CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Manufacturing firms are currently encountering problems because of changing environment, varying weather conditions, product design changes and rapidly changing customer demand. Thus, the Manufacturing Resource Planning (MRP) system and the Mass Production System (MPS) cannot respond quickly enough to product design changes. This results in, amongst other things, high levels of obsolete stocks.

Also, the environment is too turbulent to allow accurate forecasting. This results in excessive obsolescence. This can only be improved by reducing the lead time below what can be achieved by Manufacturing Resource Planning (MRP). However, the need to be more responsive to rapidly changing customer demand as a result of market competition remains a constant dominant challenge. In the highly competitive manufacturing environment, many companies around the world are searching for ways to improve manufacturing performance. This is in response to changes in the manufacturing environment reflected by shortened product life cycles, diverse customer needs and the rapid progress of manufacturing technology (Shadrack, 2015).

Just-In-Time (JIT) manufacturing, a Japanese manufacturing concept, is amongst the available technology and techniques that emphasizes *waste* elimination. This is an appropriate means for a company that wants to perform in a competitive market. Some potential benefits that can be obtained by applying JIT concepts include: significant reduction of setup time, reduced cost of quality (such as scrap/rework reduction), increased inventory turn-over, increased manufacturing flexibility and shorter lead time. Companies operating in highly competitive environments are the most appropriate for implementing JIT concepts. There are four reasons for using JIT in industries (Edosomwan & Arvind, 2009). First, some industries are characterised by a short product life cycle, therefore, lead time and inventory reduction must become main concerns. Secondly, a large proportion of the cost of goods sold is material cost so decreased inventory and scrap is absolutely essential. Thirdly, the combined effects of short life cycle and high material costs lead to a high level of material obsolescence, thereby, reduction of lead time and inventory again become main concerns. Finally, rapid technological progress causes shorter life cycle, so the company must be able to reduce time required to meet customer needs.

Since the beginning of the 80's, much attention has been focused on a Japanese manufacturing system which is known in the western world as Just-In-Time (JIT). JIT concepts have focused on improvement of manufacturing processes, reducing setup times and lot sizes, developing mistake-proof operations and using simple scheduling techniques. This may be seen as eliminating waste, where waste is anything other than the minimum amount of resources. Successful JIT implementation usually results in reduced costs, improved quality and smoother production flow.

JIT has been credited for the economic success that has transformed Japanese firms into world class companies. However, some observers point out that there are other factors that contribute to the success, including government support for industry, the Japanese management culture, and the characteristics of Japanese workers. In addition, the Japanese workers are also characterised as multi-skilled workers who are able to handle various jobs without being restricted by rigid demarcation, so this achieves high flexibility (Huang, 2013). The JIT production concepts were firstly pioneered at the Toyota Motor Company (TMC) by Taiichi Ohno, and later adopted by other Japanese companies. The idea of JIT was derived from the mechanisms used in American supermarkets to replenish shelves as customers withdraw goods from them (Suzaki, 2014). This idea was then applied by Ohno at the TMC. Today many companies in the world have employed the JIT concepts.

JIT, in various modified forms, as a production management concept, has been adapted by western companies with considerable success. Authorities in this area are Hall (2013) by introducing the concepts of zero inventory, Deming (2016) by coining the 14 points for management and Mitra (2013) by proposing the quality management grid. Today, many companies in the world regard JIT or its modified forms as a major component of competitive strategy.

Optimal common frequency routing of a JIT-Kanban manufacturing system replenishes raw materials from outside suppliers, converts them into finished products and sells finished products to customers. The total demand of the finished products is assumed to be a known quantity that resulted from a forecast. A linear demand of final products in a fixed interval of time is considered in this research to roughly capture the life cycle pattern of the demand of a product. Raw materials are supplied to the production system and their ordering policy is dependent on the shipping plan of the finished products. Therefore, according to the known shipping strategy of the finished products, it is necessary to determine the ordering policy of the associated raw materials.

In a production line operating under a JIT production policy, the production rate of each work-stage is generally dictated by the demand of the following stage or final products. Therefore, the production rates of each work-stage should be treated as the decision variables. The problem can be addressed as: minimizing the integrated inventory cost of the system as well as determining the production system operation policy about raw material procurement rate, finished product delivery rate, and the associated Kanban system configuration under flexible production capacities.

Intense competition in today's economy, the shrinking life cycles of products, and the heightening expectations of customers have forced business enterprises to focus their attention on correctly arranging and controlling their production and supply chain systems. The production and supply chain system presented in this research is a serial multi-stage JIT-Kanban controlled manufacturing system which is one of the most popular systems among contemporary manufacturing companies because they can minimize the inventory build-up, increase flexibility, and minimize waste of material resources, human resources and facilities.

In this research, a serial multi-stage manufacturing system controlled by Kanbans is considered which procures raw materials from outside suppliers and processes them through multiple work-stages to deliver a varying quantity of finished products to customers at a fixed-interval of time. Also, the raw materials are replenished instantaneously to the manufacturing system to meet the JIT operation and time-varying finished product demand pattern, and the production capacity of the system is flexible.

1.2 Problem Statement

Based on an investigation of the plant, problems encountered by the Drug Process Plant can be classified into three major problems:

a. Long lead time to customers

The Drug Process Plant produces various items. This results in more time being required for waiting and queuing at the production facilities as well as more efforts for scheduling and resource allocation. Around 76% of the throughput time for most items is spent on non-productive time such as waiting and queuing.

b. No visual method to observe the Work in Process

As a result of space limitation, the Work in Process (WIP) of items is located on conveyors. This makes it difficult to check the status and the quantity of particular items. In addition, there is no fixed location for the conveyors so this also results in less consciousness of the importance of reducing inventory. Therefore, a more visual system should be established to increase the timeliness of the status and the location of the inventory.

c. Extra storage held to anticipate rapid changes of demand

The production process in the Drug Process Plant was conducted by the MRP system. This led to extra inventory of finished items stored at the Drug Process Plant. Therefore, the introduction of the JIT system at the Drug Process Plant is crucial to eliminate this problem.

Furthermore, the manufacturing operations face considerable uncertainty and are considered stochastic due to:

1. Uncertainty in timing customer orders,
2. Variability in processing time, rework, and scrap rate,
3. Inaccuracy of demand forecasting, and,
4. Uncertainty of equipment failure.

These problems affect all organisational units and levels particularly the Drug Process Plant.

1.3 Aim and Objectives of the Research

The aim of the study is to model an optimal Common Frequency Routing (CFR) for a JIT manufacturing system with time-varying demand and flexible production capacities. The objectives for the research are as follows:

i. To design computer-based production control systems using kanban loops which integrates information flow with material flow.
ii. To develop a discrete event simulation model to study the designed Just-in-Time Supply Delivery System (JSS) of the drug process plant.
iii. To deduce the effect of JIT manufacturing system alternative on total inventory level.
iv. To deduce the effect of trigger point on cycle time and WIP.
v. To deduce the effect of number of kanbans on flow time and orders satisfied.
vi. To deduce the effect of JIT manufacturing system alternative on average throughput-time, demand fill rate, and/or net operating income for a given level of product mix

complexity and manufacturing overhead level in the drug process plant.

vii. To develop an optimal Common Frequency Routing (CFR) and meta-heuristics for Just-in-Time supply delivery system of a drug process plant.

1.4 Significance of the Research

Just-in-time manufacturing keeps stock holding costs to a bare minimum. The release of storage space results in better utilization of space and thereby bears a favorable impact on the rent paid and on any insurance premiums that would otherwise need to be made. Just-in-time manufacturing eliminates waste, as out-of-date or expired products; do not enter into this equation at all. As under this technique, only essential stocks are obtained, less working capital is required to finance procurement. Here, a minimum re-order level is set, and only once that mark is reached, fresh stocks are ordered making this a boon to inventory management too. Due to the aforementioned low level of stocks held, the organizations return on investment (referred to as ROI, in management parlance) would generally be high.

As just-in-time production works on a demand-pull basis, all goods made would be sold, and thus it incorporates changes in demand with surprising ease. This makes it especially appealing today, where the market demand is volatile and somewhat unpredictable. Just-in-time manufacturing encourages the 'right first time' concept, so that inspection costs and cost of rework is minimized. High quality products and greater efficiency can be derived from following a just-in-time production system. Close relationships are fostered along the production chain under a just-in-time manufacturing system. Constant communication with the customer results in high customer satisfaction. Overproduction is eliminated when just-in-time manufacturing is adopted. JIT concepts are believed to overcome the problems, particularly those concerned with inventory. Since there are three main factors that affects inventory i.e. lead time, batch size and volatility of demand, JIT implementation should be able to reduce those factors by reducing lead times and batch size as well as stabilizing demand. Shorter lead time results in quicker response to rapid changing demand as well as lower inventory. Smaller batch sizes can cause smoother production flow, resulting in shorter lead time as well as lower inventory. Finally, more stable demand requires less buffer stocks as well as providing smoother production flow. The difference in the growth rates and profitability of manufacturing firms (or companies) of the world is largely due to the quality of manufacturing system and costing tool of companies (Evans, 2011).

JIT implementation for Juhel Pharmaceutical Drug Process Plant is considered in order to reduce inventory and lead time. Therefore, this concept was proposed for Juhel Pharmaceutical Drug Process Plant situated in Enugu, Nigeria. The first trial was conducted in the company's Drug Process Plant and demonstrated a significant reduction of inventory. The research work will be beneficial to all manufacturing organizations. It will equally be useful to small scale business, large corporations, and the government. Finally, it will be of great value to students, researchers as a point of reference and will equally form the basis for further research study.

