take advantage of special opportunities or to protect against abnormal risks (ibid, pp. 663-664).

Depending on the company's strategy and production process, once the purpose of keeping inventories is defined, the type of inventory would be determined. After that, the manager can find suitable answers for questions as when the material should be ordered, how much should be ordered at once, what level of safety stock should be kept, or how the work-in-process inventory should be maintained in the production process.

2.3.2 Inventory Review Policies

The review policy is to determine how often the inventory status should be checked. There are two types: a continuous and periodic review. With periodic review, obviously it takes less cost but it might be dangerous if the load or demand is unpredictable. Nowadays, when the new advanced software can support to maintain the real-time information of thousand products, the continuous policy is more relevant. The company updates the current inventory level frequently so that they can fill up the stock only when needed. The major advantage of continuous review is to provide the same level of customer service and it requires less safety stock than periodic review does (Silver et al., 1998, p. 237).

The study will use a (S-1, S) continuous review policy. After a time period t, the inventory level drops down after fulfilling the demand, an order is placed to bring the inventory level back to S in the next period (t + 1).

2.3.3 SKU classification

The companies often produce many different products in one production line, so-called as Stock Keeping Units (SKUs). SKUs refer to items of stock that are completely specific as to function, style, size, color, and location (Silver et al., 1998, p. 32). It is not impossible to manage thousands of variety of products and also not efficient to manage individually, while SKU classification can help to simplify and support decision-making in inventory management, forecasting and used to determine the production strategy, for e.g. make-to-stock or make-to-order. According to the research by Kampen et al. (2012), there have been analytical tools provided and developed to classify SKUs. One of popular approaches is the ABC analysis which classifies product groups based on either demand value or demand volume. Other statistical techniques such as the FNS (Fast, Normal and Slow) based on the demand rate, Decision tree, Cluster analysis, or Genetic Algorithm, are developed and applied in each particular specific context.

In order to classify SKUs, two questions need answering: how many classes are used and how are the borders between the classes determined (Kampen et al., 2012). Generally, those techniques used the evaluation based on four identified categories: volume, product, customer, and timing. Product and volume characteristics such as space or unit cost are often used in inventory management. The others are used in forecasting studies. Therefore, it depends on the aim of SKU classification in order to choose the right technique.

The classic ABC technique is used widely in different industries and some slightly adapted the technique as analyzing in annual sales (Huiskonen et al., 2005) or monthly demand (Porras and Dekker, 2008). Noticeably, Dhoka and Choudary (2013) presented the technique “XYZ” which is based on predictability and volatility of items. Wherein, items are categorized as Uniform demand as X, as Varying demand as Y, or as Abnormal demand as Z.

Regarding to the case study, it is assumed that units cost or holding cost for inventory are evenly distributed. Additionally, when the service level is a dominant factor or all products must be available when needed, demand pattern and periodical/ seasonal volume are the characteristic to classify the products or SKUs. ABC method has a limitation in periodic review and cannot precisely consider all problems of a great number or low value items (Dhoka and Choudary, 2013). For those reasons, here I would like to combine two techniques ABC based on demand volume and XYZ bases on volatility of item’s demand to point out which one has varying or abnormal. Then the decision on the stock level of those special SKUs can be made considerably, in order to reduce the cost together with the space tied up in inventories.

2.3.4 Safety Stock (SS)

The safety stock is defined as the average level of the net stock just before replenishment arrives (Silver, 1998, p. 234). The purpose of the safety stock is simply to prevent stock-outs. Stock-outs happen when there is high fluctuation in demand, forecast inaccuracy, or due to variable lead times for restoring the raw materials or manufacturing. Thus, the safety stock is to help company achieve a desired service level. Service level (SL) is the complement of the probability of a stock-out (Heizer & Render, 2008, p. 519). Or safety stocks can be built commensurate to the desired service level (Mahadevan, 2009). This topic, SL, will be discussed further in the next section.

Safety stocks are usually determined by the production strategy adopted in response to customer demand (Randal & Urlich, 2001). Safety stock determinations are not intended to eliminate all stock-outs but just a majority of them, which depends on the company's goal. If they aim to have 100% in service level, likewise there are always enough products to deliver to customers. Obviously the safety stock or buffer stock is really high. Nevertheless, some companies lower their level of service to 90-95% because of high cost in inventory. Then the safety stock will be lower and higher possibility in the case of stock-out. The level of safety stock is influenced by the effect of several random variables, typically the level of demand, the length of the lead time, and the size of shipment (Zizka, 2005).

2.3.5 Performance measure for supply chain management: Service Level (α)

First of all, I would like to review the definition of Supply Chain Management, which is 'the process of integrating suppliers, manufacturers, warehouses and retailers in a supply chain so that goods are produced and delivered in the right quantities and at the right time, while minimizing costs as well as satisfying customer's requirements' (Cooper et al., 1997). The goal of supply chain, above all, is that to achieve high customer satisfaction as important as maintaining the low cost. Customer satisfaction or the ability to effectively respond to customer demand can be gauged by measuring service level (Nahmias, 2007). Service level can be measured in several ways but in general it means getting the right product in time to the customer (Lee & Billington, 1992). Furthermore, Service level is a useful concept for modeling inventory planning in the case of stochastic demand (Mahadevan, 2009).

There are two basic types of service level defined as type 1 and type 2.

Type 1service is the probability of not stocking out in the lead time (Nahmias & Olsen, 2015, p. 274) and is represented by the symbol α. For example, α is 95% that means 95% of total demands are satisfied. Notably, since there are many items in the product and each has different cycle length, as well as, the corresponding demand, the measure will not be consistent among different products. It is more difficult to choose an appropriate decision for α.

Type 2 service measures the proportion of demands that are met from stock (known as fill rate) (Nahmias & Olsen, 2015, p. 274) and is represented by the symbol β. Equally, we will have (1-β) representing the proportion of stock-out or the percentage of lost sales if the shortage is not allowed.

It is necessary to clear the confusion between two types by looking at the small example below (See Table 2). The result is $\alpha = \frac{3}{5} = 0.6$ (60%) and $\beta = \frac{720-40}{720} = 0.94$ (94%), which are totally different.

Table 2: Example for Service Level and Fill Rate Calculation

Order Cycle	Demand	Stock-Outs
1	80	0
2	90	0
3	210	30
4	190	10
5	150	0
Total	**720**	**40**

The following equation represents the above calculation.

$$Service\ level = \frac{Number\ of\ Order\ Cycle\ with\ \ no\ Stockouts}{Total\ number\ of\ days\ in\ a\ planning\ horizon} \quad (1)$$

And,

$$Fill\ Rate = \frac{Total\ Demand - Total\ Stockouts}{Total\ Demand} \quad (2)$$

3 Methodology

This chapter is going to clarify how I approach to the research by the general framework of conducting a simulation study. After that, the information of simulation tool to be used is presented as well.

3.1 Conducting a Simulation Study

The five steps, presented by Kelton et al. (2010), used to study and implement the operation are described as follows:

Step1: Problem formulation

A simulation project is successful when a good simulation model is developed and meets the objectives set forth by the decision makers. Hence, it is important to understand and define the metrics by which the project will be measured. Before starting a simulation, the system to be modeled should be understood clearly. Then the problem is defined and formulated. It is essential to be initially involved with people who work with the system and ask questions to define a problem. If the system is a new design, develop a process flow diagram to have a rough sketch of the potential system.

Step2: System description and modeling approach

The plant layout is obtained by the process map or the flow chart. Flowchart is a common logical modeling technique. It can be used to model all processes linked with data and information. The flow chart is drawn in Excel 2010. More than that, the study needs actual operational data for simulation and verification, which is collected by interviewing, factory-visiting and email communication.

Step 3: Building and re-building a model

After collecting all the necessary information to implement the study, a model can be developed in the simulation software. If there are any difficulties, animation would help a lot to find out the errors and then the model will be fixed more logically. It takes several times to redesign the model in order to make sure that the model works in the same way as the initial model description. Therefore, the next step is verifying and validating.

Step 4: Verification and validation

In the second stage when the complete logic model is created, verification and validation is required. Verification is the task of ensuring that the model behaves as the modeler intended. The modeler verifies whether the computer representation represents the conceptual model faithfully or not. If not, the modeler needs to go back to Step 2 to find out the problem and redesign the model. Validation is the task of ensuring that the model behaves the same as the real system. In case that the system does not exist yet, it may be impossible to validate the model. Instead, concentrate on the verification.

Step 5: Model input and output

The third stage is running the experiment and designing to extract the statistics or information needed. The output of simulation can be extracted to the Excel file or taken from the automatic report from the software. However, the Excel form will be more convenient if the modeler wants to extract some customized information from simulation.

After conducting several simulations' runs, the bottlenecks could be observed. Then, alternative scenarios are tested to determine the impact of them on the system. A further analysis is conducted using OptQuest – one of simulation optimizer from ARENA software which will be introduced in the next section.

Finally the result is analyzed and presented.

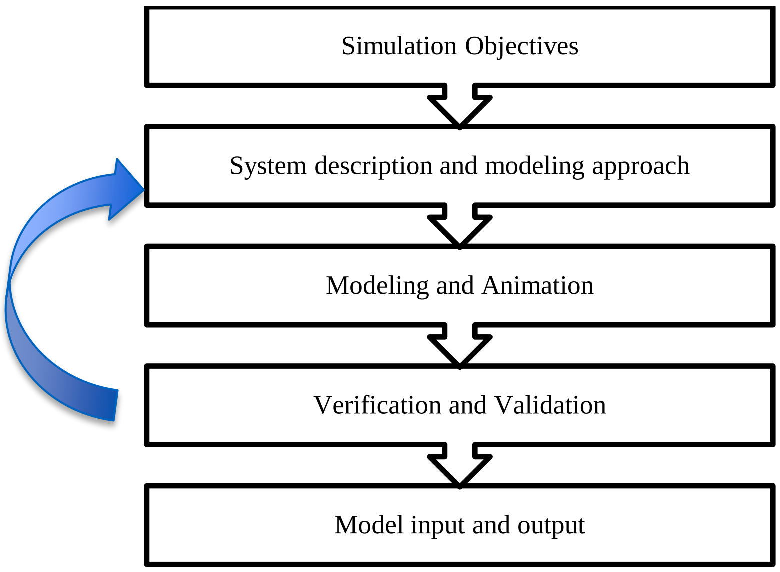


Figure 2: Components of Simulation Study Process

3.2 Simulation Tool

ARENA Simulation Software is selected for simulating the case study. ARENA is built on the SIMAN simulation language. There are fully levels of modeling in ARENA's hierarchical structure from low to high as depicted in Figure 3. For specialized models with complex algorithms or accessing data from an external application, the user can program on Visual Basic or C/C++ which cooperate with ARENA directly. For simpler cases, the Basic Process, Advanced Process and Advanced Transfer are also powerful enough to build the really complex system as I am going to use them in simulating the FMS. Even higher level, there are some ready templates that can be applied for specific industries such as, healthcare or packaging lines.

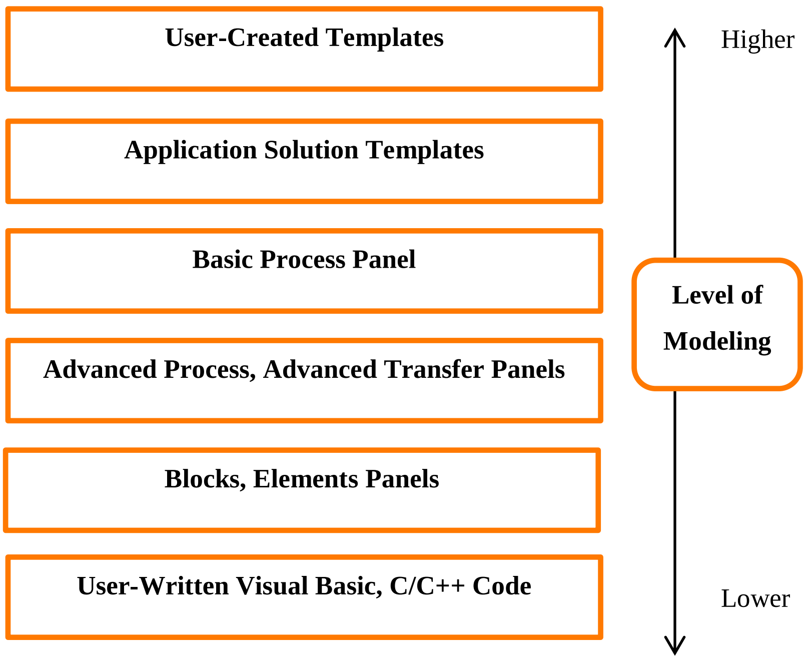


Figure 3: ARENA's Hierarchical Structure (Adapted from Kelton et al., 2010)

Generally, ARENA provides the powerful functions in modeling but not too complicated to use. ARENA is simulation software which has flexible model building capability and advanced process or transfer to help modeling from strategic business decisions as supply chain network, to operational planning improvement or more details in production process and inventory control. The setup of uncertainties, for instance, operation time, customer orders, base stock levels can be setup in different scenarios. Furthermore, it enables visualization of the designed operation system under variety conditions. It also has outstanding feature for interacting with other applications, for example, Excel with its built-in spreadsheet data interface. The animation can be conveniently built in ARENA also.

On the other hand, discrete event simulation is selected to analyze the system because it is ideally suited for flexible manufacturing system which is able to describe the complex interactions among the resources and activities within the production line. At a discrete event simulation, the state of a system changes only at discrete points in simulated time.

Regarding to the coordination between simulation and optimization, including in the ARENA package, OptQuest is an optimizing tool searching for optimal solutions within ARENA simulation models once the user define objectives, constraints and parameter controls. The input control parameters move around intelligently in the determined bound levels and try to converge quickly and reliably to an optimal point. Conceptually, an optimization model is depicted in the figure below:

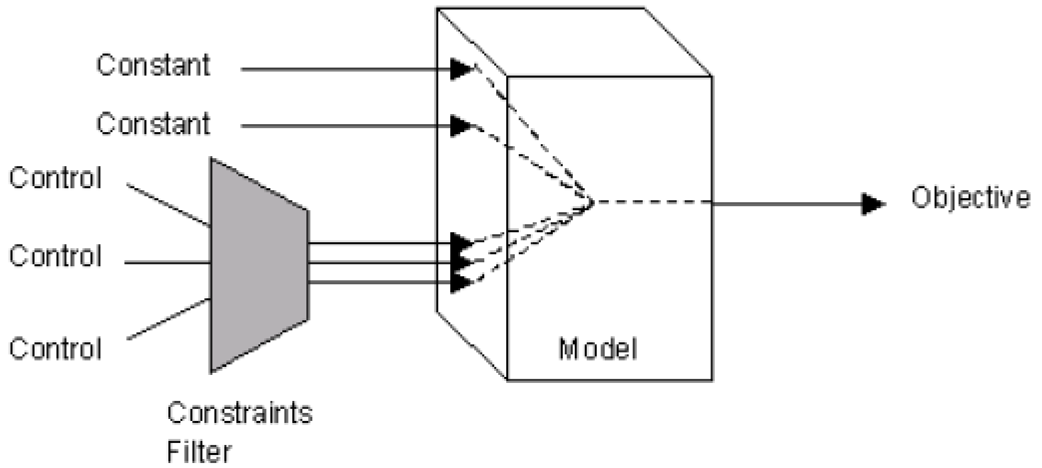


Figure 4: Optimization Model (OptQuest for Arena User's Guide)

4 Case Study

By continuing reading the overview of the case study, please take note of some terms described below in the Table 3 which are relevant to the case company's production system.

Table 3: Terms Explanation

Terms	Definition
Gas cylinder	A pressure vessel used to store gases at above atmospheric pressure. High-pressure gas cylinders are also called bottles. Packaged industrial gases are frequently called "cylinder gas" or "bottled gas" (www.wikipedia.com).
Automated cylinder gas	A type of gases can be filled by the machine automatically.
Semi-auto cylinder gas	A type of gases is filled by the machine and human.
Manual cylinder gas	A type of gases is filled manually.
Swap-body	Type of intermodal containers can be swapped from a wheeled vehicle to a railcar, with the purpose of cutting loading and unloading time, optimizing use of transport fleet, as well as, minimizing costs and emissions.
SKU	Stock-keeping-unit.
Gantry robot	Referred to as a pick and place robot that can be programmed to literally pick an object up and place it somewhere. They are especially practical in places where requires speedy and difficult tasks need to be performed with accuracy (www.wisegeek.com).
Carousel	A spinning ride placed at the filling machine for loading the gas cylinder to be filled.

4.1 Case Company

The company under study will be named as AAA hereinafter for the purpose of confidentiality. AAA is currently leading in industrial cylinder gas. With the help of innovative gas applications, AAA can improve productivity, safety and competitiveness for its customers in ways that are beneficial to the environment.

AAA operated an industrial gas processing facility where the cylinder gas are filled up from the filling plant with high quality process, and distributed to different switching points for delivery to customers. The filling plant is located in the center of the South at the intersection of main roads and railways. That helps distributing for all places in the South more easily. Furthermore, there are seven swap-body-switch-points to exchange empty and full cylinders. Then, the deliveryman continues to deliver those cylinders to customers. The customers receive their orders in the following day of the order date.

The plant can provide a variety of gases with 600 SKUs, serving in different industrial sections, hospitals and for household consumption as cooking for example. The cylinders can be automatically filled, semi-auto filled or manually filled. Most stages of work are fully mechanized. For instance, the portal robots pick cylinders to match customers' orders and transport routes. Likewise, lifting, moving and conveying are done automatically. The current system has three kilometer conveyor, and 43 individual filling stations and it takes 10 minutes to fill one cylinder in each station. Approximately, 6 cylinders can be processed at one filling station per hour and 258 cylinders in total stations. The facility operates 5 days per week and 16 hours per day.

The plant performs fairly well enough for the contemporary demand as 80% of the maximum capacity of the current process. However, the demand forecast for the next few years is promised to increase more excessively due to increasing domestic consumption in the existing market but also for the extending market in the future. Therefore, the plant manager is meditating on a plant modernization to upgrade the new technology in the gas filling production. The modernizing system would allow the plant to increase capacity per hour, decrease heavy work for humans as well as cutting cost for the company.

4.2 The Flexible Manufacturing Process

Under the new upgraded system, 82 different types of automated cylinder gas can be processed under a same machine. It is noted that only automated cylinder gas will be focused mainly in this process. Innovative manufacturing techniques use Automated Guided Vehicles (AGVs) and robots to move the cylinder pallets, and pick-and-place cylinders. Automation and precision sensors play a key role in maintaining a hard flow work and producing a quality product.

The production line has been divided into three main stages, namely 1) scanning information and sorting (by picking and placing) empty cylinders into different groups of product, 2) emptying and filling gas from/into cylinders and 3) palletizing and shipping or storing. The other production activities as stamping, examining etc… are negligible and will not be mentioned in this model.

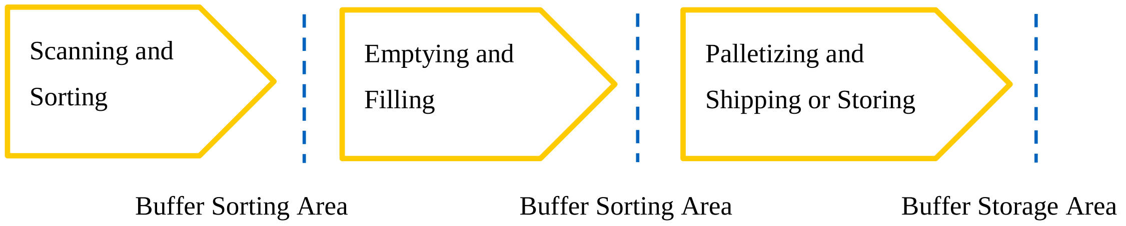


Figure 5: Stages in the Cylinder Gas Production Process

Sorting

Every day there are roughly 900 empty cylinders of automated gas that are returned from the customers. The pallets of empty cylinders will be transferred to the sorting buffer station by AGVs where there are two robotic cranes will do sorting automatically. The gripper of the crane will pick up the cylinder one by one and place it to the right location in the Buffer station and wait for filling. The robot will recognize the cylinder by barcode. The barcode will be scanned and registered to the control system at the doorstep before entering to the sorting area. The sorting area (28 x 14 meters) can contain 2682 cylinders.