1.5 Scope of the Research

The scope of this research focuses on the optimal Common Frequency Routing (CFR) for a JIT manufacturing system with time-varying demand and flexible production capacities. This research work among other things designed and developed an enhanced algorithm that control production systems using kanban loops which integrate information flows with material flows. The design stage discusses the determination of all technical aspects for running the system. The implementation is related to the execution of the new system including the preparation. The evaluation assesses how successfully the new system achieves the objectives. This stage includes formulating recommendations for further improvement. In this work, simulation is also used as a means to evaluate technical aspects contributing to improving the performance of the new system after the implementation stage. ARENA/ SIMAN and TECNOMATIX simulation software packages were used for this.

This research equally developed a discrete event simulation model to study Just-In-Time Supply Delivery System (JSS). The connections between JSS and manufacturing system under real time operations are studied. The study identifies interesting inventory dynamics and identifies factors that contribute to this behavior.

1.6 Limitations of the Research

Successful JIT implementation requires improvements in various areas including setup time reduction, vendor relationship and leveling production. These are beyond the scope of this research. It is important to remember that every research methodology has its own unique set of strengths and corresponding limitations, and simulation modeling is no exception to this rule. Probably the greatest strength of simulation modeling is that it is virtually endlessly reconfigurable and therefore may be relatively easily extended and improved to incorporate more detail. The principal limitation is that no simulation model can possibly capture the infinite number of extraneous variables that exist within any real system.

Thus, the results of any simulation study are greatly impacted by the assumptions built into the model and must be interpreted with caution. However, the benefit of being able to observe the behavior of the performance measures under the same environmental settings is the major benefit of simulation modeling, and may provide insight and guidance for future research. The software package used ensures the simulation represents the system accurately. However, the developed model is useful to get insight into the behaviour of the system modeled.

CHAPTER TWO

LITERATURE REVIEW

2.1. Origins of JIT

JIT is a manufacturing philosophy, which seeks to eliminate the ultimate source of waste, in all of its forms throughout the producing processes, from purchasing through distribution. By eliminating waste, JIT targets production with the minimum lead-time and at the lowest total cost. The JIT philosophy has its roots after World War II when the Japanese were striving to compete with the U.S. manufacturing system (also known as Mass Production). TaichiOhno was the founder of this philosophy in the 1940s when he began developing a system that would enable Toyota to compete with U.S. automakers. Note that the environment dominating manufacturing over the last five decades has been based on the Material Requirements Planning (MRP) formalized by Joseph Orlicky, Oliver Wight, and George Plossl. In an MRP environment, planning is performed based on the independent (customers') demand, in an almost JIT basis. However, shop floor control is performed based on a push philosophy in which manufacturing orders are introduced in the production system and pushed through production. This is the fundamental difference between JIT and MRP.

According to Ohno JIT rests on two pillars:

1. **Just-in-time** as it is described in the following chapters and
2. **Autonomation or automation with human touch**. This term refers to i) the installation of one-touch automation so an operator will be able to place a part in a machine, initiate the machine cycle, and move on; ii) "fool proofing" or "poke yoke" which is the incorporation of sensors in the machines to signal abnormal conditions and even automatically stop machines if necessary, so operators don't need to watch machines during their cycle (Hopp & Spearman, 2001).

Ohno formulated the whole idea based on two concepts he encountered during visits in the U.S.: An American supermarket and the cable cars in San Francisco. First, he was impressed by the way American supermarkets supplied merchandise in a simple, productive and, timely manner and attempted to develop a similar concept in manufacturing. He observed that in the supermarket, each workstation would become the internal customer for the preceding workstation. The former would simply pick up the required parts from the latter, a supermarket shelf. The second concept was analogous to a simple cable car operation. Ohno observed that the cable car riders were pulling an overhead cord when they wanted to disembark. This cord produced a similar sound signaling the cable car to stop the car. Ohno applied a similar system using machine sensors. An operator will stop the operation of a machine using a cord whenever he/she found a problem (autonomation) (Black & Hunter, 2003). Another contributor to JIT was Shigeo Shingo, who developed a new methodology for the reduction of setup time. This new method, called Single-Minute-Exchange-of- Dies (SMED) system, seeks to simplify and minimize the time required for the process of changeovers, so setups become simple and fast (Black & Hunter, 2003).

The success of the JIT also rests on the principle of “respect for humanity”. According to Sugimori (2014), the Toyota Production System (TPS) makes full use of the workers’ capabilities and relies fully on them for the running and continuous improvement of the plant.

2.2. JIT Objectives

The goal of JIT is to create a production environment that enables the customer to purchase products needed at the required time and quantity needed, in a predefined quality, at the lowest cost. This is accomplished by reducing variability in all of its forms.

Thus, JIT focuses on reducing seven commonly accepted wastes as follows:

1. **Overproduction, is prevented** by a) synchronizing all processing steps by using the Pull philosophy and the kanban technique and b) by reducing set-up times.
2. **Waiting, is prevented** by a) synchronizing all processing steps by using the Pull philosophy and the kanban technique and b) organizing production in Cells
3. **Transport of materials, is prevented** by organizing production in Cells
4. **Rework processing, is prevented** by a) applying quality at the source and b) redesigning processes
5. **Unnecessary inventory is prevented** by a) synchronizing all processing steps by using the Pull philosophy and the kanban technique and b) by reducing setup times
6. **Unnecessary movement of employees is prevented** by organizing production in Cells
7. **Production of defective parts is prevented** by a) applying quality at the source and b) redesigning processes

Central themes of JIT are *Flow in Production* and *Pull of Production. Flow* is the idea of processing one single item at a time in a continuous way from raw material to finished product without interruptions, delays, defects or breakdowns. *Pull* is the concept of responding to customer demand by delivering parts to assembly, and finished products to customers in a "Just-in-Time" fashion. *Setup time* is the time taken to prepare the manufacturing processes and system for production. *Production in cells* involves the use of multiple "cells" in an assembly line fashion. Each of these cells is composed of one or multiple different machines which accomplish a certain task. The product moves from one cell to the next, each station completing part of the manufacturing process while making as little waste as possible. The number of orders that are provided to the JIT system is strictly determined by the system's capacity. In this manner, the levels of WIP between the workstations are explicitly limited and as a result, the system overloads are avoided (Black & Hunter, 2003; Hopp & Spearman, 2001; Emiliani, 1998; Womack & Jones, 1996; Hay, 2008). This is the key difference with MRP, in which work orders are provided to the system without considering explicitly the state of the system.

JIT constitutes a strategic weapon for a company because it results in a more efficient and less wasteful manufacturing system. By following the methodology of JIT, setup times are minimized successfully and frequent changeovers are feasible. Direct results include considerable reductions of lot sizes and Work In Process (WIP) and total system's inventory. The end result is the significant reduction of the total manufacturing cost. Implementation of the Flow and Pull concepts is based on a number of significant methods as shown in Figure 2.1 (Betts & Johnston, 2009). For example, the implementation of techniques such as Total Quality Management (TQM), Total Productive Maintenance (TPM) help in minimizing costly (both in terms of time and costs) rework or loop-backs (Baker, 2009).

Furthermore, in a JIT environment, a) workers should be trained to obtain multifunctional skills and b) machines should be allocated properly to the re-designed manufacturing cells to cope with unexpected fluctuations in demand. Thus, manufacturing cannot reap the benefits of JIT unless the above preconditions exist; i.e. multiskilling and problem solving by workers, elimination of rework, etc. In addition, supplier networks must support long-term and mutually beneficial relationships in order to achieve synchronization between supplies and production.

The above steps interact with one another and thus, must be achieved following an iterative process that continuously reveals waste and ensures continuous improvement or Kaizen in the system.

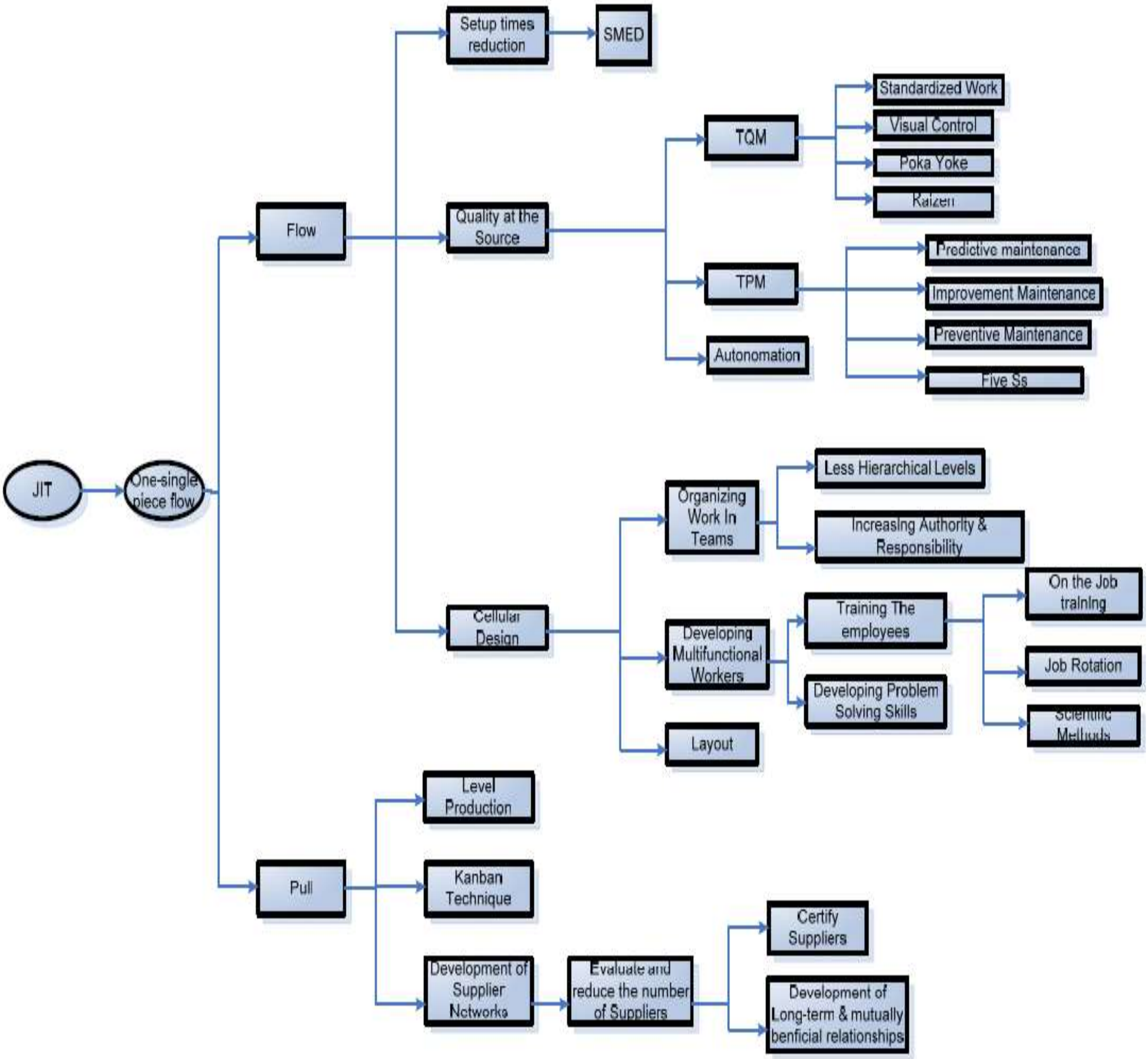


Figure 2.1: The JIT Elements

JIT in a one-single piece flow comprises Flow and Pull. Flow comprises "Set up Times Reduction," "Quality at the Source" and "Cellular Design". "Set up Times Reduction" stems to Single-Minute-Exchange-of-Dies (SMED). "Quality at the Source" comprises TQM, TPM and Automation. TQM comprises Standardized Work, Visual Control, Poka Yoke and Kaizen. TPM comprises Predictive Maintenance, Improvement Maintenance And Preventive Maintenance. Cellular design comprises organizing work in teams, developing multifunctional workers and layout. Organizing work in teams entails organizing them in less hierarchical levels and organizing them based on increasing authority and responsibility. Developing multifunctional workers involves training the employees and developing their problem solving skills. Training the employees comprises "on the job training," job rotation" and "scientific method." Pull on the hand comprises level production, kanban technique and development of supplier networks. Development of supplier networks stems to evaluating and reducing the number of suppliers which invariably comprises certifying suppliers and development of long-term and mutually beneficial relationships.

2.3. The Pillars of JIT

Figure 2.1 summarizes the results of an extensive literature research regarding JIT implementation in manufacturing. This review has shown (as already mentioned above) that JIT is founded on the pillars of: A) Implementation of Flow, and B) Implementation of Pull. Further analysis of these pillars is presented below:

2.3.1. Implementation of Flow

In order to establish flow in a system, three preconditions must exist, which are discussed below:

a) Setup Time Reduction

However, since setup time is the time taken to prepare the manufacturing processes and system for production, the method of *Setup time reduction* or *Single-Minute-Exchange-of-Dies (SMED)* comprises five steps:

1. *Maintenance, Organization, and Housekeeping*. A typical cause of setup problems is poor housekeeping, poor equipment maintenance and incorrect organization of tools. Proper maintenance, organization, and housekeeping are easy to be enforced and result in significant benefits.

2. *Separate Internal elements from External and convert them to External*. *Internal (*or mainline) elements are the processes that occur when the machine is not working, while external (or offline) elements are the processes that can be worked out while the machine is operating. The notion here is to convert as many internal elements as possible to external. Chief among internal elements that can be converted to external are *searching time* looking for the correct die, tools, carts, etc, *waiting time* for instructions, carts etc, and *setting times* for setting dies, fixtures, etc.

3. *Improve Elements*. Examine each element and try to find methods of eliminating waste.

4. *Eliminate Adjustments*. A short period of time is required to enforce a new adjustment but a long period of time is required to make this adjustment to function properly.

5. *Abolish Setup*. This composes the ultimate goal of the SMED method and it could be

achieved by either redesigning the products and making them uniform, so the same parts are required for various products or producing various parts in parallel at the same time (Black & Hunter, 2003; Hopp & Spearman, 2001; Hay, 2008).

b) Quality at the Source

Quality at the Source according to JIT constitutes of two main principles: Total Productive Maintenance (TPM), and Total Quality Management (TQM). TPM includes the techniques of preventive maintenance, predictive maintenance, improvement maintenance, and 5Ss (Sort, Set In Order, Shine, Standardize and Sustain) maintenance while TQM includes standardized work, visual control, poke yoke, and kaizen.

c) Cellular Layout

Cellular Layout is the organization of the manufacturing facility (people, materials, machines, and design) in cells, dedicated or semi-dedicated in product families.

2.3.2. Implementation of Pull

The pull production system according to Crabill, et al (2000) is two subsystem linkage in a supply chain. The producing operation does not produce until the standard Work-In-Process (WIP) between the two sub-systems is less than the set point. When the standard WIP is below the set point, this condition signals the need to replenish. Information flows in the reverse direction from product flow to signal production by the upstream cell or manufacturing process.

Pull represents a production system that explicitly limits the level of WIP in contrast to the push production system (Hopp & Spearman, 2001). According to Smalley (2004), three main types of pull systems exist: the *replenishment pull system* in which production is triggered when the stored end items are consumed, the *sequential pull system* in which the production rate is regulated according to the demand with the pacemaker to be usually established in the first process step at the beginning of the value stream map, and the *mixed pull system,* which is the combination of the replenishment and the sequential pull systems. Table 2.1 describes the basic differences between Pull and Push production systems.

In order to implement pull, as it was shown earlier, *Flow* must be established. After that a series of three additional techniques can be applied in order to realize pull production. These techniques are described below:

Table 2.1: Basic Differences between Pull and Push Manufacturing

Pull Conditions	Push Conditions
The final assembly workstation requests from the upstream cells parts to be produced in order to replenish the inventory (parts are "pulled"). ***As a result…*** - One scheduling point for the overall value stream, thus there is no confusion over the "right" schedule and everyone is marching to the same beat.	Each workstation forwards its producing parts to the final assembly workstation irrespective to the demand (parts are "pushed"). ***As a result…*** - Several scheduling points in the overall value stream, thus confusion over the "right" schedule.
Flow of production is fully accomplished (No Setup Time, No rework) ***As a result…*** - Lot sizes are minimized, thus less inventory is required	Flow of production is not fully accomplished ***As a result…*** - Orders are produced in large batch sizes, thus more inventory is required to cover breakdowns, delays or forecast mistakes (Black & Hunter, 2003).
All production processes, machines and workers are organized properly to produce at the rate given by Takt Time: ***As a result…*** - There is production smoothing and leveling of demand between the manufacturing cells and cycle time is reduced, thus items are paced and built in accordance with demand	The production is accomplished irrelevant of the Takt Time: ***As a result…*** - The line is not balanced according to demand and items are paced and built irrelevant to the demand.
No production process begins unless three prerequisites are fulfilled: 1. Demand (available kanban card) 2. Raw material 3. A Free Server ***As a result…*** - System's capacity defines the number of the orders (system is not overloaded), thus the WIP is explicitly stated and it is small (a closed queuing network).	No conditions exist for setting out the production process. Orders continue to be added in the system with no limits on WIP. ***As a result…*** - Orders are pushed in the system irrespective of its capacity (bottlenecks occur), thus the WIP is alleged and it is large (an open queuing network) (Hopp & Spearman, 2004).

a) Level Production

Level or Smoothing Production attempts to eliminate fluctuation in final assembly by eliminating variation or fluctuation in feeder processes. It represents a scheduling technique for balancing a production line by changing a) the production volume; i.e. parts are produced one single-piece at a time, and b) the production sequence of parts. Level production can improve the line performance by specifying which products are to be produced at each time interval. It is often preferred to implement level production firstly in the assembly operations, and secondly to adjust the cycle times to be equal or slightly less than the takt time.

The Japanese created a visual scheduling tool called the heijunka box. Heijunka is generally a wall schedule, which is divided into a grid of boxes, each one representing equally established time intervals during shifts which indicate what products and in what quantity should be produced during the corresponding time interval. In this box, daily orders (kanbans) are inserted by production control in order to pull products of the right mix and provide instructions to the system about sequential planning. Additional information for leveling the production can be found in the work of Black and Hunter (2003) as well as in Smalley (2004).

b) Kanban Technique

The lean method of production and inventory control is a pull system widely known as the kanban system (kan means signal and ban means card in Japanese). Kanban cards represent a visual control tool that regulates the flow of materials between cells and aim to respond to demand by delivering parts and products Just-in-Time. Therefore, it is a method of controlling the flow of information between the workstations while eliminating the WIP levels. In general, the kanban method functions as described in the following paragraph:

The downstream customer, either internal or external, pulls parts (downstream flow of parts) from the upstream supplier (internal or external) as needed. Empty product containers are a signal (upstream flow of information) for replenishment. The above is accomplished by using different kinds of kanban cards, such as production cards, move or withdrawal cards, signal cards, etc. and it comprises a significant method of production control and controlling levels of WIP.

c) Development of Supplier Networks

Finally, according to the literature on JIT, supplier networks must be developed. The integration of suppliers seeks to transfer the technological knowledge from the customer to the supplier and convert the latter to a lean manufacturer. As a consequence, suppliers evolve into remote cells in the linked-cell manufacturing system and deliveries are becoming synchronized with the buyer's production schedule. The supplier networks must consist of fewer and better suppliers and the contracts should be long-term and mutually beneficial. The rule here is to create single sourcing supplies for each component or subassembly by certifying the related suppliers (Black & Hunter, 2003; Wu, 2003; Waters-Fuller, 2011; Hay, 2008).