Filling

There will be two carousels to do filling gas into the cylinders. One cylinder will be filled in one carousel at a time. The robots will pick and place cylinders from/into both carousels. Only the gas defined as automated gas will be filled by carousels.

By adding pre cooler to the in-going gas line, the cycle time for emptying and filling one cylinder is estimated as one minute.

Palletizing

When receiving a new order, the robot can pick the cylinders stored in the sorting area and palletize them. If there is lacking of cylinders in the sorting area, the AGVs will take the pallet from the storage (A and B) to the sorting station. As similar to sorting process, the robot will pick and assemble cylinder to pallets according to the orders. After that, the AGV will take that pallet to the Shipping gate. Considered as the finished product to delivery, each cylinder item is not totally independent of one another. Dependency is due to multiple items on a customer orders and different gases can be mixed in one pallet.

Importantly, whenever AGV moves the pallet, the pallet needs to be tightened. They are untightened when entering the station for process. This task is done manually. There should be at least one person in one site to tighten and untighten the pallet and it takes 1-2 minutes to complete.

Storing

The manager planned to have two block stores A and B next to sorting station, which can contain 114 and 140 pallets respectively. Each pallet holds 12 (for 50 litters) or 16 (for 20 litters) cylinders. The production manager planned to store here both empty cylinders and full cylinders of high volume and low volume products (which can be one cylinder ordered per week). The products are belonging to the group of automated filled gas, flammable gas and import gas. As now, for the buffer stock, the company always has stock of 3 days of full cylinders and 2 days of empty cylinders in advance. With the new system, the buffer stock can be reduced as solely stock of 2 days. The stock has all types of gases due to the consumption variation. Also, the AGVs will place and arrange the pallets. The suggestion is that the same type of product should be stored in the same row. It is not necessary to comply with FIFO rule as in medical gas or food industrial gas. Nevertheless, the FIFO is preferred if there is a good solution for getting the pallet from the middle of the store out.

Transporting

Normally, the swap bodies transporting empty cylinders from customers arrive during a day. With the new system, because we have the same gate for entrance and exit, there should be an arrival and departure time rearrangement of swap bodies to avoid the queue at the gate.

On the other hand, it is assumed that the production personnel feel that they will be able to learn the new system quickly and there will be expected only few human labors working in the process. Therefore, cost to train personnel can be negligible.

4.3 Data Availability and Analysis

In order to understand the system, the system description is written down as recorded in the interview with the production manager and the team designing the system. Site visits of the present production system was carried out. However, unfortunately, there is a limitation in collecting daily demand data. Therefore there will have some assumptions for the demand distributions. The individual products will be analyzed and grouped together in this section by using the XYZ Classification technique mentioned in the literature review. The target safety stock level can be approximated for each group.

4.3.1 SKU Classification

The XYZ classification technique uses the co-efficient of variation to help determine the variance of the product's demand. The co-efficient of variation is the ratio of standard deviation divided by average demand as shown in equation 3.

$$CV = \frac{\sigma}{\bar{x}} \tag{3}$$

Where the standard deviation is calculated as follows:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2} \tag{4}$$

Table 4: Decision Variables of Co-efficient of Variation Calculation

Parameters	Description
$\boldsymbol{\sigma}$	Standard Deviation
$\boldsymbol{x_i}$	Demand value in unit of time i
$\boldsymbol{\bar{x}}$	The demand average value in a unit of time
$\boldsymbol{N}$	The total number of observation

Based on the monthly volume demand data, the SKUs classification is shown in the Table 5. Groups are distinguished by the percentage of yearly demand of each SKU over the total yearly demand.

Based on coefficient variation rank, there is slightly different in categorizing some SKUs. There are two products in group A have abnormal demand. Group B and C have more variance and abnormal demand pattern, and they have small percentage in total yearly demand. (See Table 6)

Table 5: SKUs Classification Based on Monthly Demand Volume

Group	Number of SKUs	% of Total Annually Demand	Criteria: If Average Demand Monthly is
A	29	88.15%	>=150
B	18	8.6%	>40 & < 150
C	35	3.25%	<=40

Table 6: SKUs Classification Based on Monthly Coefficient Variation

Group	Number of SKUs	% of Total Annually Demand	Criteria: If Monthly CV is
X	39	88.02%	<=25%
Y	31	6.84%	>25% & <60%
Z	12	0.43%	>=60%

Combining Table 5 and 6, we have the taxonomy of SKUs classification and all the SKUs are divided into 4 groups as shown in Table 7.

- Group 1: Products have high demand volumes and low variance to variance demand patterns.
- Group 2: Products have average demand volumes and low variance to variance demand patterns.

- Group 3: Products have low demand volumes; or average demand volumes but with abnormal demand patterns.
- Group 4: Products have high demand volumes and abnormal demand patterns.

Table 7: SKUs Taxonomy

	X	Y	Z
A	Group 1	Group 1	Group 4
B	Group 2	Group 2	Group 3
C	Group 3	Group 3	Group 3

Finally, the result of group aggregation is presented in Table 8. There are four different groups of products and the level of stock of each group will be examined in different period of time. For example, products in group 1 will be checked and filled up the stock up to the target daily stock. With group 2 and 3, the stock will be checked weekly or monthly because the demand is unpredictable in every day or every week. An example for irregular product demand would be that there could be only an order with a dozen in one week and in a specific month. Group 4 is a special case with varying average daily demand depending on the season or month of the year. Thus, the staff needs changing the target level of stock seasonally so that the company can lessen the space in the low season demand and avoid shortages in the peak season demand.

Table 8: SKUs Group Aggregation

Group	Number of SKUs	Total Demand (%)	Production Strategy
1	27	83.78%	Daily Planning
2	17	8.4%	Weekly Planning
3	36	3.5%	Monthly Planning
4	2	4.36%	Seasonally Daily Planning

4.3.2 Safety Stock Level

The setup cost/ time is not significant in the case study. The inventory cost is not the first concern to the company. Following the lean manufacturing and make to order, the service level is their priority, indicating that the shortage is not allowed. Besides, one of the constraints is allocated in the capacity and the space of the storage. For this reason, under the uncertain demand, the safety stock will be optimized under target service level and constraints of capacity and space.

There are several ways to calculate the safety stock. Selecting the appropriate approach partly depends on the competitiveness and particular environment of industry. The proportion of the service level and cost target is one of the factor that decides the safety stock level. Here, I will define the method based on the characteristic of the case study so that it will be more practical to solve the problem. Definitions of the parameters and decision variables are given in Table 9.

Table 9: Decision Variables in Safety Stock Calculation

Notation	Definition
$\boldsymbol{I}$	Number of items
$\boldsymbol{i}$	Product $i \; \forall \; i = 1, 2, \dots, I$
$\boldsymbol{\mu_i}$	Average demand of product i for a unit of time
$\boldsymbol{\sigma_i}$	Standard deviation of demand per unit of time for product i
$\boldsymbol{L_i}$	Average lead time of product i
$\boldsymbol{\sigma_{Li}}$	Standard deviation of demand during lead time of product i
$\boldsymbol{SS_i}$	Safety stock of product i
$\boldsymbol{BS_i}$	Base stock of product i
$\boldsymbol{z_i}$	Standardized score for product i

As given in Silver and Peterson (1979), the safety stock equation for normally distributed demand with standardized score z:

$$SS_i = z_i \times \sigma_{Li} \tag{5}$$

Where

$$\sigma_{Li} = \sigma_i \times \sqrt{L_i} \tag{6}$$

And the base stock is calculated as below:

$$BS_i = \mu_i \times L_i + SS_i \tag{7}$$

In order to use the formulas above, there are some assumptions applied for the demand parameters. The demand is assumed to be independent and follows the normal distribution with a mean of μ and a standard deviation σ. In addition, I assume that the lead time, which equals to the time to manufacture and palletize as 1 day, is constant. Demand is the only variable in the calculation.

Due to the difference in variation of each SKU's demand, the safety stock of each group (as categorizing above) will be experimented separately. As known that safety stock depends on the targeted service level the company wants to maintain. The higher service level is, the more the stock the bigger the cost is, depicted in Figure 6. Therefore, the SKU classification again helps decide the suitable service level for each SKU to balance the trade-off cost and service level. For example, if the product has abnormal demand for a particular season and cost to store that product is high, it would be only worth to store the product during that season and keep low stock level for other periods.

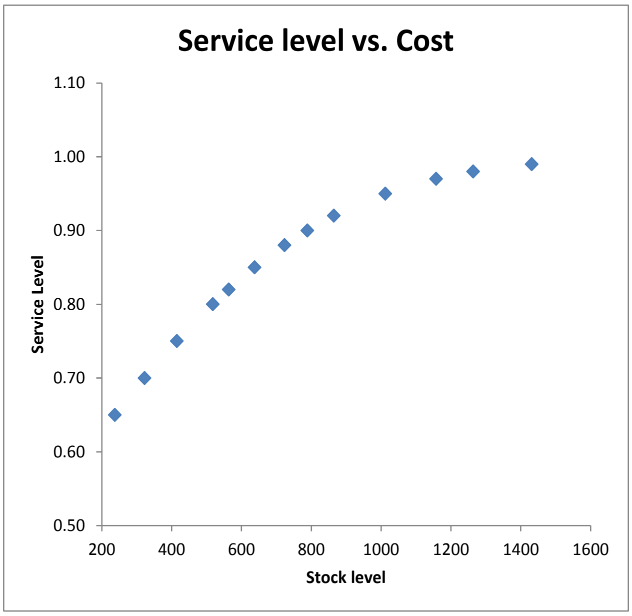


Figure 6: The Trade-off Cost and Service Level of All SKUs

As a result, Table 10 below shows the daily base stock required for different groups. Each group is divided into 2 pallet size Pallet 12 and Pallet 16. Therefore, there are total 8 groups of product.

Table 10: Required Daily Base Stock for Different Service Level

Pallet Type	Product Group	Base Stock (units) if Service Level equals as			
		99%	**95%**	**90%**	**85%**
P12	**G1**	906	746	661	604
	G2	125	98	84	74
	G3	29	20	18	15
	G4	219	159	127	106
P16	**G1**	557	457	404	368
	G2	105	81	69	60
	G3	133	100	80	70
	G4	123	91	74	63

5 Simulation Modeling

The structure of this chapter follows the five steps which are mentioned in the simulation study methodology above.

5.1 Simulation Objectives

The objective of a simulation study is to provide the company manager with a decision support tool that will assist in evaluating the new designed FMS. The simulation will aid in assessing the impact of production output rates, the resources utilization, the operation time and the level of buffer stocks in different scenarios. After comparing the results, the best solution for the new designed manufacturing system is suggested.

5.2 System Description and Modeling Approach

The following sections define the flow of products from processing to storing or shipping. The flowchart is presented in Appendix B to sketch all the activities which involve in the process. This simulation project focuses on the parts production element of the manufacturing plant. As in the proposal system design of the company facility, we are considering a multi-product plant where all different SKUs follow the same sequence of operation at two machines connected by a system of two gantry robots, few AGVs and buffer areas.

Secondly, a transfer policy suitable for the production process needs to be determined. At any given time in the manufacturing flow, the work-in-process products are either a) being processed by a filling machine, b) traveling between machine and buffer area or c) accumulating in the buffer area waiting to be processed. The throughput of the flow production is dependent on the processing capacities or speed of the robot, of the filling machine, and the capacity of the buffer sorting area.

As the purpose of minimizing the extra space of the storage and the processing time, the finite intermediate storage policy is being applied. This policy predetermines the approximate quantity of each product that requires space to be stored. Optimal estimation for the storage equipment, likewise the optimal quantity of each product type is necessarily calculated.

Thirdly, the type of production campaign selected is used for manufacturing various products in a cycle time T. Due to the demand variety of different products, the mixed product campaign, which allows to produce multiple times of a given product with different batch sizes according to a selected sequence during a production cycle, is suitable for this type of product. As a fact that the inventory level of individual product spreads over the cycle to reduce the inventory costs and meet the constraint of the space. Since the capacity of resource is greater than the current demand arrival rate, there are some SKUs, with very little demand per day, can be produced while palletizing as likely as pull production control method Kanban. Furthermore, the cleanup or setup time for changing to another product is negligible. Hence the mixed product campaign is more efficient.

5.2.1 Modeling Approach - Filling Manufacture System

The high speed manufacturing system is a fully automated sorting, filling, and palletizing system. The entire system is divided into 3 main divisions namely the sorting section, the filling process, and the palletizing section as in Figure 7-9. All aspects of these divisions are managed by the gantry robots which are controlled and monitored by computer.

The system to be modeled consists of parts arrivals as empty cylinders or full cylinders from the storages, two filling carousels, two gantry robots and parts departure as pallets of full cylinders. Each carousel has one filling machine. At one time, only one cylinder will be filled and one cylinder is in the waiting position to be filled.

At the beginning, the pallets of empty cylinders of different categories will be sent to the system to be filled in advanced. The empty cylinders are placed in Empty Buffer station, which is under gantry robots, waiting for filling. Then, the full cylinders filled by gas already will be placed in the Full buffer station which is also under gantry robots as shown in Figure 10. When the orders from customers arrive, the robots start palletizing by picking up ordered cylinders and put them into Pallet size 12 or 16. When the pallet is full, the AGVs come to move it to the Shipping Gate. In case that there are not enough full cylinders in the Full Buffer station, the controller will send a signal to the storage and request AGVs to move pallets from the storage to the Buffer station.

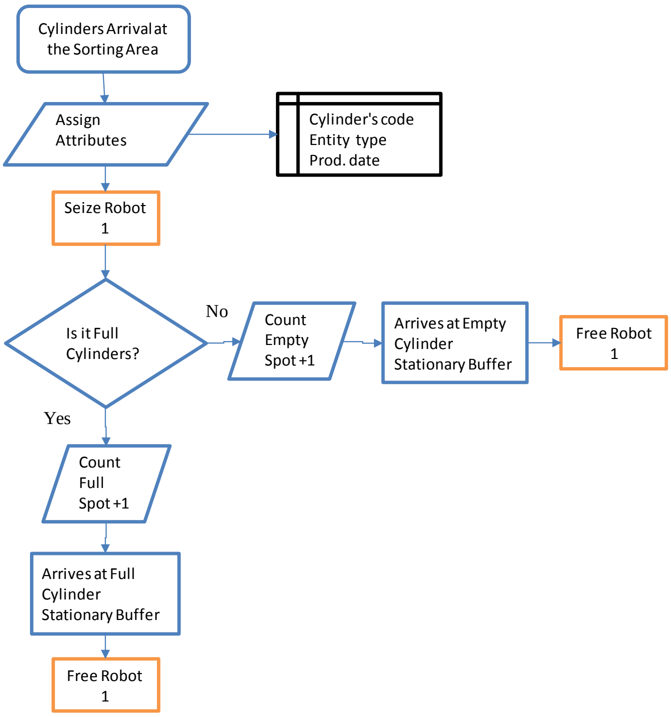


Figure 7: Division 1 – Robot 1 with Sorting Section

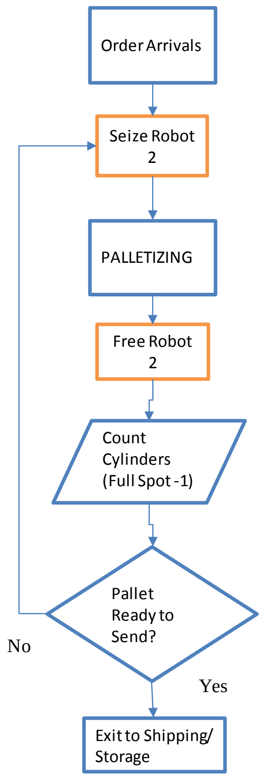


Figure 8: Division 2 – Robot 1 & 2 with Filling Process

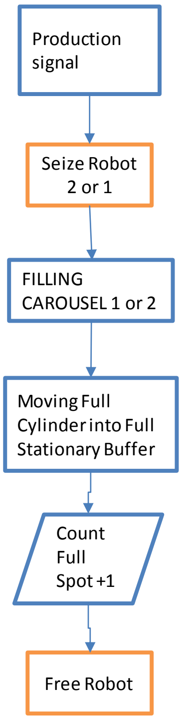


Figure 9: Division 3 – Robot 2 with Palletizing Section

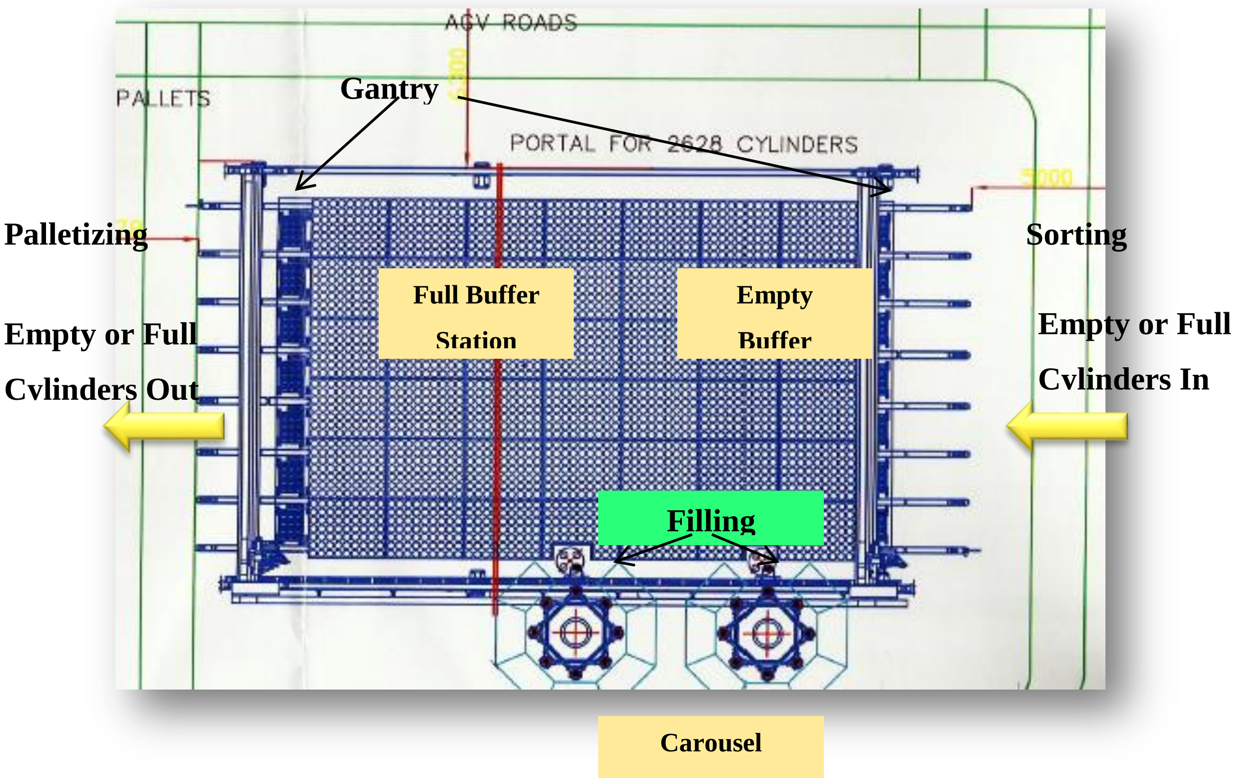


Figure 10: Overview Picture of the Filling Carousels and Buffer Sorting Station

5.2.2 Parameters, Assumptions, and Constraints for the Base Case

The main assumptions and parameters of the developed simulation model are the following:

a) Production Time Simulation

After receiving the orders in day 1 until 1pm, the production starts palletizing the cylinders in the mixed pallet according to the logistic route distribution plan. Based on this characteristic of the production process, in the simulation, time follows the day unit because of considering daily demand. The demand of each product is generated for every day, as same as standard deviation. Furthermore, the operation time will be x hours/day and it is assumed that there are only x hours in a day for simulation. Always, the production starts filling cylinders at 6am for 7 hours until 1pm. The limit time for palletizing would be 5 hours if the operation time is 12 hours, and 6 with 13 hours, etc… Importantly, no backorders are allowed for the system, thus the demand corresponding to customer orders that is not fulfilled by the finite time delivery (after limit palletizing time) is lost.

b) Demand

The demand of each product is simulated individually daily and it is assumed as following Normal distribution$N(\mu, \sigma)$. Only the product group 4 has a Uniform distribution$U(a, b)$. From monthly data, the daily standard deviation is calculated by dividing the monthly standard deviation over square root of number of working days in a month, as 23 days in this study.

$$\sigma_{i\ daily} = \frac{\sigma_{i\ monthly}}{\sqrt{23}} \tag{8}$$

The average daily demand is

$$\mu_{i\ daily} = \frac{\mu_{i\ monthly}}{23} \tag{9}$$

The parameters of daily demand of different product group each month is attached in Appendix A3. On the other hand, the number of empty cylinders collected from the customers is assumed to be equal as the amount of demand in the previous day.

c) Inventory Management

Owing to the high capacity of the flexible manufacturing system the company updates, keeping the system close to lean manufacturing so that the inventory will be reviewed continuous daily and the production will run daily. Thus, the lead time is considered as 1 day constantly. As mentioned above, the inventory review policy (S-1, S) will be conducted. S here is the target base stock policy value and calculated as shown in the Equation 7. The calculations are carried in terms of day.