2.4 Kanban Systems

Kanban means card or token. A kanban-controlled production system is one where the flow of material is controlled by the presence or absence of a kanban, and where kanbans travel in the system according to certain rules. Kanban card is a key component of kanban and signals the need to move materials within a production facility or to move materials from an outside supplier into the production facility. The kanban card is, in effect, a message that signals depletion of product, parts, or inventory. When received, the kanban triggers replenishment of that product, part, or inventory. Consumption, drives demand for more production, and the kanban card signals demand for more product -so kanban cards help create a demand-driven system.

Electronic kanban (E-kanban) systems can be integrated into enterprise resource planning (ERP) systems, enabling real-time demand signaling across the supply chain and improved visibility. Data pulled from E-kanban systems can be used to optimize inventory levels by better tracking supplier lead and replenishment times.

The study of kanban-controlled systems can be traced back to the Toyota Production System in the 1950s. The classic kanban-controlled system was designed to realize Just-In-Time (JIT) production, keeping a tight control over the levels of individual buffers, while providing a satisfactory production rate (Figure 2.2).

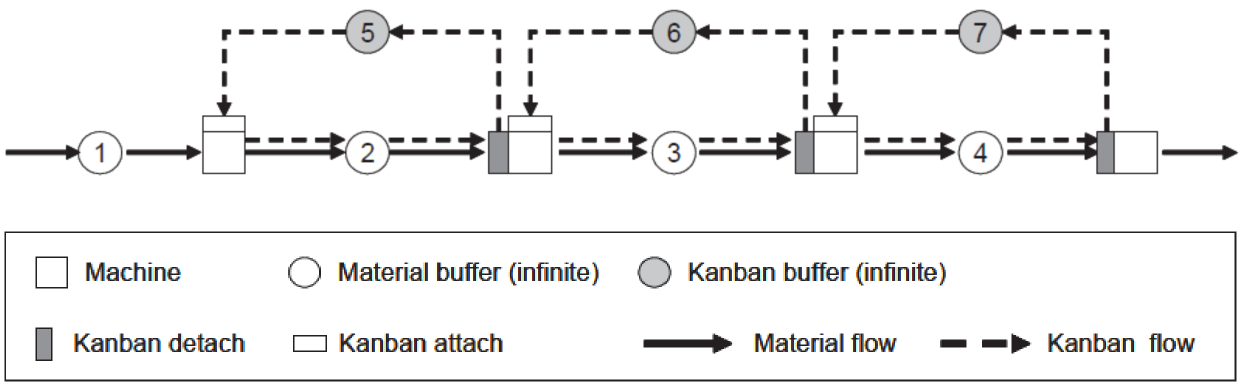


Figure 2.2: Classic kanban-controlled system

Kanban buffer is designated by shaded circles while the unshaded circles designate material buffer. Shaded rectangles represent kanban detach while unshaded rectangles represent kanban attach. Also, machines are designated by squares. The arrows indicate material flow while the dotted arrows indicate kanban flow. From the perspective of control, feedback is implemented at each processing stage by circulating kanbans from its downstream buffer to the upstream buffer. Raw material entering the production system is first placed in material buffer 1 for processing at the machine station, then material buffer 2 for the next machine operation and then material buffer 3, 4 and so on for processing at various machine stations. The circulation routes of kanbans form one closed loop per stage. As shown in figure 2.2, the circulation route of kanbans around material buffer 2 and kanban buffer 5 form a closed loop. Also, the circulation routes of kanbans around material buffer 3 and kanban buffer 6 form another closed loop. However, the circulation routes of kanbans around material buffer 4 and kanban buffer 7 also form a closed loop. Each stage has one control parameter: the number of kanbans. In the classic kanban-controlled system, a constant number of kanbans is imposed to limit the level of the buffer inventory in each closed loop. An infinite buffer controlled by a closed loop is equivalent to a finite buffer since the maximal inventory level can have in the infinite buffer is limited by the number of kanbans. The size of the infinite buffer is equal to the number of kanbans in the loop.

There are several variations of kanban control widely used in industry, such as CONWIP control and hybrid control (Figure 2.3). Unlike the classic kanban controlled system which uses kanbans to regulate the levels of individual buffers, the other two systems in Figure 2.3 implement a control strategy which limits the sum of the buffer levels within the large closed loop. Feedback is implemented from the last stage to the first stage.

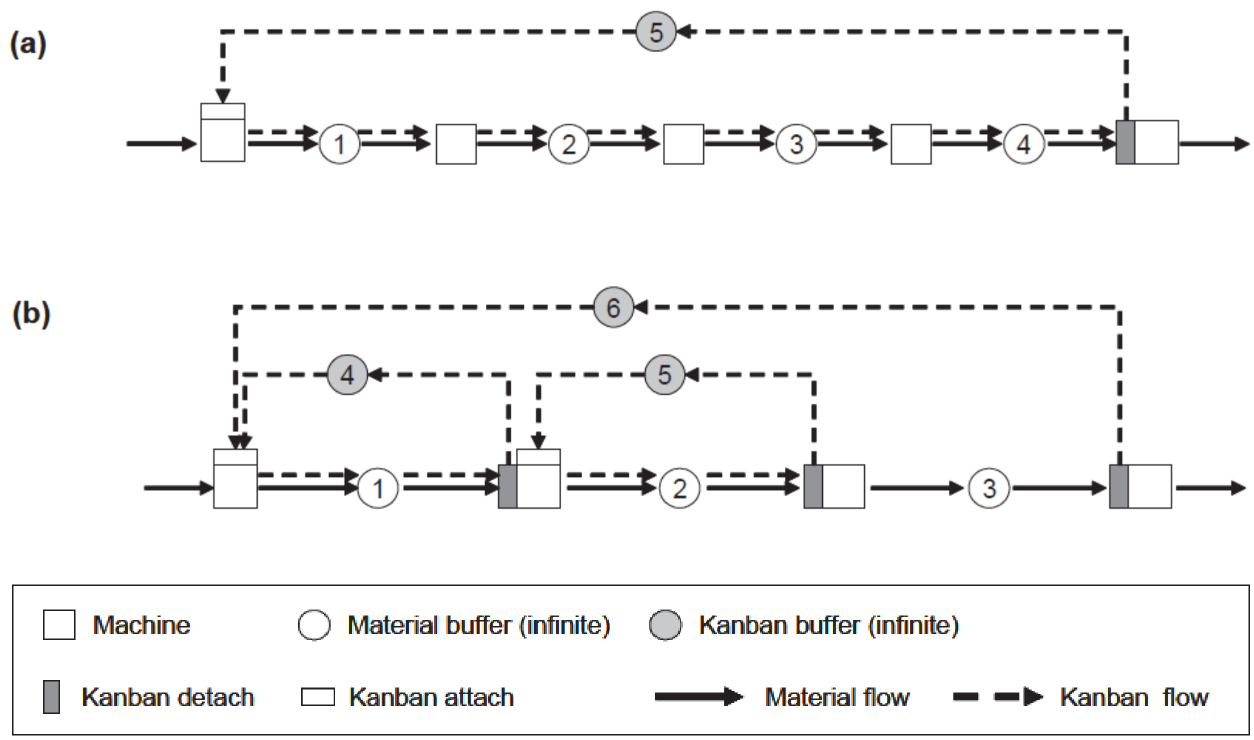


Figure 2.3: Variations of kanban systems

(a) CONWIP-controlled system; (b) Hybrid-controlled system

As shown in figure 2.3, raw material entering the production system at stage 1 is first placed in material buffer 1 for processing at the machine station, then material buffer 2 for the next machine operation and then material buffer 3, 4 and so on for subsequent processing at various machine stations. As shown in figure 2.3(a), the circulation route of kanbans around material buffer 1,2,3,4 and kanban buffer 5 forms a closed loop. Also, as shown in figure 2.3(b), the circulation routes of kanbans around material buffer 1 and kanban buffer 4 form a closed loop. The circulation routes of kanbans around material buffer 2 and kanban buffer 5 also form another closed loop. Lastly, the circulation routes of kanbans around material buffer 1, 2, 3 and kanban buffer 6 form another closed loop.

In Figure 2.2 and Figure 2.3, detaching and attaching kanbans with work pieces are separate operations before the work pieces proceed to machine operations. The operations of detaching and attaching kanbans are instantaneous compared to machine operations. Therefore, the kanban detach, kanban attach, and machine operation are integrated as one single operation (Figure 2.4). In addition, when kanbans are attached to work pieces, an integrated flow is used to represent two separate kanban and material flows in Figure 2.2 and

Figure 2.3. In the remainder of this work, rectangles will be used to represent integrated operations, and arrows to represent integrated flows.