Literally, the inventory level changes take place at the beginning and the end of the day. At the beginning of each day i, a demand is realized and the existing inventory is used to satisfy this demand. Nevertheless, during the palletizing time, one of two filling machines is still filling number of cylinders, k, will be added up to the available stock for palletizing and delivery. The total inventory available for the day i is the sum of full cylinders in the buffer station and in the storage, and k.

The (S-1, S) continuous review policy is a continuous replenishment. For example, after Day 1 and fulfilling the demand, the inventory level drops down as D, a production is placed to bring the inventory level back to S in the next Day 2. The maximum quantity produced in Day 1 equals to the exact number of units demanded as D. However, it still depends on the filling machine capacity.

d) Distance Robots Move

The distance between locations a robot moves at one time is limited in the Sorting Buffer Area with measurement as 28 x 14 meters. Preventing the two robots from colliding, each robot is assumed to be able to move within half the area (14 x 14 meters) separately. The robots move two dimensions with random number x and y. From here, the randomness of meters the robots move is the sum of random numbers x and y.

Random numbers are distributed uniformly and independently on the interval [0, 14]. In excel, the syntax of generating random number is RAND (). Moreover, in probability, the central limit theorem (CLT) asserts that that the sum of a large number of independent random variables has approximately a normal distribution (Ross, 2013, p. 26). Therefore, I use normal distribution to generate the distance robots move from one spot to another spot.

Concerning to the arrangement of product types which is described later in section 5.5.2, as shown in Figure 12, the distance moving the cylinder 121 from Empty Buffer station to

Carousel would be shorter than moving the cylinder 161 from Empty Buffer to Carousel. The distance is likely to be different for different type of cylinders while moving between two similar two stations.

The parameters of distance the robots move from station A to station B is attached in Appendix A4.

e) Constraint of Resources and Space

The filling time for one cylinder is 1 minute averagely. Hence, the maximum number of cylinders two machines can fill per day is calculated as:

$$Max\ Number\ of\ Cylinder\ Filled\ Daily = 60 \times 2 \times Operation\ Time \quad (10)$$

Based on the assumption of Distance Robots Move, the minimum average time that a robot moves in one cycle is 20 seconds. Accordingly, the maximum number of cylinders a robot can seize per day is:

$$Max\ Number\ of\ Cylinder\ Seized\ Daily = 60 \times 3 \times Operation\ Time \quad (11)$$

The maximum number of cylinders inside the Sorting Buffer Area is 2628 cylinders. The storage contains 140 pallets of cylinders in the storage at maximum.

f) Service Level Measurement

The type 1 service level for the entire planning horizon is calculated by dividing the number of days with no shortages over the total number of days in the entire planning horizon. (See Equation 1)

The type 2 service level for the entire planning horizon is calculated by dividing demand satisfied for day i over the total demand from customers. Demand satisfied for day i is the difference between total stock-outs and total demand. (See Equation 2)

g) Cost Calculation

Total cost composes of lost sales, holding cost and operation cost. However, the real cost of operation is unknown. Therefore, I will use the variables a for the cost of one cylinder lost sale, b for holding cost of one cylinder, and c for operation cost per hour. In addition, in the afternoon shift after 2pm, the extra cost per operation hour is 6 EUR, so that the cost will be (c + 6).

$$\sum Lost\ sales = sales\ price \times 1.5 \times number\ of\ lost\ sales\ units \qquad (12)$$

$$\sum Total\ Holding\ Cost = holding\ cost\ per\ unit\ per\ day \times (Inventory_{t-1} - Demand_t) \qquad (13)$$

$$\sum Operation\ cost = operation\ cost\ per\ hour \times number\ of\ hours \times 253 \qquad (14)$$

5.3 Model Detailed Elements

The basic elements of the whole system are product types, transporters, and workstations are described separately as followings.

5.3.1 Product Types

Due to similarities, variants are combined into four groups G1, G2, G3, and G4 as in the section 4.3.1. Each group is comprised of two sizes of gas cylinder as: 1) 50 litters and 2) 20 or 10 litters. There are also two sizes of pallets: P12 with 12 50l-cylinders and P16 with 16 20l-cylinders or 10l-cylinders.Thus, there are 8 different categories named as: C121, C122, C123, C124, C161, C162, C163, and C164.

Table 11: Production Mix for the Automated Filling Process

Product Type	Number of SKUs	Total Demand (%)	Production Strategy
121	16	52.5%	Daily Planning
122	10	4.97%	Weekly Planning
123	16	1.4%	Monthly Planning
124	1	2.2%	Seasonally Daily Planning
161	11	33.3%	Daily Planning
162	7	3.5%	Weekly Planning
163	20	2.0%	Monthly Planning
164	1	2.1%	Seasonally Daily Planning

5.3.2 Entities Transfer

The gantry robots are capable of picking up a required cylinder and putting it into the exact spot in the Buffer station or Filling machine. It will move to two directions x and y. The robot can handle only one cylinder at a time. Each operation carried out by the robot has three essential steps: loading, transporting and unloading. The time taken to complete one cycle depends on the velocity and the distance between a departure point and a destination point. Loading or unloading step takes approximately 5 seconds.

The second transporters are the AGVs which are advanced material handling system to transport the pallets of cylinders inside the operational plan. These driverless vehicles follow their paths to reach destinations. (The green AGV roads shown in the Figure 10)

In the automated manufacturing process, the Robots and AGVs are considered highly flexible material handling tools in order to increase the effective utilization of production. In this study, there are two active robots handling cylinders in the Buffer station and Carousel station. The task of Robot 1 is loading empty cylinders into Empty Buffer station. The task of Robot 2 is palletizing the full cylinders. Besides, during normal schedule, both Robots cyclically load empty cylinders to the Filling machines or unloading full cylinders off machines. However, when the customer orders arrive, after 1pm, the Robot 2 will do only one job which is palletizing cylinders to ensure the sufficient time for delivery. The other Robot 1 will do two jobs placing empty cylinders from pallet to Empty Buffer or loading/unloading cylinders to the Filling machines. The purpose of separating Empty Buffer and Full Buffer for Robot 1 and Robot 2 respectively is preventing the robot gantry cranes from colliding or gridlocking.

Similarly, AGVs will cyclically be requested to import pallets to the Sorting Gate and export the finished pallets to the Shipping Gate or Storages.

5.3.3 Buffer Station and Storage

Empty and Full Buffer Station

With Empty and Full Buffer station, it allows holding the materials as empty or full cylinders inside the Sorting and the Filling area until the next stage is idle. Buffer station helps in reducing the transfer time between the storage and sorting area and the time of loading and unloading pallets. Also, the storage space will be minimized thus reducing investment cost for storage equipment and space. As in the manufacture layout, the manager defines the maximum space for Buffer station is 2628 cylinders. The optimal space for each product group can be calculated in order to satisfy the customer demand in time.

Storage

Storage is considered as an anticipation inventory, which consists of stock accumulated in advance of an expected peak in sales (Silver et al., 1998, p. 31). Even though the updated system has higher capacity, it is uncertain to satisfy all demands during the peak month sales. Furthermore, Storage is prepared for any unexpected damage from machine breaking down time or insufficient supply period. Therefore, determination of anticipation inventories is always a part of production planning as well as one of questions for the simulation need answering.

Sorting Gate and Palletizing Gate

Sorting Gate is the place where the information of each cylinder will be scanned and updated to the system via barcode. Palletizing Gate is the place where the Robot palletizes the cylinders. There can be few pallets waiting here until processing. The waiting queue is defined as maximum as 10 pallets.

5.4 Arena Simulation Structure

There are many ways to cooperate different modules together. In order to create a good simulation model, at first a modeler needs to understand all functions which each module is able to operate. Accordingly, the model will be streamlined and it would be easier to examine and adjust if there is a flaw in the logic models.

5.4.1 Modules

The Arena model is built using flowchart modules and data modules. The flowchart modules are connected to form logic of a process. Table 12, next page, data modules are where we can input data as the real process information requires. Data can be numbers or mathematical expressions to model the stochastic system for instance.

In Arena Software, the Basic Process provides the highest level of modeling as its designed to allow creating high level models of most systems quickly, easily and also a great deal of flexibility (Kelton et al., 2010).The basic process is combination of the CREATE, PROCESS, DECIDE, ASSIGN, RECORD, BATCH, SEPARATE and DISPOSE modules, which are used in this simulation.

The CREATE blocks are used to determine the arrival of the entities. After creation, each entity is assigned the attributes as characteristics for each product type by ASSIGN module. The entity enters the machine resource at a PROCESS module. After being processed, the entity is moved by the transporter to another station. Each workstation is comprised of at least a STATION or ENTER, STORE, UNSTORE, and LEAVE. STORE and UNSTORE modules help us to keep track on number of available stock at any time in that STATION or STORE. LEAVE module includes the ROUTE function and also keeps a role as REQUEST-TRANSPORT. ENTER module will release the resource or transporter when the entity arrives at destination. In addition, HOLD is set up in any station for a purpose of keeping the entities inside the STORE until there is a signal to release that entity. The DECIDE module helps determining the entity type or checking the condition before releasing. For example, when palletizing the order, DECIDE distinguishes some entities-cylinders are put into the pallet P12 and the others into P16. Then, once there are enough cylinders in one pallet, the BATCH module will batch all cylinders in one pallet and REQUEST transporter to move to shipping and ending by DISPOSE module. In the opposite way, when the pallet of empty cylinders arrives, the SEPARATE module will separate it into each individual cylinders and move into system. On the other hand, the RECORD module can record any information that you want to know, for instance the moving time of a robot in one cycle or counting the number of times that lost sales happens.

Besides, there are some modules from Advanced Process and Advanced Transfer used to support the system to transfer or store/un-store entities. They provide additional and more detailed modeling capabilities and flexibility. In addition, the lower level Block panel provides the basic functionality for special purpose modeling. All the modules used are listed in the Table 12.

Table 12: The List of Modules used in the Simulation Modeling

Basic Process	**Advanced process**	**Advanced Transfer**	**Block**
Create	Hold	Station	Branch
Process	Delay	Request	
Decide	Store	Transport	
Assign	Un-store	Free	
Record	Read-Write	Leave	
Batch		Enter	
Separate			
Dispose			

5.4.2 Pieces of Simulation Model

Entity

Entities are the dynamic objects in the simulation. They are created, move around for a while and then are disposed of as they leave (Kelton et al., 2010). Each entity has a unique active entity number when created to act as its record of existence. These numbers are reused as entities are disposed and new ones are created (Arena Help). The entities, cylinders, are parts to be processed. They are created when they enter to the production facility, processed by the machine, and then disposed of as they leave the production line. Multiple different parts can be created and float around the model.

Attribute

Attributes are attached to the entities due to a purpose of individualization, in which the attached characteristics can differ from one entity to another. For instance, priority set up for each different types of gas product, which have dissimilar arrival demands. (See Table 13)

The core of attributes is their values are attached to specific entities. The attributes are subject to change by using ASSIGN module at any time during the simulation run if there is a need in the process. For example, the value "Empty" of an attribute Cylinder status of an empty cylinder can be changed to value "Full" after that cylinder is processed by filling machine.

The attribute Product type is for deciding which storage or buffer place to store the particular cylinder. The Priority is for specifying different priorities for entities to seize the Resource when there are multiple entities in the same queue. The Pallet type attribute is to decide which size of pallet that cylinder is placed.

On the other hand, the special attribute for Entities animation is Entity picture where the picture will be represented for the entity as a pallet or cylinder with P12 or cylinder with P16.

Table 13: The Attributes Assigned for Each Entity

Product	Entity Name	Attributes			
		Product Type	Priority	Pallet Type	Cylinder Status
Group 1-Pallet 12	C121	1	1	12	Empty or Full
Group 2-Pallet 12	C122	2	3	12	Empty or Full
Group 3-Pallet 12	C123	3	8	12	Empty or Full
Group 4-Pallet 12	C124	4	5	12	Empty or Full
Group 1-Pallet 16	C161	1	2	16	Empty or Full
Group 2-Pallet 16	C162	2	4	16	Empty or Full
Group 3-Pallet 16	C163	3	7	16	Empty or Full
Group 4-Pallet 16	C164	4	6	16	Empty or Full

Variable

A variable or global variable is a piece of information that reflects some characteristic of the model, regardless of how many or what kinds of entities might be around. (Kelton et al., 2010) Many variables are allowed and each is unique. There are variable that are already built inside Arena such as number in queues, current simulation lock time or number of busy machines, etc…However, the user can assign the variable to track of anything that is interesting to collect in the entire system. For example, the variable can be the transfer time from one place to another place if the speed of transporters is variable; or daily demands of different types of products are variables.

Resource

Resources represent here as two filling machines: Machine 1 and Machine 2. In addition, the material handling devices as gantry robots are also considered as resources for moving cylinders. An entity seizes (units of) a resource when available and releases it (or them) when finished. A resource can comprise several individual servers and each is called a unit of that resource.

A single resource here can serve only one entity at one time, which means that if the machine is busy, the other entities would wait in the queue or in the intermediate storage. The two filling machines have fixed capacity and assumed to work without problems. The idle and busy times of the filling machines are animated by color green and red respectively. Nevertheless, the machine capacity may be changed in different simulation in order to compare and analyze in different situation.

Last but not least, the considerable resource in the system is the robot cranes, which are modeled by using LEAVE-ENTER modules with ROUTE connection. The moving time of Robots depends on their constant setup speed, the variable distance they move within the sorting area (28 x 14 m) and the loading/unloading from machining station to the palletizing gate or from the buffer area to the machining station. The AGVs are modeled as free path transporters by using REQUEST-TRANSPORT-FREE modules.

Expression

Expressions can be viewed as specialized variables that are defined by the formula instead of storing a specific value. Whenever an expression name is encounter in the model, it is promptly evaluated at that point in simulation time, and the computed value is substituted for the expression name (Altiok & Melamed, 2007).

Queue

There is a queue existing in the model when the entity has to wait for a unit of time to be processed.

Statistic

The Statistics are recorded during the simulation run and displayed as output performance measures. The statistics are classified as tally, time-persistent and counter statistics.

Tally statistics or discrete time statistics present the average, minimum or maximum of a list of number.

Time persistent statistics or continuous-time statistics are time average statistics in simulation. For example, average number in the queue is calculated throughout simulation, or machine utilization in time scheduled.

Counter statistics are used to sum of something as accumulating.

Data Integration

As I mentioned from the beginning one of useful functions from Arena Simulation is that Arena can exploit for integrating directly with other programs, including Microsoft Excel. Microsoft Excel will be a user interface for data input and output.

Arena's standard modeling constructs supports the user in designing a model in which we read the data from an external file and then write performance data to a file by using the READWRITE module from the Advanced Process. The values from an external source can be read an assigned to variables in the model. They can be numbers or expressions.

5.5 Building the Model

The model is divided into five sub models presented in order as the logic of entities moving or being transferred in the production line. The sub model's connection is depicted in Figure 11:

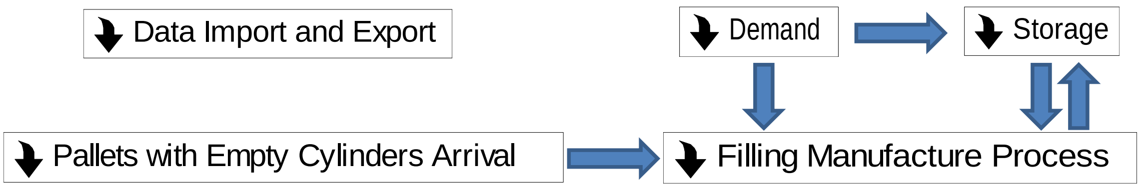


Figure 11: Logic Sub Models in Flexible Manufacturing System

5.5.1 Sub Model 1: Station Empty Pallet Control

The CREATE module creates pallets containing empty cylinders which arrive at the Factory Plant from Swap-bodies. These pallets will enter the sorting gate when there is still space from Sorting Buffer station. Next, the HOLD module is to ensure the pallet containing empty cylinders is sent when there is a signal of request. The DECISION module will control how many of pallets should be sent to meet the requirement. If there is enough, the signal will be turned off. The pallet with empty cylinders will be transported by AGV to the Sorting Gate. This activity is modeled by REQUEST-DELAY-TRANSPORT-FREE modules. Obviously when the cylinders enter the Sorting Gate, all characteristics of each cylinder will be assigned as shown in the Table 13 above in the section 5.4.2.

In the real case, the pallet might have contained many types of cylinders. It is assumed that the pallet of empty cylinders contains only one type of cylinders. This model will be repeated for the eight types of pallets containing empty cylinders: EP122, EP123, EP124, EP161, EP162, EP163, and EP164. (Simulation model presented in Appendix C1)

5.5.2 Sub Model 2: Filling Manufacture System

Once the pallet with empty or full cylinders arrives at the Sorting Gate, the pallet is dis-batched or un-palletized as 12 or 16 cylinders separately by SEPARATE module and waiting for Robot 1 come to pick up. The amount of cylinders entering the Buffer station is recorded. If the cylinders work-in-process in the whole Sorting Buffer area exceed the maximum level 2628 cylinders, the Robot 1 cannot place more cylinders into Buffer station until some full cylinders are moved out of Buffer station.

The next step is to check where the cylinder should be placed. Owing to higher demand of cylinders type Pallet 12 as 60% of total sales, those cylinders are placed together near to the Carousel stations. There are eight areas splitting up inside the Empty Buffer station, named as Store E121, Store E161, etc…Similarly, in the Full Buffer station, there are eight areas as Store F121, Store F161, etc….(Shown in Figure 12) The STORE module adds a cylinder into a particular allocated space in a Sorting Buffer station. The UNSTORE module is used to remove the entity from that space. When a cylinder arrives at the STORE module, the specified space is incremented. In the same way, the storage is diminished when the cylinder is un-stored from there. Even though the entity cylinder is thought as being kept in one place, the STORE module does not prevent the entity from proceeding in the model logic.

If a unit of the Filling machines is available, the Robot 1 or Robot 2 will proceed to load the empty cylinders to Carousel station. The PROCESS module is used to model the filling process with a set of two machines and the capacity of each is default to 1. During filling time, there can be one cylinder in the waiting position. However there cannot be more than two cylinders at one Carousel station. Therefore, there is a signal sending from Carousel station to the Robots when the Carousel is available. When the cylinder is completely filled, the Robots will place it to Full Buffer station in conformity with type of cylinders.