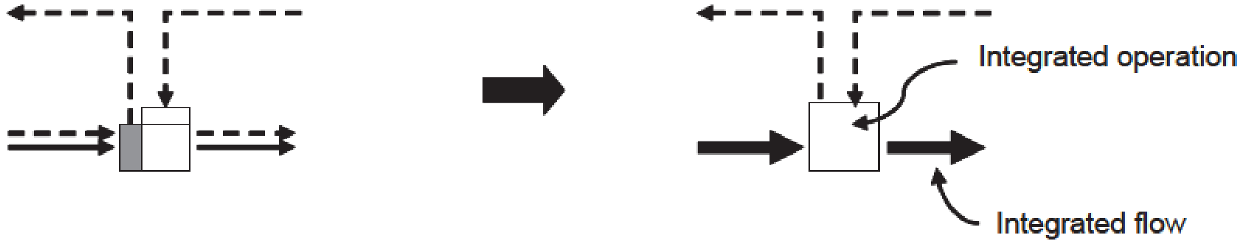


Figure 2.4: Integrated operation including kanban detach, kanban attach, and machine operation

2.4.1 Kanban Control

Consider the system in Figure 2.2. Once a part enters a closed loop, a kanban card is attached to it. The kanban card is detached from the part when it leaves the closed loop and proceeds to the next stage. The number of kanbans within the closed loop is constant. It is defined as the *invariant* of the loop. Similarly, when looking at the CONWIP loop in Figure 2.3(a), kanban cards are attached to the parts at the first stage of the production line while they are detached from the parts at the last stage. The total number of kanbans circulated within the CONWIP loop gives the loop invariant I:

$$I = b(1, t) + b(2, t) + b(3, t) + b(4, t) + b(5, t) \qquad (2.1)$$

in which $b(I, t)$ is the level of buffer Bi at time t.

The invariant imposes an upper limit on the buffer levels within the closed loop (Ezingeard and Race, 2011). For example, the total number of parts W allowed in the large CONWIP loop is constrained by:

$$W = b(1, t) + b(2, t) + b(3, t) + b(4, t) \leq I \qquad (2.2)$$

More generally, systems using kanban controls can be represented as a set of systems with multiple-loop structures. Each closed loop has a loop invariant. In the remainder of this work, material and kanban buffers are assumed to be finite because it is impossible to have infinite buffers in real world. A finite buffer is equivalent to an infinite buffer controlled by a classic kanban loop.

2.4.2 Multiple-Loop Structures

To control a given production system, a variety of kanban control methods can be used. Classic kanban control, CONWIP control and hybrid control are compared by Bonvik (1996), Bonvik et al. (1997), and Bonvik et al. (2000). The hybrid control method is demonstrated to have the best inventory control performance among these three control methods. Therefore, to study the design of control structures is valuable for developing insights into operational control.

After determining the control structure, the design parameters of the closed loop, such as the number of kanbans, are also related to the system's performance and cost. Consider a production line with pallets in Figure 2.5. CONWIP control is implemented by circulating pallets instead of kanban cards. Raw parts are loaded on pallets at machine $M1$ and unloaded from pallets at machine $M10$.

In the system, all machines are identical with failure rate p = 0:01, repair rate r = 0:1, and processing rate = 1:0. All the material buffer sizes are 20. The number of pallets Q and the size of pallet buffer B *are varied* to generate five cases.

The parameters and performance measures in terms of production rate and total inventory level are summarized in Table 2.2. The performance measures are plotted in Figure 2.6.

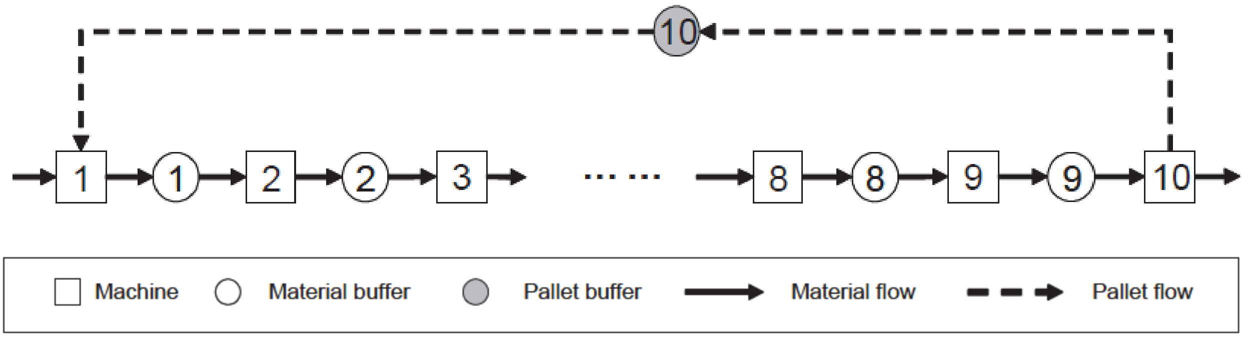


Figure 2.5: CONWIP control of a production line with pallets

Table 2.2: Design parameters and performance measures of a CONWIP-controlled production line (Gershwin, 2014)

Case Number	Q	B	Production rate P	Total inventory level T_{inv}
1	200	200	0.800288	90.1366
2	50	70	0.786535	66.41147
3	60	50	0.763461	53.30389
4	30	30	0.715328	38.18662
5	20	15	0.646548	20.80521

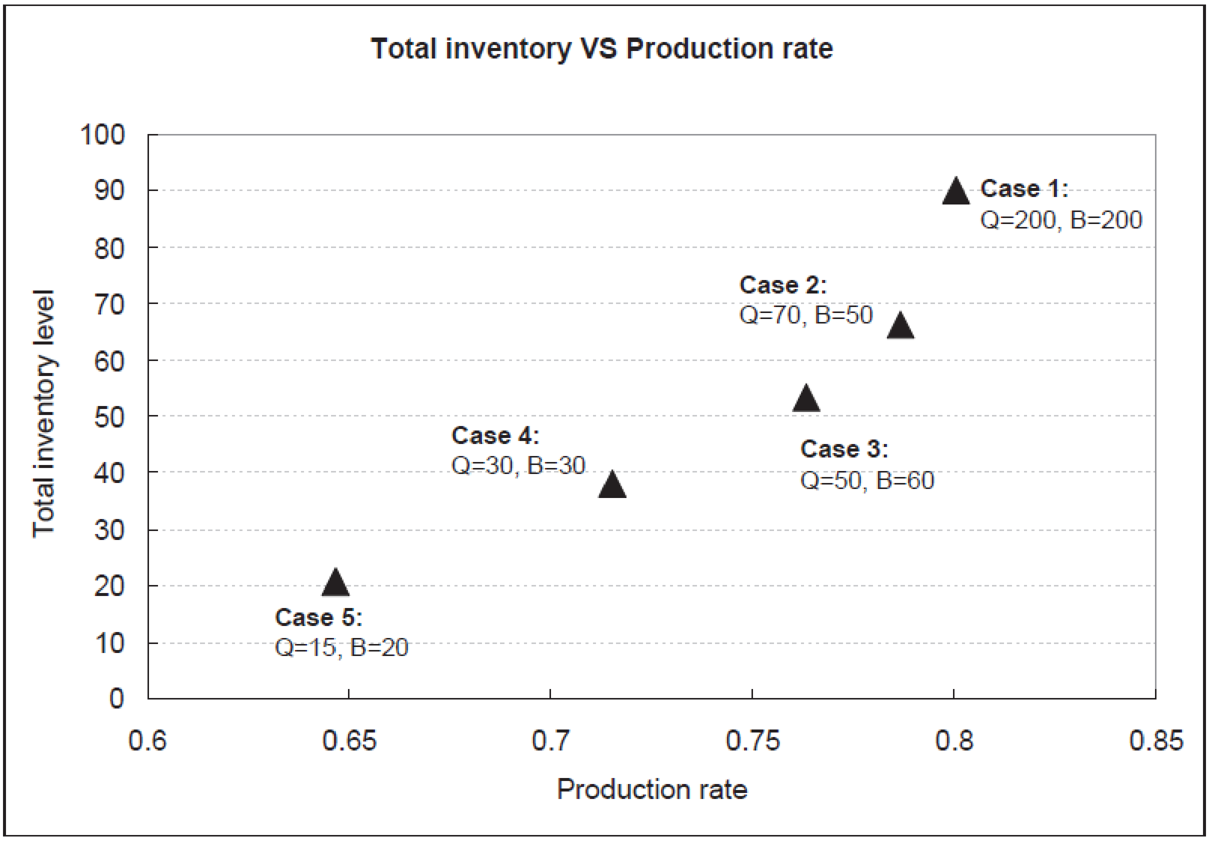


Figure 2.6: Production rate and total inventory level of CONWIP control while varying number of pallets *Q* and size of pallet buffer *B*

As these pallets cost money and take up space, the optimal selection of design parameters, such as the number of pallets and the storage buffer space of the pallets, has a significant dollar impact in profit. The profit *Y is* formulated as a function of production rate *P*, total inventory level *Tinv*, number of pallets *Q*, and size of pallet buffer *B*:

$$Y = C_P P - C_T T_{inv} - C_Q Q - C_B B \tag{2.3}$$

Where C_P is margin per unit production rate; C_T, C_Q, and C_B are cost coefficients of inventory, pallet, and pallet buffer, respectively.

A set of scenario analyses is performed by varying the margin and cost coefficients. The profits of five cases in six scenarios are listed in Table 2.3. It is observe that, when pallet cost or pallet buffer cost is high, the optimal solution is Case 5, which has the smallest number of pallets and smallest pallet buffer.