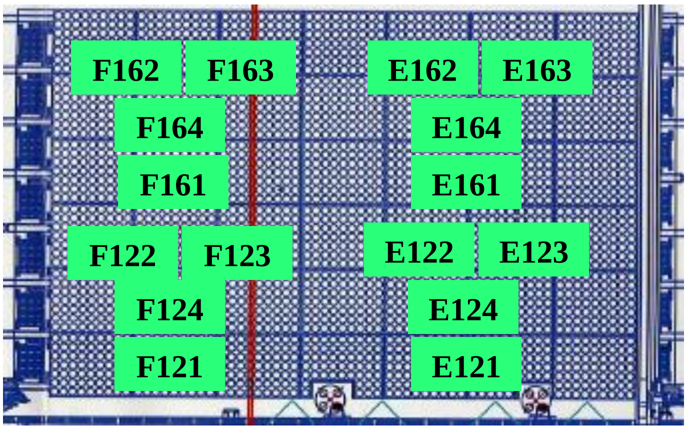


Figure 12: Arrangement of Cylinder Product Types' Location

The final stage of the system is Palletizing. The Robot 2 does palletizing when it receives a signal from the Demand Sub model or the request to fill up the storage from external Storage Sub model.

When delivering to customer, according to location distribution, the number of different types of cylinders in one pallet will be defined by logistic route plan department. The BATCH module does grouping an amount of cylinders together which is assumed as random from 8 to 12 cylinders or from 12 to 16 cylinders in one pallet. Batches are matched together based on an attribute of pallet size. Based on distribution records, approximately the randomness of number cylinders in one pallet follows Discrete Probability Distribution as syntax as DISC (0.6, 12, 0.8, 11, 0.9, 10, 0.95, 9, 1, 8) which indicates 60 % of 12 cylinders in one pallet, 20 % of 11 cylinders in one pallet, 10% of 10 cylinders in one pallet, 5% of 9 cylinders in one pallet and 5% of 8 cylinders in one pallet. The same proportion applies to the case Pallet 16 as DISC (0.6, 16, 0.8, 15, 0.9, 14, 0.95, 13, 1, 12). As soon as a pallet is ready to be delivered, the AGV will come to transport it to the expected destination, Shipping Gate to be disposed or Storages to be stored.

The logic model is presented in Appendix C2.1-5.

5.5.3 Sub Model 3: Demand

Demand for an individual product is created one time at a day. Based on the real system, all customer order before 1 pm will be palletized and delivered to customer in the following day.

The palletizing time depends on how many cylinders are ordered in that day. The rest of the cycle time is devoted to fill the cylinders and prepare the buffer stock for the next day.

The demand of each product will be generated from the expression data input in the Excel File. In the models Demand developed, the current stock level of cylinders in Buffer station will be checked when the new demand order arrives. If there is not sufficient stock in the Buffer station, the cylinders from the Storage will be sent to Buffer station to be palletized.

The logic model is presented in Appendix C3.

5.5.4 Sub Model 4: Storage

The Storage Sub model is to send pallets of full cylinders to Buffer station when there is high peak in demand. If the level of safety stock is under the determined amount, the Storage will send a request signal to Robots to fill up the Storage. However, the request from the Storage will be carried out once Palletizing for Shipping is completed and the level of Full Buffer station is filled up. The target level of Storage is read from the Excel File.

The logic model is presented in Appendix C4.1-2.

5.5.5 Sub Model 5: Data Import and Export

The simulation is initiated by importing data from Excel File to assign the decision variables' value. The list of decision variables and data collected are listed in the Table 14 and 15. On the other hand, the data "Time for moving any cylinder" from any station can be recorded by Record Module and extract to another form of file as .txt or .dat.

The logic model is presented in Appendix C5.

Table 14: Dicisions Variables for Simulation Model

Decision Variables
Operation Time
Constraint of Sorting Buffer Area
Velocity of Robots
Filling Machine Process Time
Target Level of Full Buffer Station
Target Level of Storage
Daily Demand Expression
Distance Expression that Robots Move from One Location to Another Location

Table 15: Statistic Ouput from Simulation Model

Data Output	**Type of Statistic**
Level of Stock in Buffer Station	Counter
Level of Stock in the Storage	Counter
Number of Cylinders Filled Daily	Counter
Number of Empty Cylinders Arrival	Counter
Resources' Utilization	Persistence
Daily Demand	Tally
Daily Lost Sales	Tally
Time for Completing Palletizing	Tally
Time for Moving any Cylinder from One location to Another Location	Tally

5.5.6 Run Length

The system simulated is inherently a steady state system, in which the quantities to be estimated are defined in the long run. Due to seasonal demand throughout the year, the preparation for the stock will be different. Therefore, the simulation will run 257 days in one replication with 4 days warm up for preparing initial condition as the beginning level of stocks. Critically, the setup of number of hours per day will be equal to number of hours the production operates. The reason is that the study is interested in the performance of the facility only during the operation time.

The software and hardware required to run the model include:

- Arena with Academic License - Version 14.70.00000
- Computer Model: Intel Core i5 CPU Quad 2.50 GHz
- 8103 MB RAM.
- Windows 7
- Microsoft Excel 2013

5.6 Verification

The model is verified by ensuring that entities moved through the correct model: from Sorting Gate to Empty Buffer, from Empty Buffer to Carousel station and from Carousel to Full Buffer station and then Palletizing Gate. Furthermore, the robots are ensured to be used at the right task. Robots 1 and 2 have individual tasks but both cyclically load cylinders in/off from carousels. The amount of cylinders inside the sorting area at any time must be under the maximum capacity as 2628 cylinders. The model is validated at the range 700 – 800 cylinders/day demand level by comparing with real monthly demand data from the AAA. On the other hand, the velocity of robots and filling time process are known before hand, total amount of cylinders filled per day maximum and the total time to palletize the order are performed as expected.

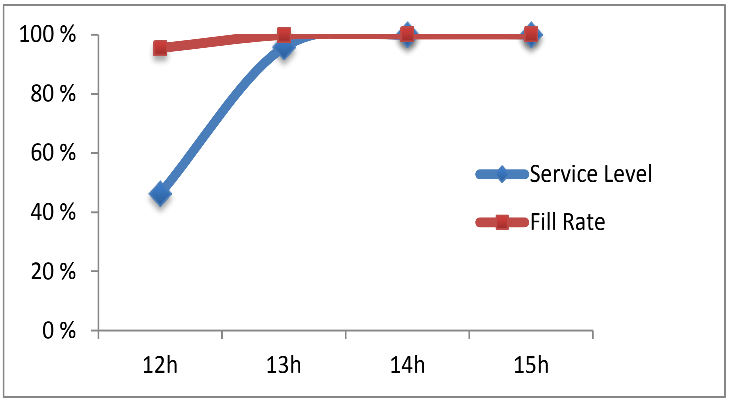
6 Scenarios Analyses

In order to check the credibility of the models, the simulation will be run with different sets of system parameters. The results of different scenarios will be presented in this chapter.

The experiment aims to investigate the resource utilization of the new system. With the model built and verified, it is a relatively straightforward scenario to implement the model. The base case will be experimented in different scenarios of operation time per day as 12 hours, 13 hours, 14 hours and 15 hours.

6.1 Base Case Results

Under the base case scenario, the system has two filling machines, two robots. The simulation model results show that with the current demand rate (see Appendix A3), the line is capable of palletizing the orders within 4 to 6 hours as shown in Figure 16. Thus, if the production starts at 6 am and begin palletizing after 1 pm, the operation time should be 13 - 14 hours per day. As a result, the service level alpha is above 95% when the production runs until at least 6pm, equally 13 hours operation time. (Figure 13)



Scenario	Service Level	Fill Rate
12h	46 %	95 %
13h	96 %	100 %
14h	100 %	100 %
15h	100 %	100 %

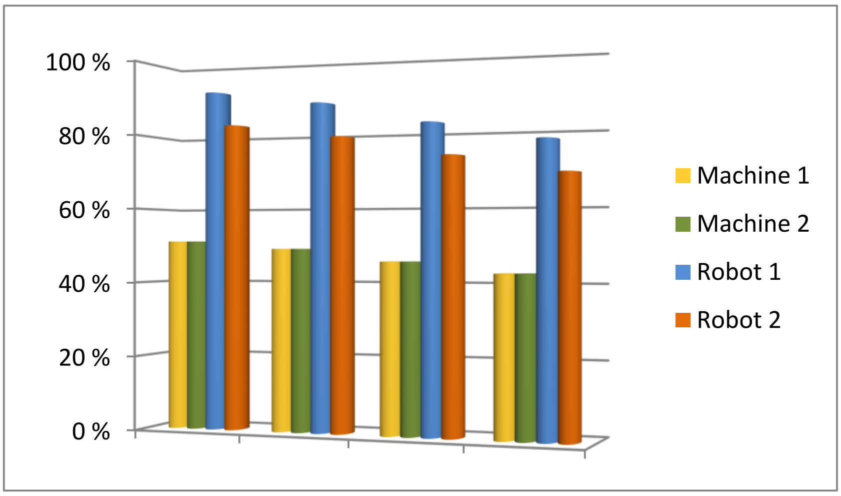
Figure 13: Service Level and Fill Rate for Different Daily Operation Time

Nevertheless, the two machines' utilization, shown in Figure 14, was pretty low under 50% for filling machines. The robots and machines' utilization are negatively correlated to the operation time hours. The explanation would lie on the big gap between the capacity of resources and the current demand rate. The resources are idle when there is no need to fulfill the stock or the demand is not so high compared to the capacity of machines.

According to Arena book (Kelton et al., 2010), Scheduled Utilization is the time average number of units of the Resource that are busy (taken over the whole run), divided by the time average number of units of the resource that are scheduled (over the whole run). The formula is shown as follows:

$$\frac{\int_0^T B(t)dt}{\int_0^T M(t)dt} \tag{15}$$

With $B(t)$ be the number of units of the Resource that are busy at time t and $M(t)$ be the number of units that resource that are scheduled (busy or not) at time t.



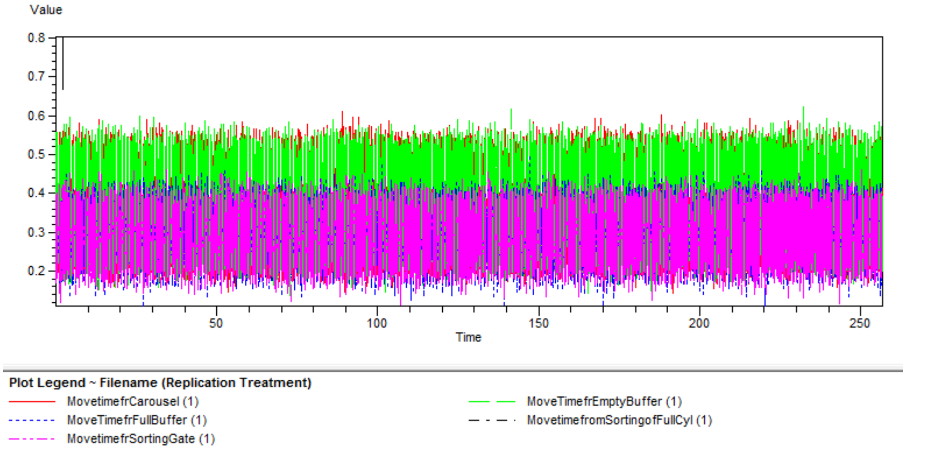
	Utilization			
Scenario	**Machine 1**	**Machine 2**	**Robot 1**	**Robot 2**
12h	51 %	51 %	92 %	83 %
13h	49 %	49 %	88 %	79 %
14h	46 %	46 %	82 %	73 %
15h	43 %	43 %	77 %	69 %

Figure 14: Utilization for Different Daily Operation Time

Time study for completing palletizing is Tally Statistic and collected at the end of the day. The palletizing time depends on the moving time to pick up cylinders to pallets. The moving time is dependent with the cylinders' location inside the Sorting Buffer station. There are two strategies to decide which area for which type of products. Then the palletizing time is presented correspondingly.

Strategy 1: As mentioned in the section building simulation model, the products with high demand is located closer to the carousels. (See Figure 12) The cylinders with the same size are located in the same area. With this solution, the random moving time of the robot from one station to another station is drawn in Figure 15. The average time to move from Carousel to Full Buffer is 0.363 minutes (21.78 seconds); from Full Buffer to Palletizing Gate as 0.294 minutes (17.64 seconds); from Empty Buffer to Carousels as 0.362 minutes (21.72 seconds); from Sorting Gate to Empty Buffer as 0.293 minutes (17.58 seconds); and from Sorting Gate to Full Buffer is 0.729 (43.74 seconds). From Output Analyzer tool in Arena, it is analyzed that the statistic of time to palletize the customers' orders in Figure 16, as approximately 5 hours in average. There is a correlation between the palletizing time and the demand as expected as 0.04, indicating that naturally the higher the demand is, the longer time it takes to palletize.

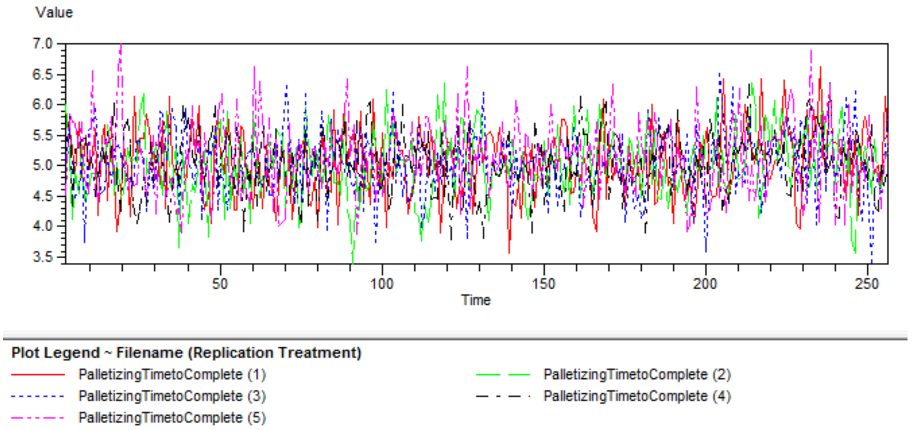
Strategy 2: All types of cylinders of different products are placed randomly inside the Sorting Buffer station. The Robot's moving time for one cycle follow the Normal distribution $N(24, 1)$ regardless of the distance between Carousel to Full Buffer station or from Sorting Gate to Empty Buffer station, and so on. As shown in the Figure 17, the average moving time is 0.381 minute or 23 seconds. Accordingly, the palletizing time is resulted differently from Strategy 1 as one hour longer in average. The average of palletizing time in this case is 6 hours. (See Figure 18)



Classical C.I. Intervals Summary

IDENTIFIER	AVERAGE	STANDARD DEVIATION	0.950 C.I. HALF-WIDTH	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBS.
MovetimefrCarousel	0.363	0.079	0.000348	0.143	0.619	198205
MoveTimefrFullBuffer	0.294	0.0403	0.000178	0.11	0.493	196572
MoveTimefrEmptyBuffer	0.362	0.079	0.000348	0.136	0.623	198205
MovetimefromSortingofFullCyl	0.729	0.0403	0.0215	0.669	0.803	16
MovetimefrSortingGate	0.293	0.0403	0.000178	0.112	0.462	198272

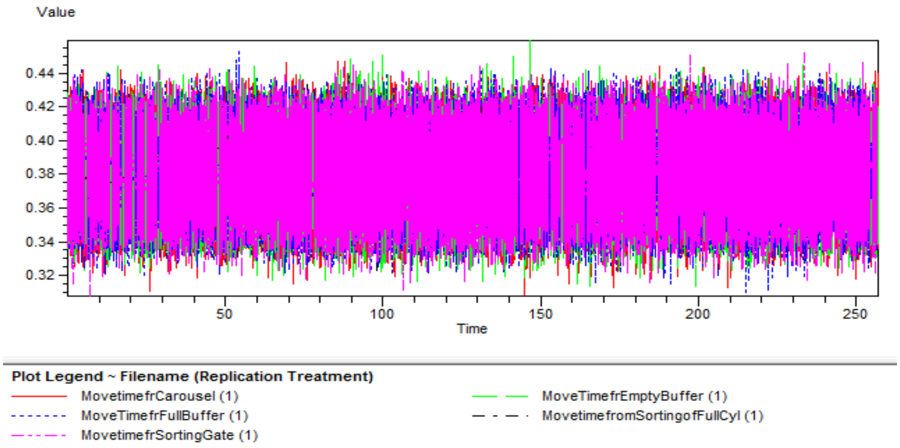
Figure 15: The Statistic of Robot's Moving Time with Strategy 1



Classical C.I. Intervals Summary

IDENTIFIER	AVERAGE	STANDARD DEVIATION	0.950 C.I. HALF-WIDTH	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBS.
PalletizingTimetoComplete	5.06	0.564	0.0695	3.56	6.63	255
PalletizingTimetoComplete	5.03	0.554	0.0683	3.39	6.37	255
PalletizingTimetoComplete	5.04	0.538	0.0664	3.41	6.52	255
PalletizingTimetoComplete	5.05	0.504	0.0622	3.8	6.34	255
PalletizingTimetoComplete	5.15	0.592	0.0731	3.89	7	255

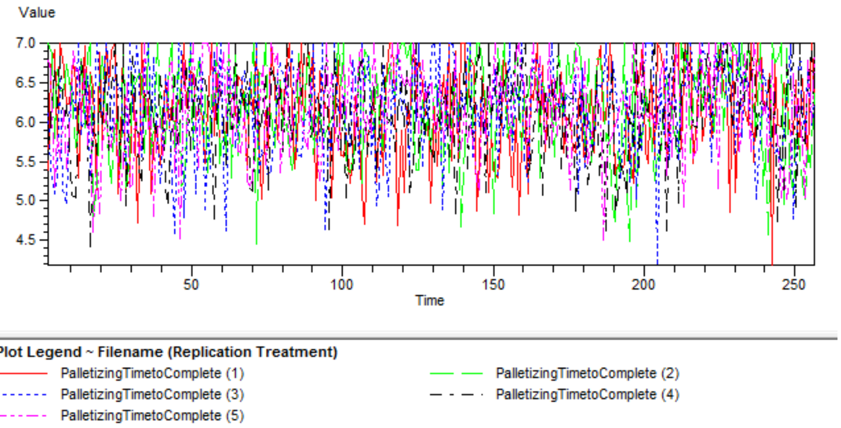
Figure 16: The Statistic of Palletizing Time According to Daily Demand with Strategy 1



Classical C.I. Intervals Summary

IDENTIFIER	AVERAGE	STANDARD DEVIATION	0.950 C.I. HALF-WIDTH	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBS.
MovetimefrCarousel	0.381	0.0159	7e-005	0.308	0.447	197085
MoveTimefrEmptyBuffer	0.381	0.0159	7.01e-005	0.313	0.459	197085
MoveTimefrFullBuffer	0.381	0.0159	7.02e-005	0.31	0.453	196139
MovetimefromSortingofFullCyl	0.381	0.0157	0.00108	0.323	0.433	816
MovetimefrSortingGate	0.381	0.0159	7.02e-005	0.308	0.452	197308

Figure 17: The Statistic of Robot's Moving Time with Strategy 2



Classical C.I. Intervals Summary

IDENTIFIER	AVERAGE	STANDARD DEVIATION	0.950 C.I. HALF-WIDTH	MINIMUM VALUE	MAXIMUM VALUE	NUMBER OF OBS.
PalletizingTimetoComplete	6.13	0.611	0.0754	4.19	7	255
PalletizingTimetoComplete	6.17	0.624	0.077	4.45	7	255
PalletizingTimetoComplete	6.16	0.621	0.0766	4.2	7	255
PalletizingTimetoComplete	6.11	0.595	0.0734	4.42	7	255
PalletizingTimetoComplete	6.15	0.581	0.0717	4.5	7	255

Figure 18: The Statistic of Palletizing Time According to Daily Demand with Strategy 2

The last concern of operating the production is the cost estimation, shown in the Table 16.

Table 16: Relevant Cost for a Year in Different Operation Times

	Relevant Cost for a year			
Scenario	**Lost Sales**	**Holding Cost**	**Operation Cost**	**Extra Working Hours cost**
12h	8582a	261047b	3036c	6072
13h	414a	269589b	3289c	7590
14h	0a	292803b	3542c	9018

The total cost comparison between scenarios depends on the ratio a: b: c (explained in section 5.2.2 g). The goal of company is reaching service level at least 95%, so that the scenarios considered are 13 hour, 14 hour or 15 hour-operation time. If the operation cost per hour is greatly high, the 13hour-operation time would be the choice. But if the lost sale costs are high, then the 14 hour will be a better solution. The case with 14 hour-operation time is likely expensive because the company cannot run up the utilization of resources and the demand is pretty lower than available capacity. That is why the holding cost is greater than the other cases. Moreover, the operation cost is higher and might be unnecessary.

6.2 Bottleneck Analysis

Capacity analysis involves determining the throughput capacity of workstations in a system and ultimately the capacity of the entire system (Heizer & Render, 2011, p. 320). The key to improve the productivity is an ability to point out the bottleneck or the role of constraint. Potential bottlenecks are determined by evaluating a combination of three types of process time: i) ***process time of a robot in one operation*** as the time the robot move a cylinder from one station to a destination; ii) ***process time of a system*** as the time of the longest process in the production line; iii) ***process cycle time*** as the time starting from when a cylinder enters a system and be filled and palletized without waiting. The assembly line of a cylinder is demonstrated in the Figure 19.

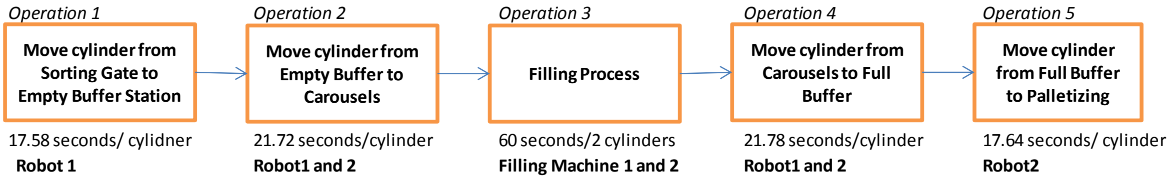


Figure 19: A Flowchart of Time One Cylinder Moving in an Assembly Line

Because Robot 1 or Robot 2 has to do multiple tasks in the system, the time for one operation is dependent on the previous operation. For example, when the filling machines finish filling one cylinder, they request Robot 1 or 2 to load another empty cylinder. However, the filling machines need to wait for the robots completing the current task if they are not in idle state. Consequently, the process time of a system might last longer as the waiting time incurred. For this particular case, separate partial operation cannot be done simultaneously, excluding the operation 3 because the two filling machines only do a single task as filling gas. Therefore, the process time of the assembly line is the longest process time of operation under filling machines, operation under Robot 1, and operation under Robot 2. The process time of the two filing machine operation is 60 seconds per two cylinder, or 30 seconds per cylinder.

Next, the operation time under Robot 1 or 2 is examined into two different times. Before 1pm, Robot 1 only does Operation 1 plus 2 and Robot 2 does Operation 2 plus 4. After 1pm when orders arrive, Robot 1 does Operation 1 plus 2 plus 4 and Robot 2 does only Operation 5 until finish palletizing.

As a result, the system process time before 1pm is about 40 seconds and 60 seconds after 1pm. The longest processing time is Operation under Robots. The moving time of Robots or the speed of Robots becomes the bottleneck in the system. The capacity per hour equals 90 cylinders and 60 cylinders respectively for the morning before 1pm and for the afternoon after 1pm. The expected capacity is 120 cylinders per hour if the machine utilization is 100%. The process cycle time equals $17.58 + 21.72 + 60 + 21.78 + 17.64 \approx 140$ seconds or 2 minutes 20 seconds.

To see clearly how the machine usage is allocated in a day, the frequency statistic is shown below in Figure 20 as a result of a simulation run with 14 hour-operation time. The report of busy state for Robot 1 and 2 before 1pm can reach to the highest utilization rate 80% to 90%. However, there are few days in a year that the machines don’t need to operate before 1pm at all during low seasonal demand. The left bell curve (utilization before 1pm) in the Figure 20 has longer tail, which means the utilization is more varying. It can be referred that the demand is not high enough to reach the maximum capacity of the system. After 1pm, the utilization collected in 254 days is almost constant with 50%.

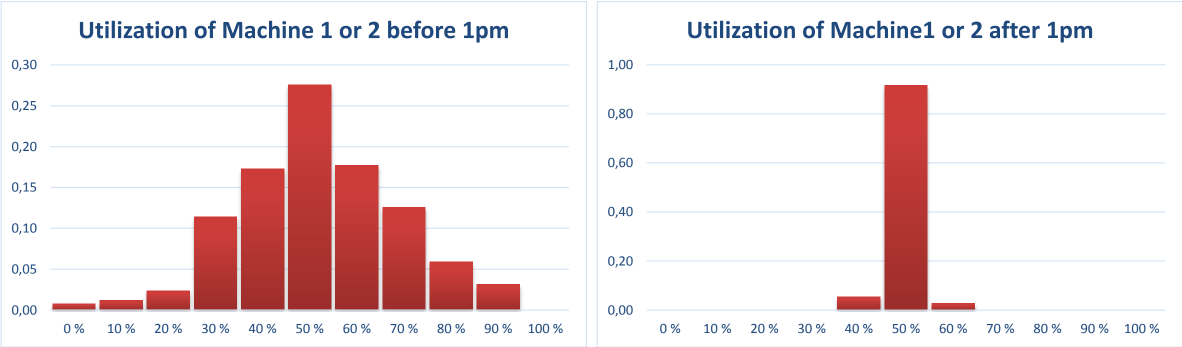


Figure 20: Frequency Statistic of Sate of Machine at Time Before and After 1pm

6.3 Scenarios Results

The bottlenecks are addressed apparently at the robots' speed. With the current demand level, the speed of robot as 63 meters per minute is still good enough to satisfy the demand. However, the utilization of the machines is not pretty low as under 50%. Since the main reason for designing the new system is preparing for the future growing demand, scenario with higher demand level is analyzed to see how the bottleneck would respond to different robot's velocity parameters. The two scenarios consisted of the following:

a) The Robot speed 63 meters/minute and demand increases 10%
b) The Robot speed 80 meters/minute and demand increases 10%

In addition, the alternative operating system is at the ability to program the movement of the gantry robots. With the assumption above, the Robot1 and 2 do not have the interchange of tasks. If the two Robots can move freely and can "share" tasks together, both Robots can palletize at the same time or pick and place the empty cylinders from Sorting Gate to Empty Buffer. How the utilization and process time of a system would be changed is tested in the latter part. Now, the third alternative scenario is:

c) The Robots can "share" tasks together and the speed is remained at 63 m/min. The demand also increases 10%.

6.3.1 Comparison between Scenario (a) and (b) with Different Robots' Speed

Firstly, when the robot can move faster as 80 meters per minute, obviously the capacity of the robot would increase. As a result, the Figure 21 reports that the system process time before 1 pm is 31 seconds and capacity per hour is 116 cylinders. After 1pm, the system process time is 48.2 seconds and capacity per hour is 75 cylinders. The capacity increases 20 percent in comparison with the base case.

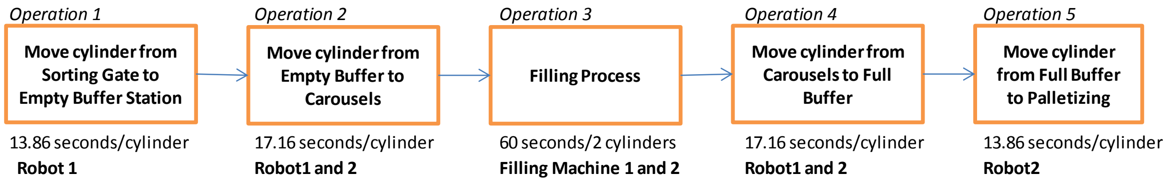


Figure 21:A Flowchart of Time One Cylinder Moving in an Assembly Line with Robot Speed 80m/min

By setting up three different daily operation times, the obtained results of Service Level and Fill Rate are as follows:

Table 17: Service Level and Utilization when Demand Increase 10% and Robot's speed remains at 63m/min

Scenario	Service Level	Fill Rate
12h	16 %	89 %
13h	72 %	98 %
14h	99 %	100 %
15h	100 %	100 %

	Utilization			
Scenario	Machine 1	Machine 2	Robot 1	Robot 2
12h	53 %	53 %	95 %	86 %
13h	53 %	53 %	95 %	87 %
14h	50 %	50 %	91 %	80 %
15h	48 %	48 %	87 %	75 %

Comparing to the base case with current demand level, it is clearly to see that the bottle neck is at the robot speed. With 13-hour-operation time from 6am to 7pm, there are only 6 hours to palletize. The speed of the Robot 2 is not capable to ensure delivery on time. Hence, the service level is only at 72%. With the current demand level and 13 hour operation, service level is 96%.

In the scenario2, by set up the Speed of Robot to 80 meters per minute, the system can shorten the palletizing time. Consequently, service level is ensured 100% even the operation time is 13 hours. (Table 18)

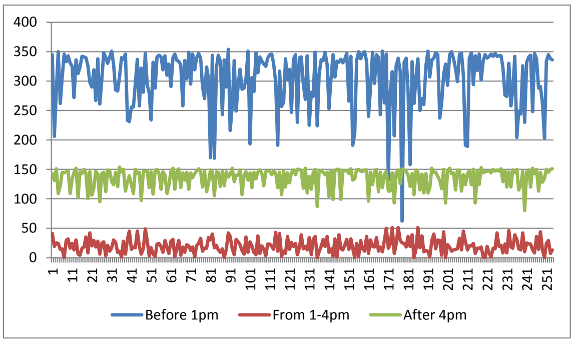
Table 18: Service Level and Utilization with Demand Increase 10% and Robot speed 80m/min

Scenario	Service Level	Fill Rate
12h	73 %	99 %
13h	100 %	100 %

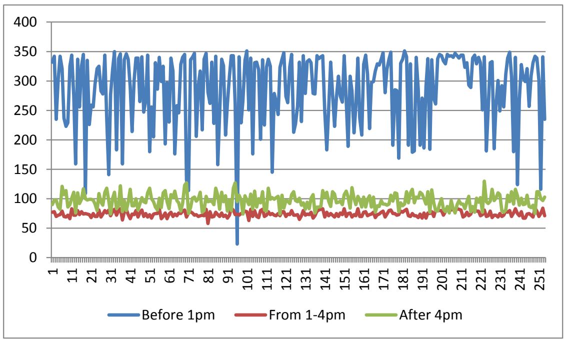
	Utilization			
Scenario	Machine 1	Machine 2	Robot 1	Robot 2
12h	58 %	58 %	87 %	79 %
13h	54 %	54 %	81 %	74 %

6.3.2 The Result of Scenario (c) when Two Robots Freely Interchange Tasks

In this case, the observations of how many cylinders can be filled in three different periods of time (before 1pm, from 1 to 4pm and from 4 to 7 pm) are collected to help us point out the difference between the base case and scenario c). The operation time set up is 14 hours and demand increases 20%. Consequently, the palletizing time will be diminished as half of the reported time above as 2 to 3 hours. Clearly shown in Figure 22 a), the machines have more idle state in the period of time 1-4pm. In Figure 22 b), the machines capacity was spreading out after 1pm and the utilization was low evenly. When observing the utilization of two cases, there is a just slightly difference in Robots utilization but the machines' utilization is undifferentiated. Hence, the robots' routing does not impact on the utilization. Nevertheless, the production manager is able to consider another alternative to reschedule the production time. In a real production system, there is a certain period of time the machines are shut down. With this information, the manager can think of whether the shut down time for filling machines should be allocated at the same time when two robots are palletizing or not.



a)Two robots freely share tasks together



b)Two robots do not share tasks

Figure 22: Number of Cylinders a Machine Fill in Different Periods of Time

6.4 Using OptQuest for defining an optimal level of base stock

As described in section 3.2, OptQuest uses metaheuristics to determine the best solution to the user's objectives. Base on the discussion above, the main bottleneck is at Robot speed. However, if the robot speed cannot be adjusted, another alternative solution is building up the storage level. The stock will be prepared in advance. Currently, the company has the stock for three days. In the new system, the stock might be diminished owing to higher capacity.

Optquest is set up to determine the optimal combination of the target stock of each product group in order to minimize the holding cost and ensure the service level is 99%. Since the operation time is not varying and all the demands must be satisfied, the extra cost for hours of operation time after 2 pm is not included in the objective function.

The objective function is minimizing:

$$TC = \sum_{i=1}^{8} c_h \times I_i = \sum_{i=1}^{8} c_h \times (Target\ Base\ Stock_i - Demand_i) \tag{16}$$

Where $c_h$is holding cost per cylinder of one day andI_i is inventory of product group i left after fulfilling demand.

The constraint setting must also be set up from the users. There are two types of constraints: control variable constraint as Target Base Stock, and overall process constraint as Service level in this case.

The constraint of Buffer station space

$$\sum_{i=1}^{8} Target\ Base\ Stock_i < 2628\ (cylinders) \tag{17}$$

The constraint for Service level

$$\alpha = 1 - \frac{Number\ of\ days\ has\ lost\ sales}{Total\ number\ of\ sales\ days} \geq 99\% \tag{18}$$

Once the control variables are established, their range must be determined. The settings selected are the target base stock of each product group with maximum as the calculated base stock in the Chapter 4. The minimum is set to half of the maximum.

Table 19: OptQuest Control Variable Settings

Control Variable	Minimum (Cylinders)	Maximum (Cylinders)
Target Base Stock F121	450	906
Target Base Stock F122	60	125
Target Base Stock F123	15	30
Target Base Stock F124	110	219
Target Base Stock F161	280	560
Target Base Stock F162	55	110
Target Base Stock F163	70	140
Target Base Stock F164	30	125

As requested, OptQuest evaluated 1000 scenarios of a 23-day replication and 14-hour operation time, finding the best one among them as the 819th scenario it considered. The best level of target base stock for each group of cylinder in one month (23 days) is presented in the Table 20. The best total holding cost in one month is 10245b. The holding cost in one month in the base case is reported in Table 16 with 14 hour-operation-time is $\frac{292803b}{12} = 24400b$ in average, which is greater than two times of OptQuest output. The final optimization window for OptQuest is shown in Figure 23.

Table 20: Output from the OptQuest scenario

Control Variable	Base Case	Optquest
Target Base Stock F121	906	456
Target Base Stock F122	125	62
Target Base Stock F123	30	16
Target Base Stock F124	219	110
Target Base Stock F161	560	281
Target Base Stock F162	110	69
Target Base Stock F163	140	70
Target Base Stock F164	125	30

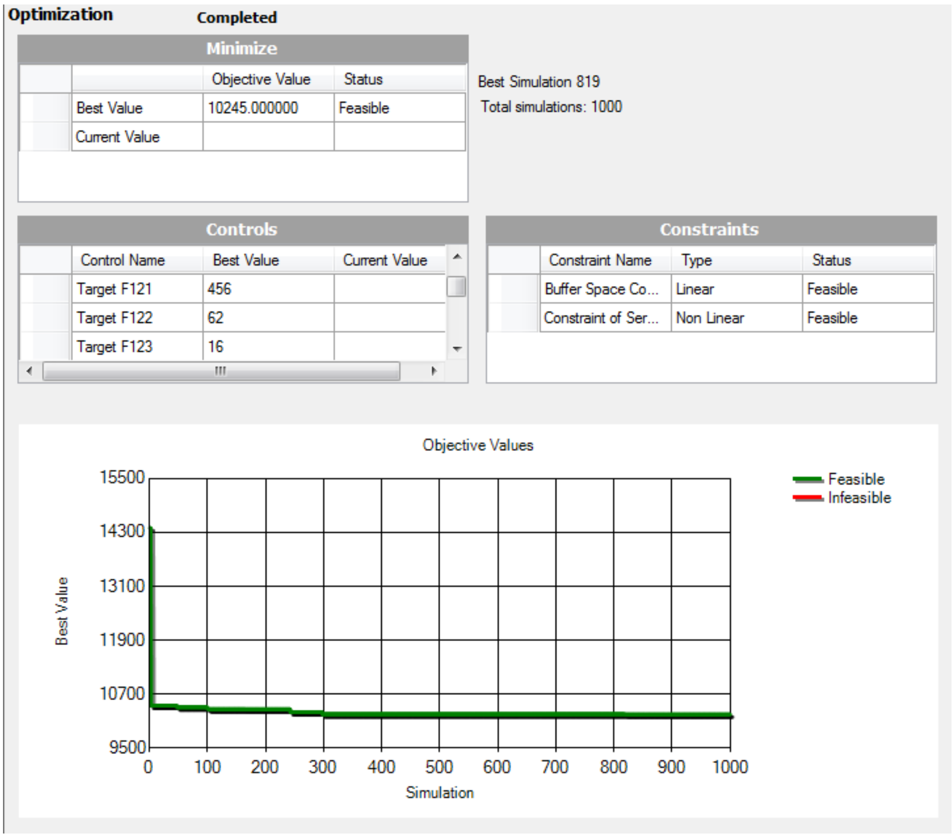


Figure 23: Final Optimization Windowfor Optquest

7 Conclusions

The thesis demonstrated the modeling simulation Arena tool and methods to address uncertain factors associated with the design and implementation of flexible manufacturing systems. The simulation model is an effective tool to evaluate the manufacturing system in short and long term period. The contribution of the simulation methodology in the modernized production becomes significant when the technology has strongly developed and the automated systems or FMSs have become more popular. Simulation was able to deal with the complex system by testing routing and control strategies. The use of animation of simulation software helped to convey the results of model to the production management. Generally, simulation becomes a powerful tool to process and evaluate performance of business operation and identify the constraints in operation. Especially, these can be done even when the system is not existed yet. By imitating all the possibilities that can happen, the statistics of customized metrics are collected and analyzed. Then, the lead time, utilization, buffer size and location are optimized. In the literature review, there have been a fair amount of research about the simulation application in the FMSs. Simulation can be used in different industries as hospital health care, transportation system, production system, or in military services. The need of simulation arises when there are questions of how the system will work for non-existing system or how the system is working with existing system in order to find out the bottlenecks. The advantage of simulation is giving the system designer the understanding overview and possibilities exploration for improvement. When the problems in the design production line are diagnosed beforehand, the production manager can specify the requirements to change and invest wisely. On the negative side of simulation, it is not easy and can take a lot of time to verify and validate the system, especially with non-existing system. Sometimes, the verification is relied on the modeler’s judgment itself. Secondly, I found difficulties in interpreting the output of the simulation run and determine how the result is shown reasonably. Even it is worse when the simulation may be used inappropriately in some cases. Therefore, the modeler needs investigate thoroughly about the system before modeling.

The applicability of the simulation modeling, in this thesis, was employed to evaluate a new designed FMS in cylinder gas production based on the case company. The objective was to provide the company the analysis of the FMS with information of the system utilization and productivity improvement. The results of the simulation model were presented to the managers from the case study's company. The model was considered to be valid by conducting a simulation model with the management team and they were satisfied with the simulation. The simulation's outcome contributed good quantitative results, which helped the company figure out the bottlenecks of the designed system and reconsider better solutions in resources' capacity, logical sequences of workstation and the space in the Sorting Buffer area and Storages.

The contribution for the practical case was the performance measures of system productivity, resource utilization, and service level reported for different scenarios of operation time. Further, how flexibility the system performed and then the bottlenecks, throughput and capacities were analyzed. The output results showed that the system with two filling machines has really high capacity comparing to the current demand of production. In the existing system, the process time to fill one cylinder is swinging because of the technique issue where the time to fill a pressurized gas cylinder depends on the ambient temperature. Obviously, this is the bottleneck of the system at the current time. Now, the company wants to update the filling system as the filling time is shortened to 1 minute so that the bottleneck would be removed. Even so, on the terms of flexibility, there should be a flexible cooperation among the resources, Filling machines and Robots. In the same manner, not only the filling machines are upgraded, but also the handling equipment should be compatible with the upgrade. Otherwise, the bottleneck would exist and aggregate to another station. Eventually, increasing the capacity of filling machines has no influence on the system's overall capacity. From all the aspects, this implies the non-bottleneck station has more idle time and the utilization is just so low. In my opinion, increasing capacity utilization, where the system is able to increase the throughput in a unit of time, is important because it will increase and assure the targeted service level of the company. Further, the utilization of the machine is also critical. The higher the utilization is, the more efficiently machine is used, along with, the return on investment is quicker.