Table 2.3: Profits of five cases in six scenarios

Scenario Number	Coefficients				Profit of 5 cases					Optimal Case
	C_P	C_T	C_Q	C_B	Case 1	Case 2	Case 3	Case 4	Case 5	
1	1000	1	0	1	510.15	650.12	660.16	647.14	610.74	3
2	1000	1	0	2	310.15	580.12	610.16	617.14	595.74	4
3	1000	1	0	10	-1289.85	20.12	210.16	377.14	475.74	5
4	1000	1	1	1	310.15	600.12	600.16	617.14	590.74	4
5	1000	1	2	1	110.15	550.12	540.16	587.14	570.74	4
6	1000	1	10	1	-1489.85	150.12	60.16	347.14	410.74	5

In summary, the performance and cost of multiple-kanban production systems depend not only on control structures, but also on parameters such as number of kanbans. Therefore, an exhaustive study of the behavior of multiple-loop structures is needed. This study is challenging but highly valuable. It will provide a theoretical basis and practical guidelines for factory design and operational control using multiple-loop structures.

In recent years there has been a large amount of literature on the analysis and design of kanban systems. The methods can be categorized into simulation and analytical methods. As the analysis and design of kanban systems usually involve evaluating a large number of variations with different structures and parameters, analytical methods are much more promising in terms of computational efficiency. Another advantage of analytical methods is their effectiveness in investigating the properties of multiple-loop structures and developing intuition for system design and control. In this section, the development of manufacturing systems engineering will be reviewed with focus on the analytical work. Key issues and difficulties in analyzing systems with multiple-loop structures are explained. The review helps further understand the motivation of this research.

2.4.3 Manufacturing Systems Engineering Models and Techniques

A large number of models and methods have been developed to address the design and operations of manufacturing systems. An extensive survey of the literature of manufacturing systems engineering models up to 1991 appeared in Dallery and Gershwin (1992). More recent surveys can be found in Gershwin (1994), Altiok (1997), and Helber (1999). A review focused on MIT work and closely related research was presented by Gershwin (2003). Initially, the research of this area started from modeling two-machine transfer lines with unreliable machines and finite buffers using Markov chains (Buzacott & Shanthikumar, 2013). When Markov chains are used to model the stochastic behavior inherent in larger manufacturing systems, the scale and complexity of these systems often result in a huge state space and a large number of transition equations. Decomposition was invented as an approximation technique to evaluate complex manufacturing systems by breaking them down into a set of two-machine lines (building blocks). These building blocks can be evaluated analytically by using methods in Gershwin (1994). Selvaraj (2008) was one of the first authors to analyze finite buffer production lines by developing an approximate decomposition method. Huang et al. (2013) and Shadrack (2015) extended the decomposition method to analyze tree structured assembly/disassembly networks.

Consider the decomposition of a long production line in Figure 2.7. Each buffer in the original system has a corresponding two-machine line (building block). The buffer of this building block has the same size as the original buffer. In each building block, its upstream and downstream machines are pseudo-machines which approximate the behavior observed in the original buffer. Each pseudo-machine is assigned one failure mode. The building blocks are evaluated iteratively and the failure rate and repair rate of each failure mode are updated till convergence.

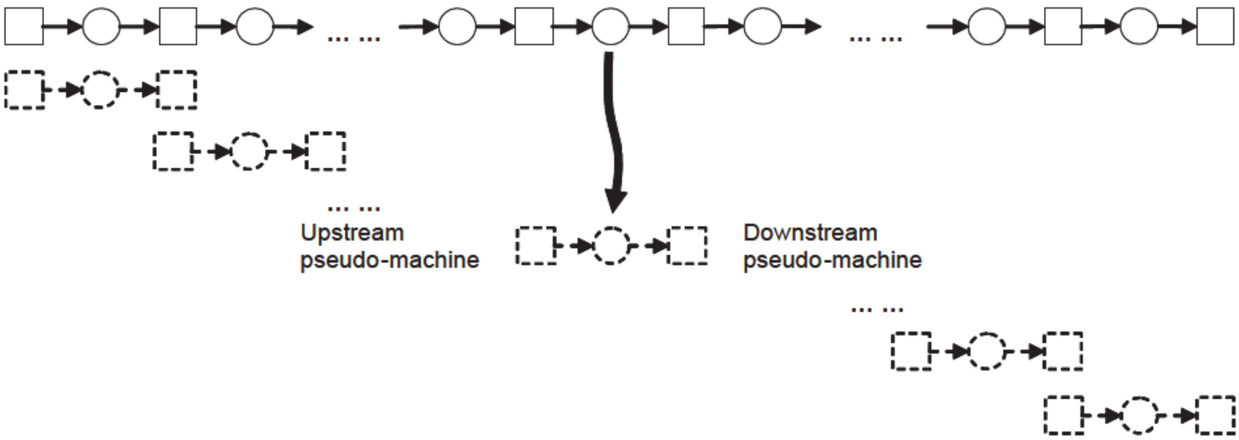


Figure 2.7: Long production line decomposition

2.4.4 Decomposition Using Multiple-Failure-Mode Model

A new decomposition method was presented by Tolio and Matta (1998). This method models the two-machine lines (building blocks) by assigning multiple failure modes to the pseudo-machines, instead of using single failure mode for each pseudo-machine. In this model, the downstream pseudo-machine is assigned all the failure modes in the original system that can cause the original buffer to be full. The failure modes in the original system that can cause the original buffer to be empty belong to the upstream pseudo-machine.

For example, the decomposition of a six-machine production line using Tolio's multiple failure-mode model is shown in Figure 2.8. When the tandem line is decomposed into a set of building blocks, the building block corresponding to buffer *B*2 approximates the behavior observed by a local observer at *B*2. The failure modes of machines *M*1 and *M*2 are assigned to the upstream pseudo-machine *Mu*(2) as they can cause *B*2 to be empty; while the failure modes of *M*3, *M*4, *M*5, and *M*6 are assigned to the downstream pseudo machine *Md*(2) as they can cause *B*2 to be full.

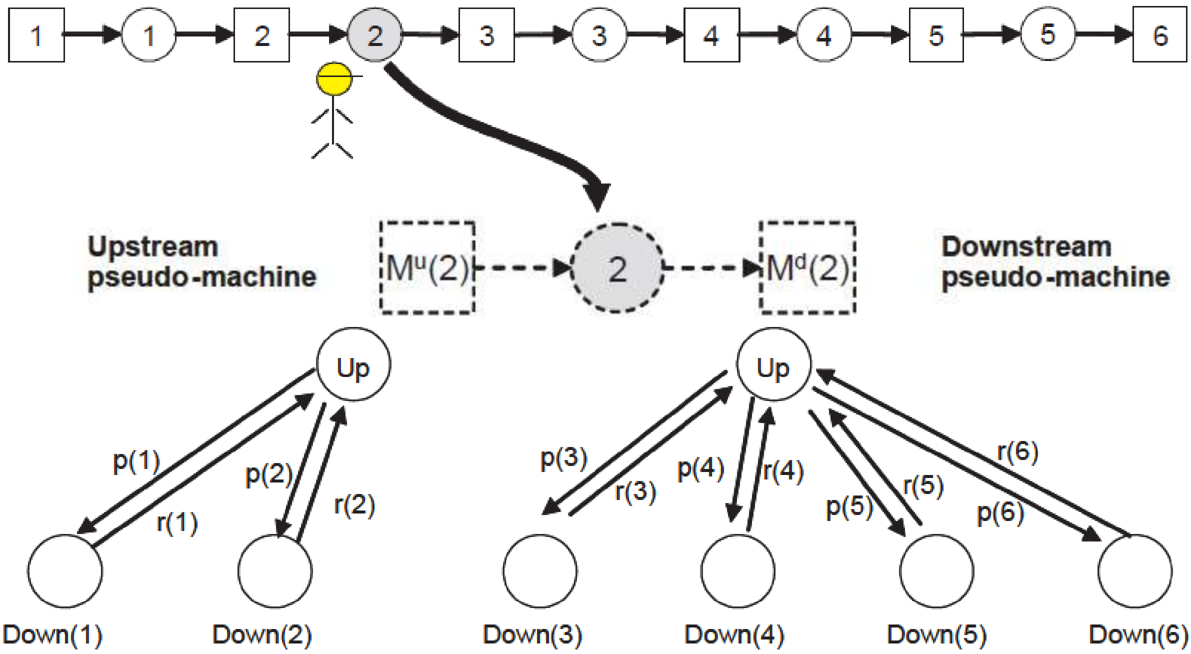


Figure 2.8: Decomposition of a six-machine production line using multiple-failure-mode Model

Up to this point, the systems discussed are acyclic systems. In other words, there is no closed loop in these systems.

2.4.5 Systems with Closed Loops

In the studies of systems with closed loops, Frein et al. (1996),Werner (2001) and Ershwin and Werner (2006) developed an efficient method to evaluate large single-loop systems using the decomposition method based on multiple-failure-mode model. Levantesi (2001) extended it to evaluate small multiple-loop systems. However, this method is not able to provide satisfactory speed and reliability while evaluating large scale multiple-loop systems.

Levantesi's method demonstrated the feasibility of his approach. But it had a very inefficient method for analyzing the propagation of blocking and starvation.

In addition, a systematic understanding of the behavior of multiple-loop structures has not been developed yet. It is important as it is needed for developing methods for optimal design and control using multiple closed loops. Key issues include how to choose control structures, and determine kanban quantities. In the literature, Monden (2011) presents the Toyota approach for determining the number of kanbans for each stage. This method, however, does not fully consider the randomness due to machine failures and depends on subjective parameters, such as safety factor. Several methods are presented in Hopp and Spearman (2001), Hopp and Roof (1998), Ryan et al. (2000), and Ryan and Choobineh (2003) to determine WIP level for CONWIP-controlled systems. These methods have the disadvantages that the manufacturing systems for control are simple production lines, and the methods are limited to specified control structure - CONWIP. There are some studies on the variations of kanban control structures in Gaury et al. (2000, 2001). However, these approaches are simulation-based and the number of variations is limited.

2.5 Cellular Manufacturing

The *cellular system* also known as *lean shop with linked-cell design* is considered to be a basic component of the lean-production philosophy (Black and Hunter, 2003). Nevertheless, alternative types of manufacturing systems also exist depending on the product characteristics and mix, the type of manufacturing philosophy, etc. The existing layout types are divided mainly into four categories (Tompkins, 1996):

The *Fixed Product Layout* is best applied in low volume production processes with low standardization and stable demand. It is the method of combining all workstations required to produce one product such as an aircraft, ship etc. within the area required for staging the product. A typical characteristic of this facility layout is that workstations are brought to the material since the referred product is usually very large and bulky.

The *Product Layout* is best applied in high volume production processes with high standardization and stable demand. It is the method of combining all workstations required to produce one product with *continuous flow* processing. Thus, the processing sequence is linear with the products flowing from one workstation to another.

The *Group Family Product Layout (Assembly Line)* is best implemented in medium volume production with medium process standardization. In this case, few products are produced at the same time under varying demand. The products are grouped into families and each family is treated as a pseudo product. Equipment is dedicated or semi-dedicated to manufacturing each family.

The *Process Layout* is more practical in low volume production with low process standardization. In this case, the demand is usually unstable. The production is conducted in *batches* and identical workstations are combined into departments. In this case what determine the layout is the process and not the product. The Product Layout and the Group Family Product Layout are the two types that mostly fit the lean philosophy. Further analysis of the cellular system is presented in detail in the following paragraphs.

Cellular Layout

Lean-production cells are designed to operate at less-than-full-capacity. The workstations within a cell are typically arranged in a U-shape for flexibility, so that workers may move from machine to machine, loading and unloading them with parts, following the shortest walk distance with the least possible obstacles.

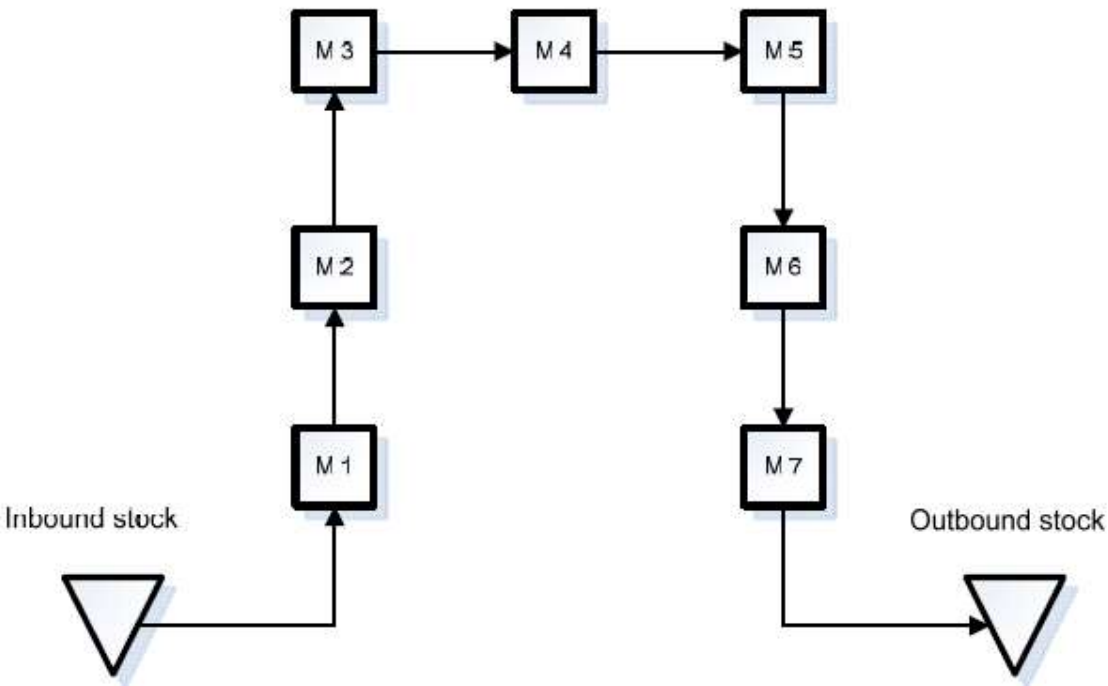


Figure 2.9: A U-shaped Cellular Layout (Hopp and Spearman, 2001)

In a JIT manufacturing cell, one operator is able to run two, three or more different machines, all performing operations on the same part, moving this part from operation to operation in sequence one-single piece at a time. This is due to the fact that a U-line layout enables the operators to be physically together side-by-side, back-to-back without interrupting, annoying or hindering each other. The workstations that perform successive operations are located close to each other, so that products and parts can flow easily from one to another. Moreover, this kind of layout supports flexibility in the number of workers since one worker may operate more than one (and possible all) workstations within the cell. Therefore, the number of workers can be easily adjusted to the demand and to the calculated cycle time (or takt time if the cell is the final assembly station).

However, in order to fully exploit the benefits of cellular manufacturing certain conditions must hold: a) cells must be staffed with multifunctional workers, organized in teams, and b) automation should be an integral part of all workers and other resources within the cell.

In order to organize the available machines properly in manufacturing cells one has to fully analyze the product (and part) characteristics and form appropriate part families. There are many methods of cell formation. A typical one is the one presented by Braglia, *et al* (2006) and includes the following steps:

1. Specify which machines are used by which parts
2. Use the "Jaccard" similarity function to estimate the similarity of the products via the machine part matrix:

$$S_{ij} = \frac{X_{ij} + \sqrt{X_{ij} . Y_{ij}}}{X_{ij} + X_i + X_j + \sqrt{X_{ij} . Y_{ij}}} \tag{2.4}$$

Where $0 \leq S_{ij} \leq 1$

X_{ij}= number of machines used by both part 'i' and part 'j' (number of matches),
X_i= number of machines used by part 'i' only,
X_j = number of machines used by part 'j' only,
Y_{ij}= number of machines that are used neither by part 'i' nor by part 'j' (number of misses).
3. Accumulate the results in a similarity matrix and assemble the follow-on part group.
4. Reorganize the machine part-matrix by determining the machine sharing. The norms are:

i) the machines that are not shared should be positioned into a cell, in order to accomplish continuous flow processing,

ii) for the machines that are shared use the "Signal Kanban".

Having formed a cell, capacity or cycle time (or takt time) is adjusted to respond to changes in the customer demand: It is set to produce parts at exactly the rate set by the parent subassembly, no faster or slower. Cellular design results in significant benefits. Reductions in setup times, raw materials, WIP, number of defects; as well as reduction of the cycle time variability. As a result, quality is improved and total manufacturing costs are reduced. Finally, a smoother and faster flow of products through operations is achieved.

2.6. Quality at the Source Techniques

The implementation of *Quality at the Source* techniques aim to reduce significantly manufacturing costs (e.g costs occurring by the shorter life cycle of the machines, major equipment repairs, etc) while upgrading the quality of the products at the same time. As referred previously, Quality at the Source rests on two principles: a) the Total Productive Maintenance (TPM), which aims to preserve and enhance equipment reliability, and b) Total Quality Management which focuses on qualitative management by fostering an overall environment supportive of quality improvement.

The tools of TPM and TQM are described below. The techniques of achieving TPM focus on: Preventive Maintenance which is the scheduled maintenance to avoid breakdowns, Predictive Maintenance which is the prediction of pending machine breakdowns, and appropriate intervention to prevent them, Improvement Maintenance which is the upgrading of a workstation to prevent a problem before its reappearance, 5 Ss maintenance: the *Seiri*, *Seiton*, *Seiso*, *Seiketsu*, and *Shitsuke*. *Seiri* is segregation of unnecessary tools from the necessary and the elimination of what is not needed. *Seiton* is the process of arranging the tools in the production space in a way that simplifies access and use. *Seiso* is the process of daily cleanliness, which enhances the quality level. *Seiketsu* is the frequent revisiting and the standardization of the above three steps. *Shitsuke* is the motivation to sustain and the promotion of adherence through visual performance measurement tools (Crabill & Harmon, 2000; Womack & Jones, 2003).

The techniques of TQM focus on the following:

Standardized Work is attained by applying the takt time to the final assembly. This is accomplished by defining the sequence of the processes tasks, designing properly the cell and establishing the minimum number of pieces (stock-on-hand) needed to maintain a smooth flow of work so that the cycle time to be equal or slightly less than the takt time (Black & Hunter, 2003).

Time studies and work methods techniques are used to determine the minimum amount of work needed to perform a task. Process standardization is applied to expose problems and motivate their solution by implementing new methods. In this manner, inherent sources of variation are eliminated.

Visual Control is referred to the design of a production system that controls itself by clearly identifying where the problems are, and by creating a sense of urgency wherever is necessary. In particular, visual means of control should be designed in order for each worker to assume actions for maintaining the control of the production system (Crabill *et al*, 2000). Autonomation is one example, in which and on light systems are installed to warn the workers when a problem occurs, or even stop the machines if necessary. Kanban cards and the heijunka box represent other visual control means to inform the system at any time about the level of WIP, the rate of the production process, the production targets, etc. In summary, visual control establishes the means to visualize whether the state of the system is within acceptable limits, and to pinpoint waste (Crabill *et al*, 2000).