Numerically, the optimized operation time was 14 hours per day instead of 16 hours as currently. The utilization of the two filling machines was only about 50% of the designed capacity. The solution to increase the utilization of filling machine is cutting off one machine so there would be only one machine in the system. However, the system is built with one machine is not recommended though because there is possibility that machine is broken down. Alternatively, with extra capacity, the product manager can increase the utilization by considering other products which are able to be processed under this system.

As reported, the *process cycle time* as the time starting from when a cylinder enters a system and be filled and palletized without waiting, was 2 minutes and 20seconds. The limiting factor is at the robots' speed 63m/minute as in a designed model. If the demand increases, the machine capacity is sufficient to provide the required quantity but the robots cannot operate to increase the overall capacity. Furthermore, the company wants to reduce the working hours and extra labor cost for evening shift. The consideration of Robot's velocity is one of the key to make the production line run more smoothly. Speeding up the robot's velocity will shorten the time to pick order or palletize. As well as, the robots are capable to load cylinders into/off from carousels quickly to make sure that the machine can be continuously active and reduce the unnecessary idle time.

Concerning the Buffer stock level, the limit is 2628 cylinders, which is perfectly adequate for the current demand. The optimized level of buffer stock was suggested through OptQuest Analysis as equal as only half of the limit space. However, the stock level would be increased and the storage might be necessary if the manager plans to have the other lines of products operated under this system, in order to improve the utilization of the filling machines. The holding cost of the storage is considered small withal.

Together, these contributions lay the groundwork for applying the simulation tool in exploring the behavior of a complex system and reduce the risk of ineffectiveness of the designed operation.

8 Limitation and Further Research Opportunities

Overall, there were several limitations to the model. The model was not capable to give the best optimization for the system operation. Instead, it gave the whole picture of how system was going to operate under different circumstances. From there, the manager is able to understand the process better and avoid the potential bottleneck when building the system.

This study is the first attempt to test the system at the beginning stage. The research on this project can be deeply investigated further. For instance, the machine failure rates and different processing times can be added into the simulation to determine how it will affect the production flow and what the backup plan is for that situation. The optimized stock level might be changed accordingly. Another study is to add the relevant production costs and shortage cost to the optimized model in order to find out a more practical target level of stocks. Furthermore, the design for the storage system can be simulated in the Arena simulation too. That would be another story of inventory management. On the other hand, a flowing sequence of cylinders was assumed as following the rule First-In-First-Out (FIFO). However, in the practical case, the robots sometimes can pick up a cylinder straight from the filling machines to a pallet in order to reduce palletizing time. Owing to the long expiry time feature of a product, it is not really essential to comply with the rule FIFO although it would be preferred as usual. The further research could also account for learning in setups and different rules of inventory.

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Appendix A: Data Input

Table A1: Monthly Demand Data

		Demand Volume Forecast in Month														
Product No.	Material	1	2	3	4	5	6	7	8	9	10	11	12	Grand Total	% of Total Sales	Average
1	420950	1541	1476	1432	1535	1751	1435	1054	1370	1546	1584	1403	953	17078	7.5 %	1,423
2	D20050	1286	1160	1163	1240	1289	991	899	1105	1315	1268	1244	968	13930	6.1 %	1,161
3	D20150	1181	1176	1212	1320	1219	1074	889	1104	1168	1286	1284	902	13816	6.1 %	1,151
4	A20050	882	1008	868	972	1094	1070	931	1234	1217	1390	1193	896	12755	5.6 %	1,063
5	A20020	928	810	1116	902	1136	968	883	1049	1157	1220	1270	730	12169	5.3 %	1,014
6	B20850	1074	1084	1166	1015	1032	956	594	929	1126	1168	989	732	11864	5.2 %	989
7	420920	1003	972	1002	906	1079	852	859	1004	1208	1170	991	770	11818	5.2 %	985
8	J20020	727	872	846	829	964	928	785	667	833	906	725	580	9661	4.2 %	805
9	D20120	870	779	871	791	791	656	646	610	766	841	728	691	9040	4.0 %	753
10	D20020	706	590	786	748	744	544	643	595	726	700	709	580	8070	3.5 %	673
11	J20050	746	600	742	667	733	695	479	683	691	749	697	504	7986	3.5 %	666
12	420940	679	697	769	806	688	536	564	517	736	728	569	558	7848	3.4 %	654
13	420050	622	593	594	684	701	642	499	695	689	685	584	563	7550	3.3 %	629
14	220050	533	613	671	500	667	622	458	656	612	756	554	515	7158	3.1 %	597
15	P20240	53	167	1255	1564	184	118	132	107	192	263	60	973	5066	2.2 %	422
16	P20220	59	113	756	1007	432	486	181	294	570	341	145	482	4866	2.1 %	406
17	U08923	265	364	498	299	382	324	344	202	482	372	316	395	4242	1.9 %	354
18	D20005	287	256	341	304	329	310	395	346	403	359	298	251	3876	1.7 %	323
19	420905	352	337	299	269	275	299	300	341	368	386	329	247	3802	1.7 %	317
20	220020	292	282	326	278	359	397	286	342	300	337	302	276	3778	1.7 %	315
21	2093A7	277	292	348	312	317	326	250	284	316	360	251	248	3581	1.6 %	298
22	C20450	302	246	283	253	266	239	166	222	247	216	270	326	3037	1.3 %	253
23	2007A7	235	197	258	218	240	265	217	214	282	276	199	186	2788	1.2 %	232
24	P60050	204	221	245	229	236	234	204	236	228	308	199	203	2748	1.2 %	229
25	420820	226	210	218	203	282	152	175	245	205	325	187	236	2665	1.2 %	222
26	B20250	202	181	193	179	215	242	167	193	296	246	252	230	2597	1.1 %	216
27	B20450	204	204	259	251	186	209	187	194	212	223	203	179	2512	1.1 %	209
28	2057A7	205	220	154	169	191	188	180	178	167	223	155	192	2221	1.0 %	185
29	220810	115	168	282	150	149	227	192	181	136	168	178	241	2186	1.0 %	182
30	220010	130	79	124	133	156	162	168	168	133	185	132	149	1718	0.8 %	143
31	260050	133	131	188	143	137	116	116	121	150	181	132	137	1686	0.7 %	141
32	D20650	108	118	179	108	128	110	95	127	131	158	167	78	1507	0.7 %	126
33	C20550	172	162	130	89	178	118	78	109	138	119	110	72	1474	0.6 %	123
34	420020	76	109	80	114	245	110	96	124	125	115	110	88	1392	0.6 %	116
35	420850	53	100	157	70	101	132	96	113	130	138	110	70	1268	0.6 %	106
36	P20305	149	95	48	174	121	137	44	143	114	136	31	31	1223	0.5 %	102
37	420450	72	84	76	88	103	85	103	67	119	98	84	91	1070	0.5 %	89
38	D20040	108	130	108	113	110	84	78	91	106	56	34	26	1044	0.5 %	87
39	U08924	103	95	79	83	98	49	102	70	89	109	77	86	1040	0.5 %	87
40	420910	70	80	84	66	90	56	83	61	127	104	88	108	1018	0.4 %	85
41	B20420	154	137	90	65	74	31	72	56	55	73	44	48	900	0.4 %	75
42	220650	64	67	50	72	73	74	67	60	70	79	68	60	805	0.4 %	67
43	320050	56	37	37	86	68	95	79	56	60	68	70	68	782	0.3 %	65
44	C20350	66	62	95	61	95	72	40	48	38	60	58	22	716	0.3 %	60
45	A20450	36	40	56	19	55	95	88	78	70	84	40	55	715	0.3 %	60
46	U08922	68	42	54	77	62	38	60	38	59	66	70	62	697	0.3 %	58
47	J20010	37	40	67	47	55	44	50	48	35	43	59	47	572	0.3 %	48
48	A20820	12	12	26	41	41	41	41	112	25	77	44	61	533	0.2 %	44
49	A20420	362	112	0	0	40	0	0	0	0	0	8	0	522	0.2 %	44
50	220850	48	41	32	48	41	30	46	35	47	48	44	38	498	0.2 %	42
51	220005	29	38	32	29	48	38	42	44	47	48	36	29	461	0.2 %	38
52	220750	35	29	36	38	28	47	29	50	35	30	32	41	430	0.2 %	36
53	B20350	14	19	34	35	30	30	22	43	40	79	42	40	427	0.2 %	36
54	B20220	29	49	35	10	26	20	26	22	30	44	28	23	342	0.2 %	29
55	A50050	23	22	28	25	23	28	32	31	28	37	29	34	338	0.1 %	28
56	A20040	23	28	35	22	16	17	24	30	35	29	47	30	334	0.1 %	28
57	D20620	26	26	25	10	42	13	23	37	25	6	61	26	322	0.1 %	27
58	C20050	41	54	26	19	29	13	25	22	20	20	19	14	304	0.1 %	25
59	D20010	20	23	19	28	17	23	25	22	37	26	19	44	304	0.1 %	25
60	A20005	18	20	25	43	19	40	26	5	35	25	18	20	295	0.1 %	25
61	420650	30	19	11	42	42	13	12	25	28	12	13	13	260	0.1 %	22
62	B20820	16	19	24	18	19	18	20	7	42	19	14	19	236	0.1 %	20
63	320020	12	11	14	14	14	12	12	16	14	64	11	31	226	0.1 %	19
64	420750	14	23	11	22	13	11	11	19	11	20	16	13	184	0.1 %	15
65	2093A5	12	14	16	14	18	11	11	8	7	22	20	20	174	0.1 %	15
66	2007A5	2	10	8	19	11	10	22	5	19	16	11	19	151	0.1 %	13
67	420620	4	6	11	10	6	11	4	13	25	17	8	14	128	0.1 %	11
68	210767	17	12	16	16	4	7	0	5	11	12	0	14	113	0.0 %	9
69	2007A4	1	11	0	14	4	7	22	2	8	11	17	12	109	0.0 %	9
70	2093A4	6	6	14	4	12	18	2	4	7	13	4	12	102	0.0 %	9
71	E20750	0	1	1	4	2	5	53	17	7	8	2	0	101	0.0 %	8
72	2057A6	12	13	5	4	24	2	0	5	11	4	14	5	98	0.0 %	8
73	IG0250	0	14	0	14	0	0	0	12	17	4	0	19	80	0.0 %	7
74	IG1050	7	0	0	6	6	0	1	0	1	42	4	13	80	0.0 %	7
75	2057A4	2	1	2	8	6	4	8	5	0	11	4	7	59	0.0 %	5
76	420610	0	1	0	5	10	5	0	6	12	12	2	2	55	0.0 %	5
77	2007A3	2	4	0	0	5	0	2	2	4	0	5	2	26	0.0 %	2
78	2093A6	6	1	6	0	2	1	0	0	0	1	0	0	18	0.0 %	2
79	C20250	0	1	2	2	4	0	0	1	4	1	0	2	18	0.0 %	2
80	R20010	4	2	0	6	0	0	0	0	0	2	0	0	14	0.0 %	1
81	IG0050	0	0	0	0	0	0	1	0	2	1	1	4	10	0.0 %	1
82	2093A3	0	0	0	0	0	0	1	0	0	7	0	0	8	0.0 %	1
	Grand Total	**18536**	**18137**	**21151**	**20776**	**20480**	**18071**	**15618**	**17981**	**20574**	**21499**	**18342**	**16532**	**227698**	**100%**	

Table A2: SKUs Classification

Product No	Material	1	2	3	4	5	6	7	8	9	10	11	12	Total	% Total Yearly Demand	Average	Stdeve	CV	XYZ	ABC	Group
1	420950	1284	1230	1193	1279	1459	1196	878	1142	1288	1320	1169	794	14232	7.5 %	1186	177	15%	X	A	1
2	D20050	1072	967	969	1033	1074	826	749	921	1096	1057	1037	807	11608	6.1 %	967	112	12%	X	A	1
3	D20150	984	980	1010	1100	1016	895	741	920	973	1072	1070	752	11513	6.1 %	959	111	12%	X	A	1
4	A20050	735	840	723	810	912	892	776	1028	1014	1158	994	747	10629	5.6 %	886	133	15%	X	A	1
5	A20020	773	675	930	752	947	807	736	874	964	1017	1058	608	10141	5.3 %	845	135	16%	X	A	1
6	B20850	895	903	972	846	860	797	495	774	938	973	824	610	9887	5.2 %	824	138	17%	X	A	1
7	420920	836	810	835	755	899	710	716	837	1007	975	826	642	9848	5.2 %	821	102	12%	X	A	1
8	J20020	606	727	705	691	803	773	654	556	694	755	604	483	8051	4.2 %	671	90	13%	X	A	1
9	D20120	725	649	726	659	659	547	538	508	638	701	607	576	7533	4.0 %	628	70	11%	X	A	1
10	D20020	588	492	655	623	620	453	536	496	605	583	591	483	6725	3.5 %	560	63	11%	X	A	1
11	J20050	622	500	618	556	611	579	399	569	576	624	581	420	6655	3.5 %	555	73	13%	X	A	1
12	420940	566	581	641	672	573	447	470	431	613	607	474	465	6540	3.4 %	545	80	15%	X	A	1
13	420050	518	494	495	570	584	535	416	579	574	571	487	469	6292	3.3 %	524	51	10%	X	A	1
14	220050	444	511	559	417	556	518	382	547	510	630	462	429	5965	3.1 %	497	69	14%	X	A	1
15	P20240	44	139	1046	1303	153	98	110	89	160	219	50	811	4222	2.2 %	352	420	119%	Z	A	4
16	P20220	49	94	630	839	360	405	151	245	475	284	121	402	4055	2.1 %	338	224	66%	Z	A	4
17	U08923	221	303	415	249	318	270	287	168	402	310	263	329	3535	1.9 %	295	67	23%	X	A	1
18	D20005	239	213	284	253	274	258	329	288	336	299	248	209	3230	1.7 %	269	39	14%	X	A	1
19	420905	293	281	249	224	229	249	250	284	307	322	274	206	3168	1.7 %	264	34	13%	X	A	1
20	220020	243	235	272	232	299	331	238	285	250	281	252	230	3148	1.7 %	262	30	12%	X	A	1
21	2093A7	231	243	290	260	264	272	208	237	263	300	209	207	2984	1.6 %	249	30	12%	X	A	1
22	C20450	252	205	236	211	222	199	138	185	206	180	225	272	2531	1.3 %	211	34	16%	X	A	1
23	2007A7	196	164	215	182	200	221	181	178	235	230	166	155	2323	1.2 %	194	26	13%	X	A	1
24	P60050	170	184	204	191	197	195	170	197	190	257	166	169	2290	1.2 %	191	24	12%	X	A	1
25	420820	188	175	182	169	235	127	146	204	171	271	156	197	2221	1.2 %	185	37	20%	X	A	1
26	B20250	168	151	161	149	179	202	139	161	247	205	210	192	2164	1.1 %	180	30	17%	X	A	1
27	B20450	170	170	216	209	155	174	156	162	177	186	169	149	2093	1.1 %	174	20	11%	X	A	1
28	2057A7	171	183	128	141	159	157	150	148	139	186	129	160	1851	1.0 %	154	18	12%	X	A	1
29	220810	96	140	235	125	124	189	160	151	113	140	148	201	1822	1.0 %	152	38	25%	Y	A	1
30	220010	108	66	103	111	130	135	140	140	111	154	110	124	1432	0.8 %	119	22	19%	X	B	2
31	260050	111	109	157	119	114	97	97	101	125	151	110	114	1405	0.7 %	117	18	16%	X	B	2
32	D20650	90	98	149	90	107	92	79	106	109	132	139	65	1256	0.7 %	105	24	23%	X	B	2
33	C20550	143	135	108	74	148	98	65	91	115	99	92	60	1228	0.6 %	102	28	27%	Y	B	2
34	420020	63	91	67	95	204	92	80	103	104	96	92	73	1160	0.6 %	97	35	36%	Y	B	2
35	420850	44	83	131	58	84	110	80	94	108	115	92	58	1057	0.6 %	88	25	28%	Y	B	2
36	P20305	124	79	40	145	101	114	37	119	95	113	26	26	1019	0.5 %	85	40	48%	Y	B	2
37	420450	60	70	63	73	86	71	86	56	99	82	70	76	892	0.5 %	74	12	16%	X	B	2
38	D20040	90	108	90	94	92	70	65	76	88	47	28	22	870	0.5 %	73	26	36%	Y	B	2
39	U08924	86	79	66	69	82	41	85	58	74	91	64	72	867	0.5 %	72	13	19%	X	B	2
40	420910	58	67	70	55	75	47	69	51	106	87	73	90	848	0.4 %	71	17	23%	X	B	2
41	B20420	128	114	75	54	62	26	60	47	46	61	37	40	750	0.4 %	63	29	47%	Y	B	2
42	220650	53	56	42	60	61	62	56	50	58	66	57	50	671	0.4 %	56	6	11%	X	B	2
43	320050	47	31	31	72	57	79	66	47	50	57	58	57	652	0.3 %	54	14	26%	Y	B	2
44	C20350	55	52	79	51	79	60	33	40	32	50	48	18	597	0.3 %	50	17	35%	Y	B	2
45	A20450	30	33	47	16	46	79	73	65	58	70	33	46	596	0.3 %	50	19	38%	Y	B	2
46	U08922	57	35	45	64	52	32	50	32	49	55	58	52	581	0.3 %	48	10	21%	X	B	2
47	J20010	31	33	56	39	46	37	42	40	29	36	49	39	477	0.3 %	40	7	19%	X	C	3
48	A20820	10	10	22	34	34	34	34	93	21	64	37	51	444	0.2 %	37	22	61%	Z	C	3
49	A20420	302	93			33						7		435	0.2 %	109	116	107%	Z	B	3
50	220850	40	34	27	40	34	25	38	29	39	40	37	32	415	0.2 %	35	5	15%	X	C	3
51	220005	24	32	27	24	40	32	35	37	39	40	30	24	384	0.2 %	32	6	19%	X	C	3
52	220750	29	24	30	32	23	39	24	42	29	25	27	34	358	0.2 %	30	6	19%	X	C	3
53	B20350	12	16	28	29	25	25	18	36	33	66	35	33	356	0.2 %	30	13	45%	Y	C	3
54	B20220	24	41	29	8	22	17	22	18	25	37	23	19	285	0.2 %	24	8	36%	Y	C	3
55	A50050	19	18	23	21	19	23	27	26	23	31	24	28	282	0.1 %	24	4	16%	X	C	3
56	A20040	19	23	29	18	13	14	20	25	29	24	39	25	278	0.1 %	23	7	30%	Y	C	3
57	D20620	22	22	21	8	35	11	19	31	21	5	51	22	268	0.1 %	22	12	53%	Y	C	3
58	D20010	17	19	16	23	14	19	21	18	31	22	16	37	253	0.1 %	21	6	30%	Y	C	3
59	C20050	34	45	22	16	24	11	21	18	17	17	16	12	253	0.1 %	21	9	44%	Y	C	3
60	A20005	15	17	21	36	16	33	22	4	29	21	15	17	246	0.1 %	21	8	41%	Y	C	3
61	420650	25	16	9	35	35	11	10	21	23	10	11	11	217	0.1 %	18	9	51%	Y	C	3
62	B20820	13	16	20	15	16	15	17	6	35	16	12	16	197	0.1 %	16	6	39%	Y	C	3
63	320020	10	9	12	12	12	10	10	13	12	53	9	26	188	0.1 %	16	12	77%	Z	C	3
64	420750	12	19	9	18	11	9	9	16	9	17	13	11	153	0.1 %	13	4	28%	Y	C	3
65	2093A5	10	12	13	12	15	9	9	7	6	18	17	17	145	0.1 %	12	4	32%	Y	C	3
66	2007A5	2	8	7	16	9	8	18	4	16	13	9	16	126	0.1 %	11	5	47%	Y	C	3
67	420620	3	5	9	8	5	9	3	11	21	14	7	12	107	0.1 %	9	5	55%	Y	C	3
68	210767	14	10	13	13	3	6		4	9	10		12	94	0.0 %	9	4	39%	Y	C	3
69	2007A4	1	9		12	3	6	18	2	7	9	14	10	91	0.0 %	8	5	60%	Z	C	3
70	2093A4	5	5	12	3	10	15	2	3	6	11	3	10	85	0.0 %	7	4	58%	Y	C	3
71	E20750		1	1	3	2	4	44	14	6	7	2		84	0.0 %	8	12	148%	Z	C	3
72	2057A6	10	11	4	3	20	2		4	9	3	12	4	82	0.0 %	7	5	71%	Z	C	3
73	IG0250		12		12				10	14	3		16	67	0.0 %	11	4	37%	Y	C	3
74	IG1050	6			5	5		1		1	35	3	11	67	0.0 %	8	10	125%	Z	C	3
75	2057A4	2	1	2	7	5	3	7	4		9	3	6	49	0.0 %	4	2	54%	Y	C	3
76	420610		1		4	8	4		5	10	10	2	2	46	0.0 %	5	3	64%	Z	C	3
77	2007A3	2	3			4		2	2	3		4	2	22	0.0 %	3	1	30%	Y	C	3
78	C20250		1	2	2	3			1	3	1		2	15	0.0 %	2	1	42%	Y	C	3
79	2093A6	5	1	5		2	1				1			15	0.0 %	3	2	72%	Z	C	3
80	R20010	3	2		5						2			12	0.0 %	3	1	41%	Y	C	3
81	IG0050							1		2	1	1	3	8	0.0 %	2	1	50%	Y	C	3
82	2093A3							1			6			7	0.0 %	4	3	71%	Z	C	3
Grand Total		**15447**	**15114**	**17626**	**17313**	**17067**	**15059**	**13015**	**14984**	**17145**	**17916**	**15285**	**13777**	**189748**	**100%**	**15908**					

Table A3: Daily Demand Parameters for Different Group of Products in each Month

Daily Demand

Daily Demand / Type	121	122	123	124
Jan	ANINT(ABS(NORM(376,65)))	ANINT(ABS(NORM(43,10)))	ANINT(ABS(NORM(19.1,4)))	ANINT(ABS(UNIF(2,10)))
Feb	ANINT(ABS(NORM(376,65)))	ANINT(ABS(NORM(43,10)))	ANINT(ABS(NORM(19.1,4)))	ANINT(ABS(UNIF(2,10)))
Mar	ANINT(ABS(NORM(376,65)))	ANINT(ABS(NORM(43,10)))	ANINT(ABS(NORM(19.1,4)))	ANINT(ABS(UNIF(35,57)))
Apr	ANINT(ABS(NORM(376,65)))	ANINT(ABS(NORM(43,10)))	ANINT(ABS(NORM(19.1,4)))	ANINT(ABS(UNIF(35,57)))
May	ANINT(ABS(NORM(376,65)))	ANINT(ABS(NORM(43,10)))	ANINT(ABS(NORM(19.1,4)))	ANINT(ABS(UNIF(2,10)))
Jun	ANINT(ABS(NORM(376,65)))	ANINT(ABS(NORM(43,10)))	ANINT(ABS(NORM(19.1,4)))	ANINT(ABS(UNIF(2,10)))
Jul	ANINT(ABS(NORM(376,65)))	ANINT(ABS(NORM(43,10)))	ANINT(ABS(NORM(19.1,4)))	ANINT(ABS(UNIF(2,10)))
Aug	ANINT(ABS(NORM(376,65)))	ANINT(ABS(NORM(43,10)))	ANINT(ABS(NORM(19.1,4)))	ANINT(ABS(UNIF(2,10)))
Sept	ANINT(ABS(NORM(376,65)))	ANINT(ABS(NORM(43,10)))	ANINT(ABS(NORM(19.1,4)))	ANINT(ABS(UNIF(2,10)))
Oct	ANINT(ABS(NORM(376,65)))	ANINT(ABS(NORM(43,10)))	ANINT(ABS(NORM(19.1,4)))	ANINT(ABS(UNIF(2,10)))
Nov	ANINT(ABS(NORM(376,65)))	ANINT(ABS(NORM(43,10)))	ANINT(ABS(NORM(19.1,4)))	ANINT(ABS(UNIF(2,10)))
Dec	ANINT(ABS(NORM(376,65)))	ANINT(ABS(NORM(43,10)))	ANINT(ABS(NORM(19.1,4)))	ANINT(ABS(UNIF(35,57)))

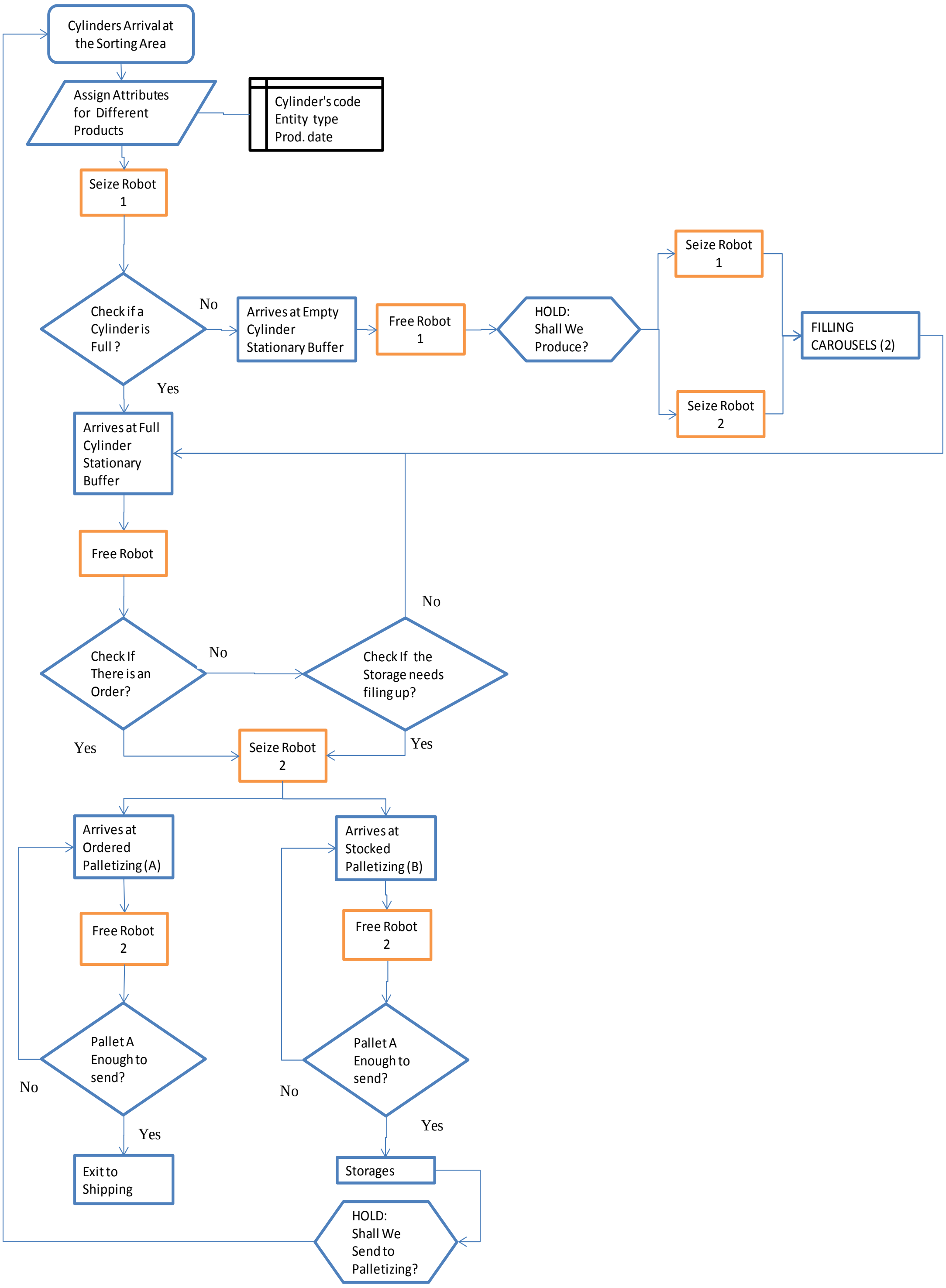
Daily Demand / Type	161	162	163	164
Jan	ANINT(ABS(NORM(230,44)))	ANINT(ABS(NORM(33.5,10)))	ANINT(ABS(NORM(43.5,15)))	ANINT(ABS(UNIF(2,7)))
Feb	ANINT(ABS(NORM(230,44)))	ANINT(ABS(NORM(33.5,10)))	ANINT(ABS(NORM(43.5,15)))	ANINT(ABS(UNIF(2,7)))
Mar	ANINT(ABS(NORM(230,44)))	ANINT(ABS(NORM(33.5,10)))	ANINT(ABS(NORM(43.5,15)))	ANINT(ABS(UNIF(27,36)))
Apr	ANINT(ABS(NORM(230,44)))	ANINT(ABS(NORM(33.5,10)))	ANINT(ABS(NORM(43.5,15)))	ANINT(ABS(UNIF(27,36)))
May	ANINT(ABS(NORM(230,44)))	ANINT(ABS(NORM(33.5,10)))	ANINT(ABS(NORM(43.5,15)))	ANINT(ABS(UNIF(11,21)))
Jun	ANINT(ABS(NORM(230,44)))	ANINT(ABS(NORM(33.5,10)))	ANINT(ABS(NORM(43.5,15)))	ANINT(ABS(UNIF(11,21)))
Jul	ANINT(ABS(NORM(230,44)))	ANINT(ABS(NORM(33.5,10)))	ANINT(ABS(NORM(43.5,15)))	ANINT(ABS(UNIF(2,7)))
Aug	ANINT(ABS(NORM(230,44)))	ANINT(ABS(NORM(33.5,10)))	ANINT(ABS(NORM(43.5,15)))	ANINT(ABS(UNIF(11,21)))
Sept	ANINT(ABS(NORM(230,44)))	ANINT(ABS(NORM(33.5,10)))	ANINT(ABS(NORM(43.5,15)))	ANINT(ABS(UNIF(11,21)))
Oct	ANINT(ABS(NORM(230,44)))	ANINT(ABS(NORM(33.5,10)))	ANINT(ABS(NORM(43.5,15)))	ANINT(ABS(UNIF(11,21)))
Nov	ANINT(ABS(NORM(230,44)))	ANINT(ABS(NORM(33.5,10)))	ANINT(ABS(NORM(43.5,15)))	ANINT(ABS(UNIF(2,7)))
Dec	ANINT(ABS(NORM(230,44)))	ANINT(ABS(NORM(33.5,10)))	ANINT(ABS(NORM(43.5,15)))	ANINT(ABS(UNIF(11,21)))

ANINT	Round to nearest integer
ABS	Absolute value
NORM	Normal distribution

Table A4: Distance Parameters Robots between Two Stations

Product Group	Sorting Gate Empty Buffer	Empty Buffer Carousel Station	Carousel Station Full Buffer	Full Buffer Pallet	Sorting Gate Full Buffer
121	NORM(19.2,2.4)	NORM(19.2,2.4)	NORM(19.2,2.4)	NORM(19.2,2.4)	NORM(47.5,2.5)
161	NORM(17.5,2.4)	NORM(28,2.5)	NORM(28,2.5)	NORM(17.5,2.4)	NORM(45.6,2.5)
122	NORM(19.2,2.4)	NORM(19.2,2.4)	NORM(19.2,2.4)	NORM(19.2,2.4)	NORM(47.5,2.5)
162	NORM(17.5,2.4)	NORM(28,2.5)	NORM(28,2.5)	NORM(17.5,2.4)	NORM(45.6,2.5)
124	NORM(19.2,2.4)	NORM(19.2,2.4)	NORM(19.2,2.4)	NORM(19.2,2.4)	NORM(47.5,2.5)
164	NORM(17.5,2.4)	NORM(28,2.5)	NORM(28,2.5)	NORM(17.5,2.4)	NORM(45.6,2.5)
163	NORM(17.5,2.4)	NORM(28,2.5)	NORM(28,2.5)	NORM(17.5,2.4)	NORM(45.6,2.5)
123	NORM(19.2,2.4)	NORM(19.2,2.4)	NORM(19.2,2.4)	NORM(19.2,2.4)	NORM(47.5,2.5)

Appendix B: Production Process Modeling Approach



Appendix C: Logic Sub-Models

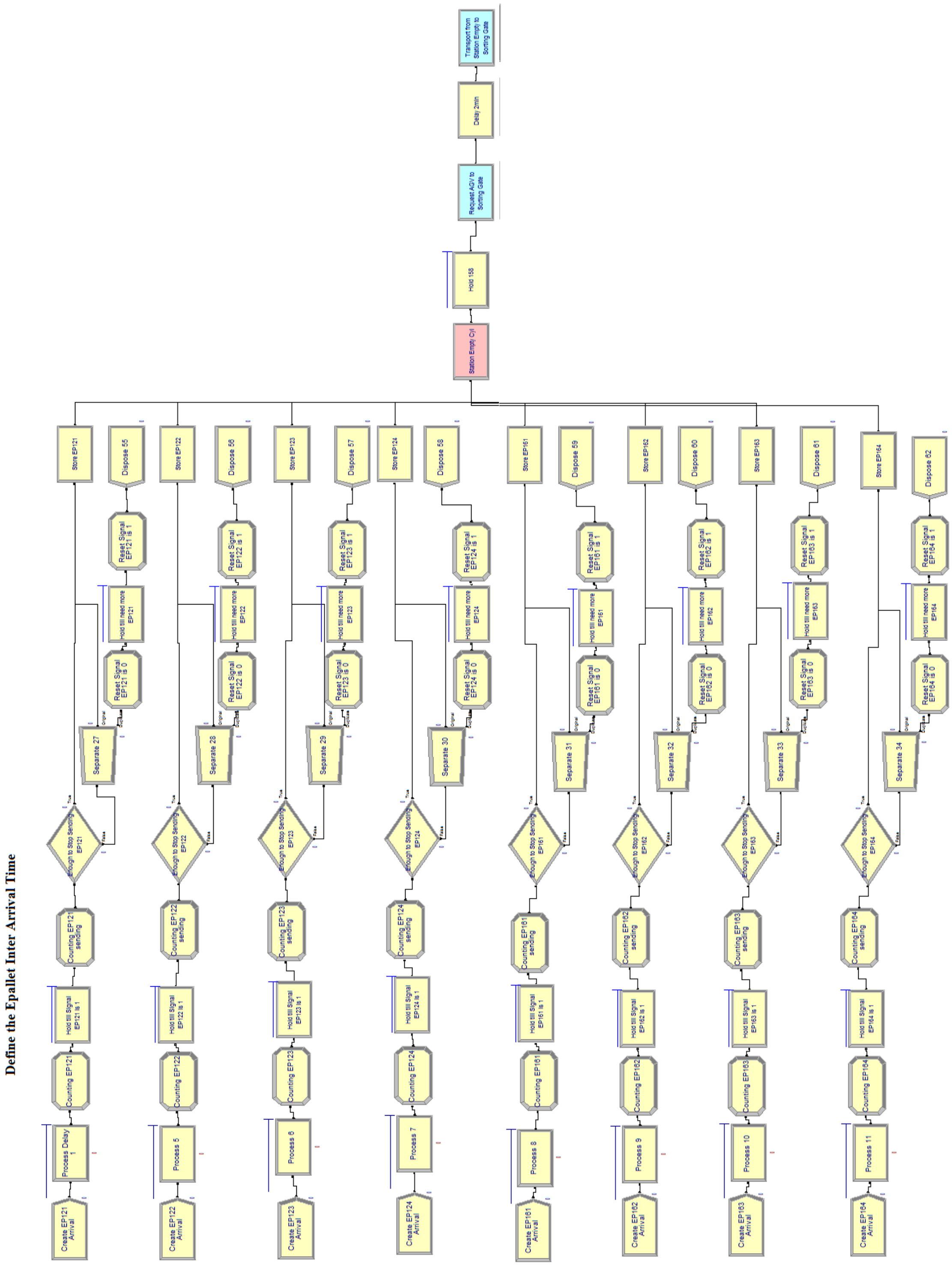


Figure C1: Pallet of Empty Cylinders Arrival Sub- Model

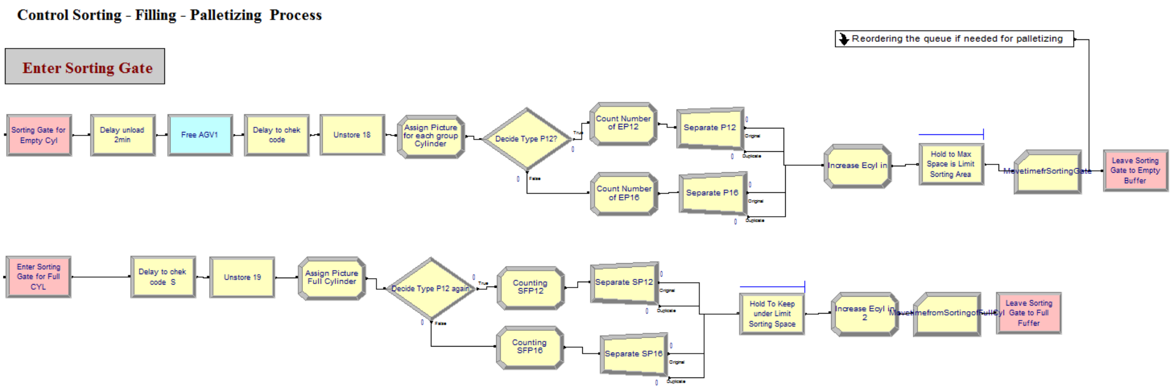


Figure C2.1:Cylinders Enter Sorting Gate – Filling Manufacturing Process Sub-Model

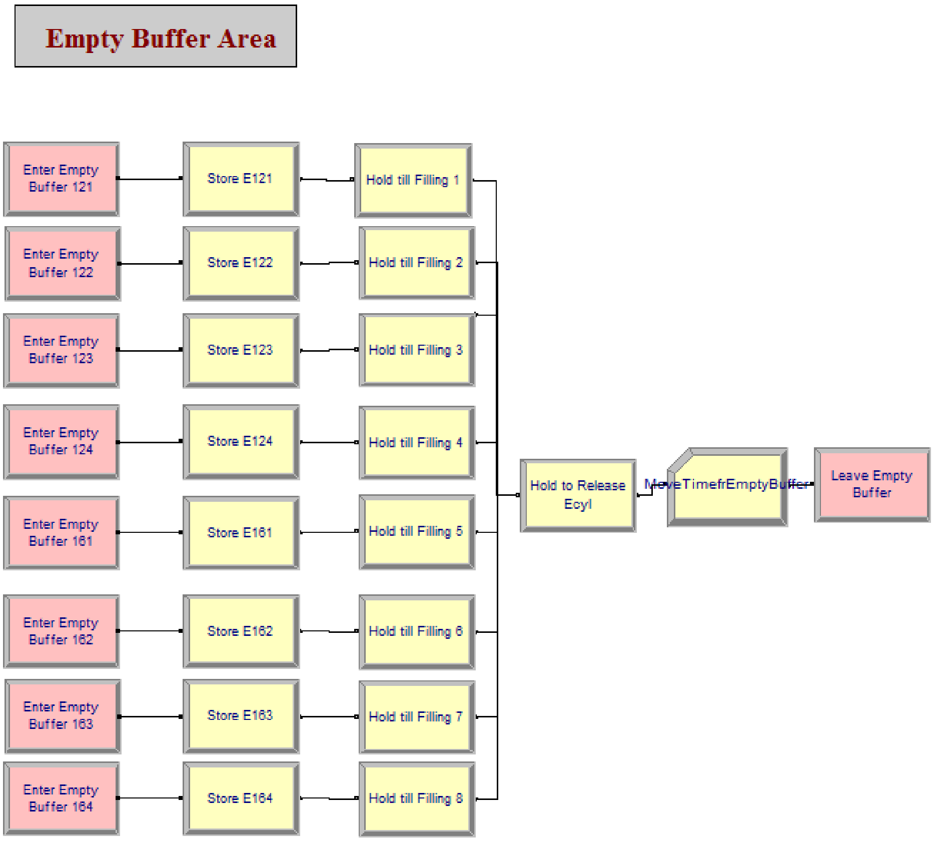


Figure C2.2: Cylinders Enter Empty Buffer Station– Filling Manufacturing Process Sub-Model

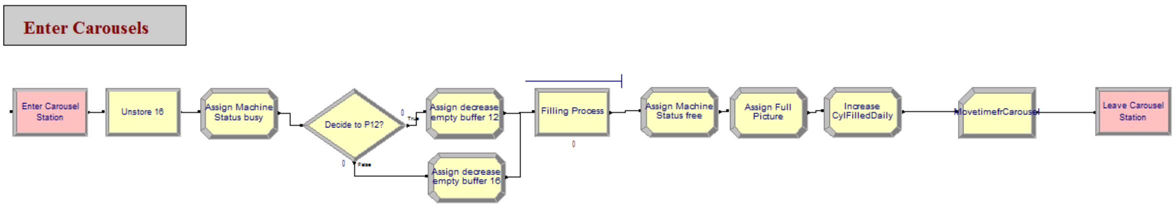


Figure C2.3: Cylinders Enter Filling Machines– Filling Manufacturing Process Sub-Model

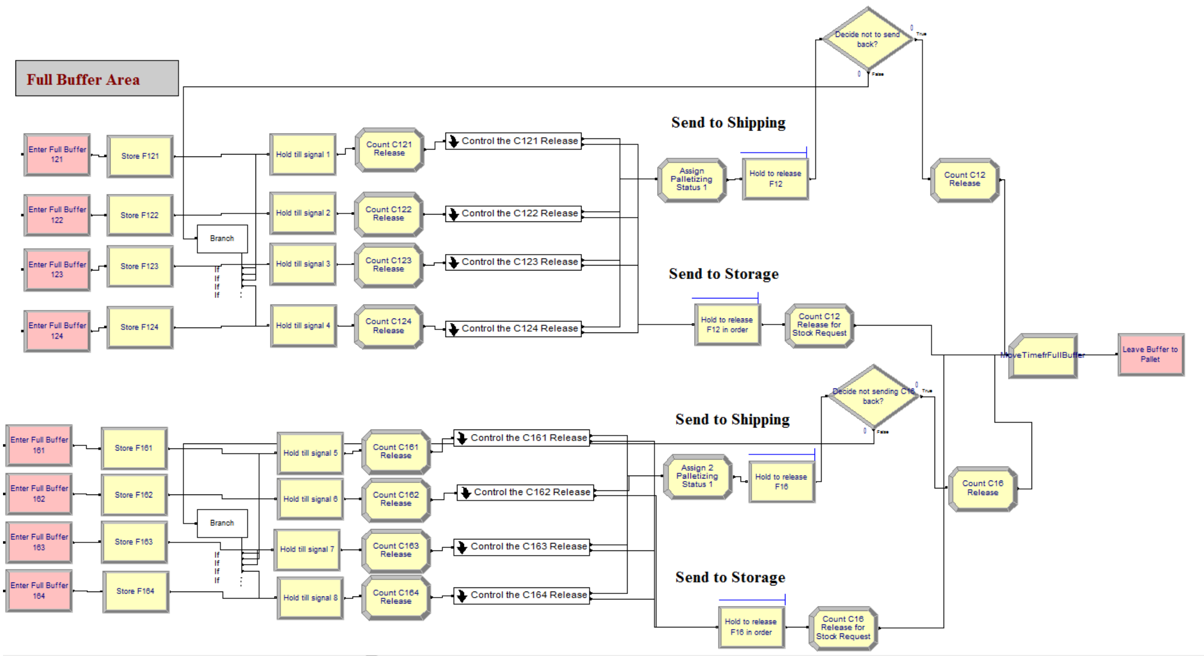


Figure C2.4: Cylinders Enter Ful Buffer Station– Filling Manufacturing Process Sub-Model

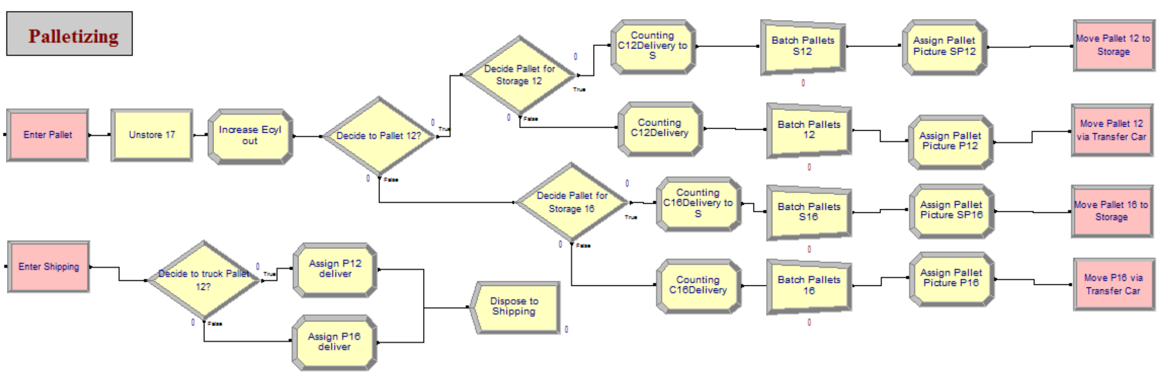


Figure C2.5: Cylinders Enter Palletizing Gate– Filling Manufacturing Process Sub-Model

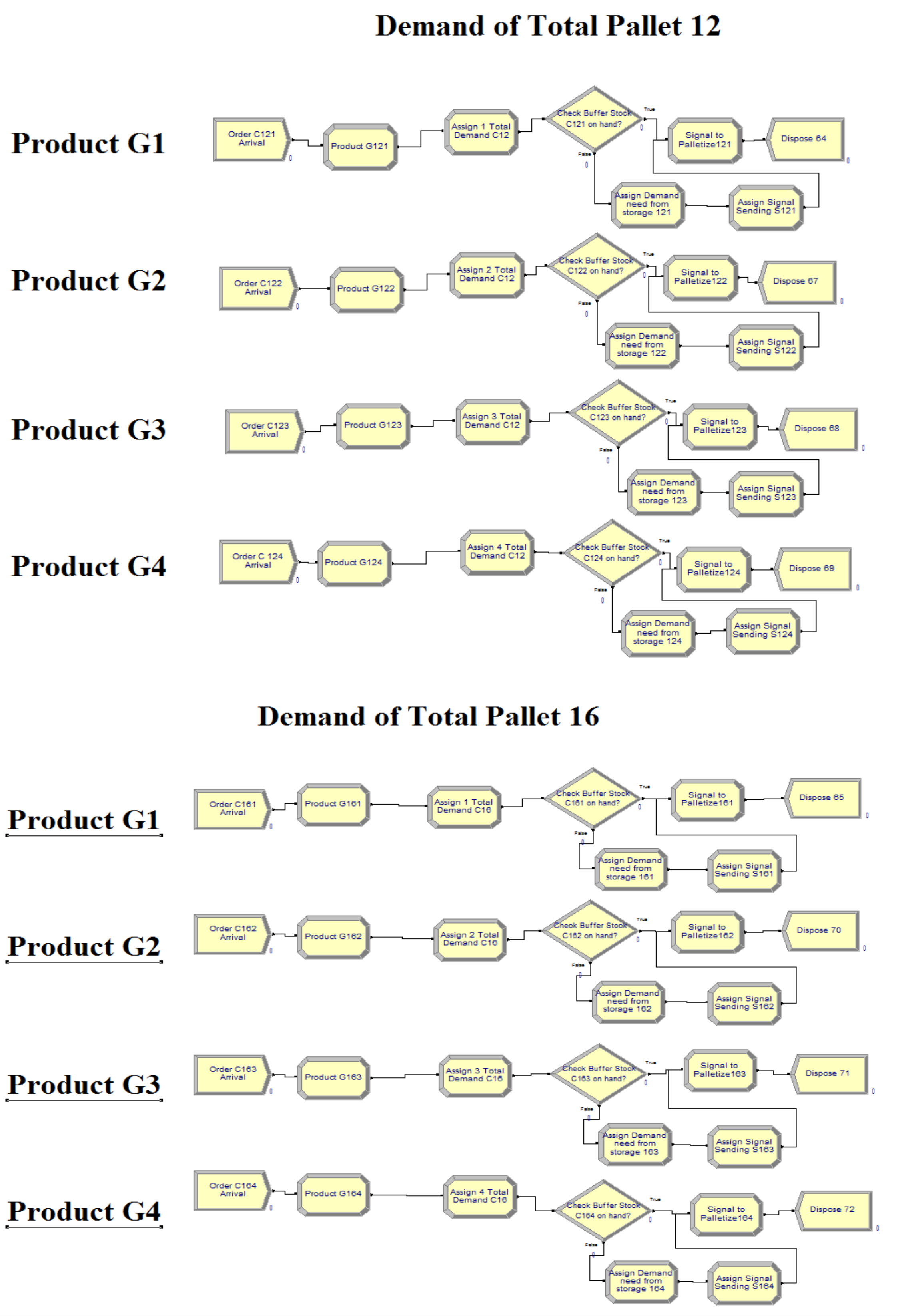
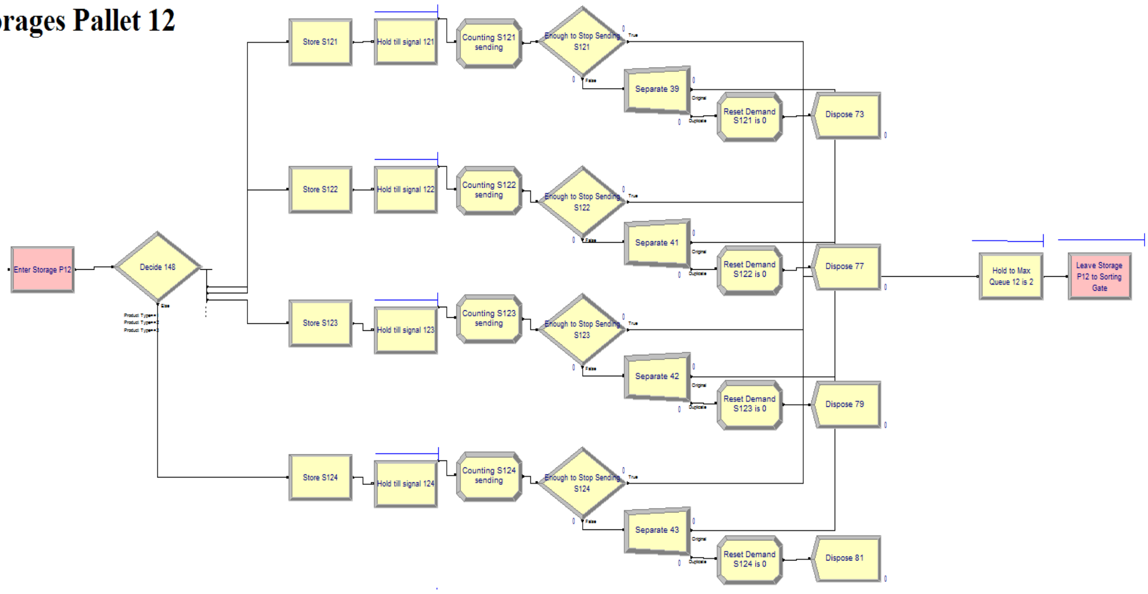


Figure C3: Demand Sub-Model

Storages Pallet 12



Storages Pallet 16

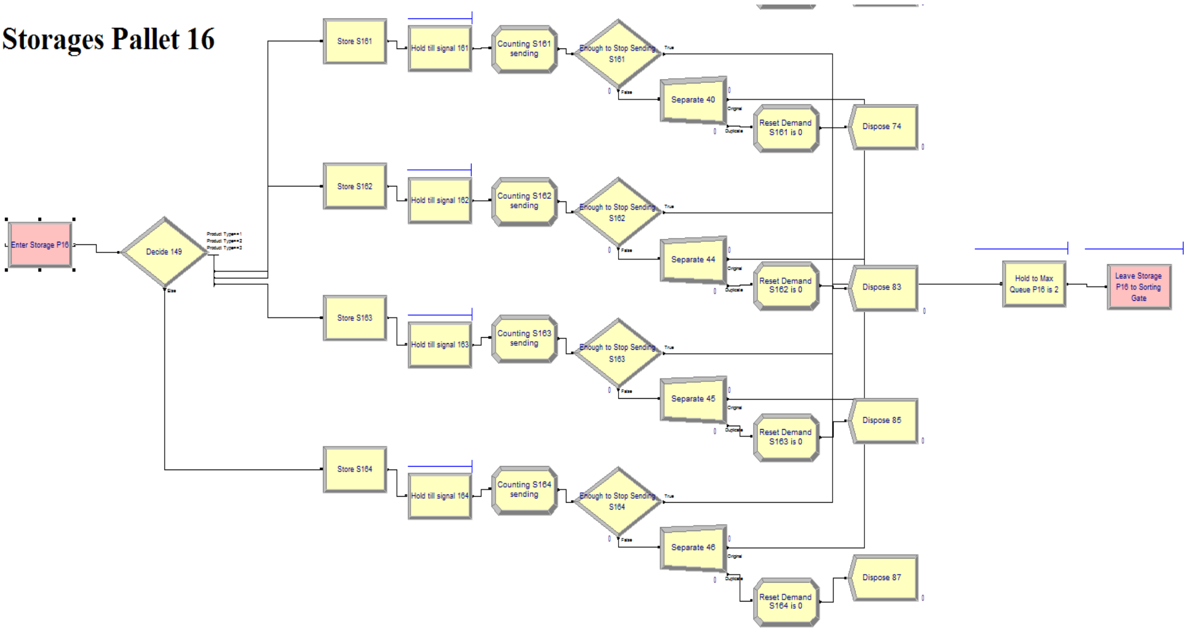


Figure C4.1: Sending Pallets from Storage toSorting Buffer Station - Storage Sub-Model

Request to fullfill the Storage when Demand n Buffer are already fulfilled

Storages Pallet 12

Product G1

Product G2

Product G3

Product G4

Storages Pallet 16

Product G1

Product G2

Product G3

Product G4

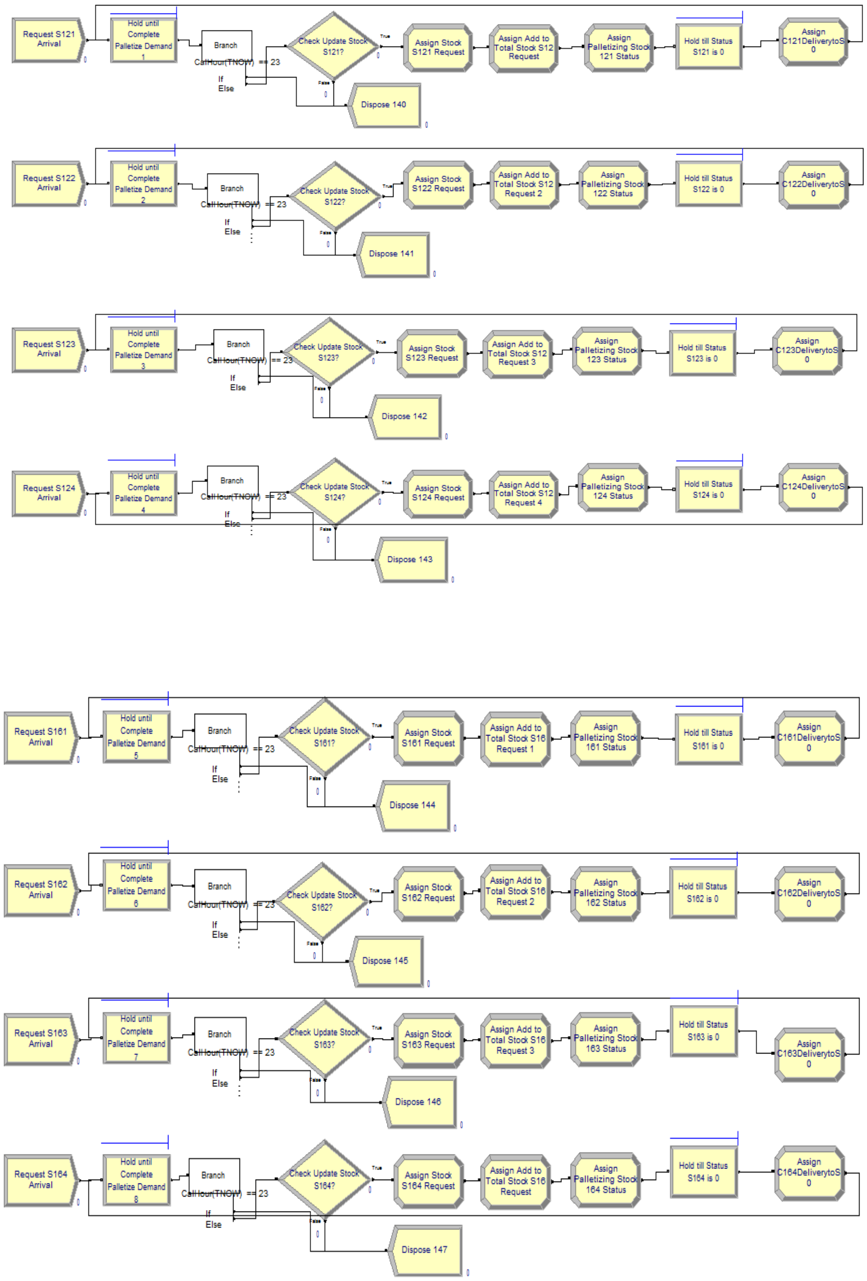


Figure C4.2: Request to Fill Up the Storage - Storage Sub-Model

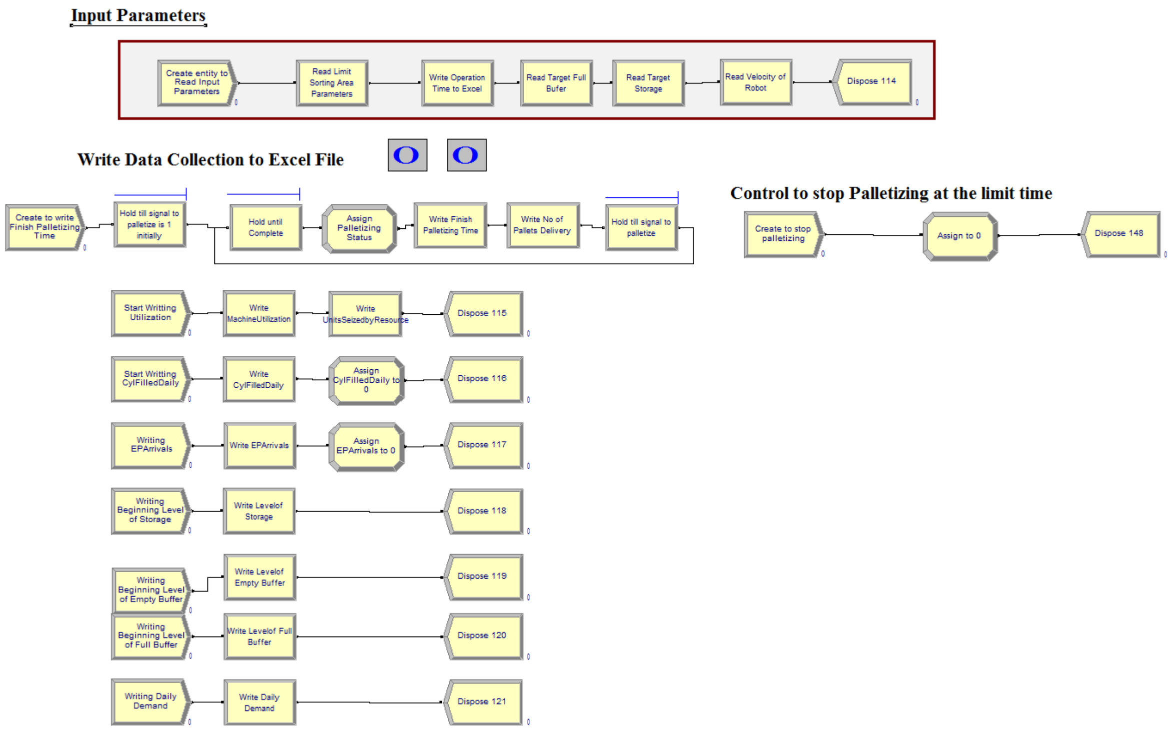


Figure C5: Data Import and Export Sub-Model

Appendix D: Simulation Animation