Poka Yoke (or mistake proofing)is a device or a process for defect prevention that aims to avoid errors in the receiving of orders or in the manufacturing process. The whole idea is to produce zero defective products by using the poka yoke, a bunch of small devices that are used to either detect or prevent defects from occurring in the first place. An example is a beam of photocells on the material boxes along an assembly line that blocks the product flow to the next step if some components are missing. If the beam of cells is not switched off in each container that contains each part of the product, the flow of the product towards the next workstation is blocked.

Kaizen (or Kaizen Event (Blitz)) is a Japanese term meaning continuous and unending improvement in the processes in order to eliminate waste and to enhance value. Kaizen operates mainly in two levels: a) in an on-going process of identifying opportunities for improvement and b) in short-term projects (Kaizen Event). The kaizen technique aims in reducing non-value added activities such as setup times, unnecessary transport of materials, etc. This kind of improvement is mainly attained by training properly the employees in order to obtain problem solving skills and thus, to be able to identify and implement potential improvements (Womack & Jones, 2003; Crabill *et al*, 2000).

The frequent and scheduled implementation of the above quality at the source techniques has long-term benefits. Operators are more recognizable with production equipment and pending problems. The application of visual controls improves the quality of the products since processes are in better control. Consequently, system's reliability, flexibility, and capability are improved by eliminating the level of WIP at the same time and by extension the total manufacturing costs.

2.7 Optimization Approach to Route Design of a Just-in-Time System

A large part of a just-in-time supply system (JSS) is routing. Routing may be formulated and solved as an optimization process, and a problem specifically tailored for JSS was first accomplished by Chuah and Yingling (2012). Such a problem looks simple when it is small, but becomes very complex as soon as the number of parts and suppliers increases. The goal of routing is to provide efficient transportation routes between the suppliers and the plant. Routing is presented as math programming problems that consider a variety of requirements expressed as constraints on the system. These constraints describe the roles of JSS in supporting the manufacturing plant and the suppliers' production systems. It is noted that in practice that JSS routing is done manually with computer assistance and is very time consuming.

Indeed, the routing process is a bottleneck in the re-planning process for JIT systems to accommodate demand changes over time. Optimization shows promise for automating and speeding this process and may someday open the door for more frequent re-planning as well as day-to-day modifications of routes as unplanned events transpire.

2.7.1 General Frequency Routing Problem

General frequency routing problem (GFR) is a mathematical formulation developed in this dissertation that is designed to determine JSS routes described in the previous chapter. GFR may be viewed as an extension of the vehicle routing problem (VRP), VRP with time windows (VRPTW), and common frequency routing (CFR), a class of problems whose objective is to minimize the cost of delivery between a depot and a number of suppliers in a series of round trip routes.

A detailed review of VRP can be found in Bramel and Simchi-Levi (1997). VRPTW is VRP with time windows constraints, where every supplier in VRPTW has an opening and a closing service hour that restrict routing to that window. In contrast to VRP, VRPTW requires temporal as well as spatial representation of the problem, dramatically increasing dimensionality. The problem is first discussed in Solomon (2016) and there are many ways to solve it (e.g., Bard et al., 2014; Desrochers et al., 2012; Taillard and Badeau, 1997). A feasible solution of VRPTW is also a feasible solution of VRP, since they have the same objective function. Common frequency routing problem (CFR) is a vehicle routing problem that builds upon VRPTW to meet the needs of JSS (Chuah & Yingling, 2012). CFR is restricted in the sense that it permits only one route to visit a part source, instead of multiple routes, but such routes have an optimized pickup frequency that performs multiple pickups. Although in reality JSS routes do not have this limitation, simplifying the route designs this way has many advantages both from the point of view of practical solution of the routing problem using optimization methods as well as execution and management of the routes in practice. It is important to note that CFR employs a system-level space (or, effectively, total inventory) constraint that forces the routes to carry fewer parts in higher variety, such that every route needs several rounds of pickups each time period to ship their respective parts and keep pace with demand. Such multiple pickups reduce the shipment size while increasing the pickup frequencies.

The GFR problem presented below has the load constraints of VRP, the time windows constraints of VRPTW, and the pickup frequency and space constraint of CFR. Furthermore, all part sources in GFR have their own pickup frequencies, which are independent of the routes' pickup frequencies. In contrast to CFR, which requires each part source be served by a single route run at a determined frequency, a GFR schedule can use multiple routes to cover a set of part sources, while each route may only visit a partial set of these part sources. A solution to GFR consists of a number of these schedules that together cover all the part sources. This relaxation greatly expands problem dimensionality in order to more fully explore candidate route designs that might be deployed in practice. Note that a CFR solution can be converted to a GFR solution, but CFR cannot generate all the feasible solutions in GFR. The differences between the two problems will be clear after comparing their respective mathematical formulations.

CFR is a unique problem with only a number of related papers (Chuah, 2000). The review below summarizes the literatures for GFR. Concerning prior work that directly addresses JIT logistics, Popken devises an approach to consolidate inbound freight for JIT systems through transshipment points (Popken, 1994). He models the inventory costs of freights based on weights and volumes and considers tradeoffs in transportation and inventory holding costs, but his algorithm is intended for long term planning and does not directly consider vehicle routing.

Crainic and Rousseau developed a multi-commodity, multimode freight transportation algorithmic framework that includes frequency and vehicle routing (Crainic & Rousseau, 2016). The frequency is measured in terms of quality of service for each mode of transportation, instead of its effect on pickup loads. Although the paper does not concern JIT, it may be applied to the GFR problem by adding heijunka and space constraints.

Inventory Routing Problem (IRP) (Bard et al, 1998; Chien et al, 2009) combined the inventory system with the vehicle routing problem and usually deals with the distribution of goods rather than pickup of goods. IRP assumes that each supplier maintains a number of pallets and receives a delivery from a central depot when the number of pallets at that supplier is low. The IRP treatment of the problem differs from the kanban system for inventory control in JIT routing. The kanban system emphasizes a smooth flow of parts, instead of a complete reduction in total cost. Parts are preferably transported directly to the consumption points when they arrive at the plant without going through a warehouse.

In split delivery vehicle routing (SDVR), the suppliers' pickup loads may be split into different routes to save the distance cost. Dror and Trudeau analyze SDVR and present a local search heuristic on the problem (Dror & Trudeau, 2011). Mohri et al. suggested a mathematical programming based approach to the problem (Mohri et al, 1996). Fizzell and Giffin extend SDVR to consider time windows and present three heuristics to solve the extended problem (Frizzell & Giffin, 2011). The problem in this paper addresses SDVR in a different way, where arbitrary splitting of loads is not allowed unless the splitting is by frequency. It performs actual splitting of loads based on volume where a split of loads may, in certain cases, increase or decrease the total shipment volumes due to rounding. If a load from a supplier is going to several different consumption points in the plant, the load may split among multiple routes based on these consumption points. There are two general approaches to solve VRP type problems: exact methods and heuristics. The exact methods are direct solving with linear programming (Bard et al., 2014) and column generation with Dantzig-Wolfe decomposition (Desrochers et al., 2012). Both methods employs branch and bound techniques to achieve integer solutions. In this research, the focus is on the meta-heuristic approach as a practical approach for solving realistic size problems. Before jumping into that, we first discuss the mathematical formulation for GFR in the next section.

2.7.2 Mathematical Formulation of the General Frequency Routing Problem

GFR, as formulated in this dissertation, is a mixed-integer non-linear optimization problem. Although the objective function is linear, some of the constraints are not linear. The objective function and the constraints are expressed in terms of variables, parameters, and inequalities. The objective of GFR is to minimize the sum of the transportation cost and the transport space/inventory cost. The transportation cost is proportional to the sum of all travel distances between the suppliers. The transport space cost is proportional to the sum of the average load per pickup for each transported part.

There are five types of constraints: flow, space, load, time, and heijunka. The flow constraints are similar to the flow constraints in VRP problem, except for the addition of the supplier (part source) pickup frequency. As such they insure continuity of the route through a given supplier and that the route starts and ends at the appropriate location. The space constraints define the transport space allocated to the various suppliers on the route. It is similar to the space constraint in CFR. The load constraints define the accumulation of load during the course of picking up parts at the suppliers. They also define the vehicle capacity constraint. The time constraints are constraints similar to those in VRPTW problem, where trailer can only visit the suppliers during their respective service hours. The heijunka constraint controls the supplier pickup volume by restricting the visiting time. Good heijunka means that pickups occur frequently and are evenly spaced over time; bad heijunka means otherwise. Heijunka is a Japanese word that means make things level and standard. It is a very important concept in this problem because it can reduce overall inventory needs and enable the enhanced operations control that results from continuous flow of parts through the supply chain in a JIT environment.

Figure 2.10 shows the complete GFR formulation. Parameter definitions are given in Table 2.4 and variable definitions are given in Table 2.5. A detailed explanation follows.

Objective function:

$$\min \sum_i \sum_j \sum_k c_{ij}^k x_{ij}^k + \sum_i \sum_k \beta_i D_i^k$$

Bounds on variables:

$$x_{ij}^k = \{0,1\}$$
$$T_i^k \geq 0$$
$$L_i^k \geq 0$$
$$D_i^k \geq 0$$
$$s_i \geq 0$$
$$r_i \geq 0$$

flow:

$$r_i \sum_j \sum_k x_{ij}^k = 1 \quad \forall i$$
$$\sum_j \sum_k x_{ij}^k \geq 1 \quad \forall i$$
$$\sum_i x_{ij}^k - \sum_i x_{ji}^k = 0 \quad \forall j, \forall k$$
$$\sum_i x_{io}^k = 1 \quad \forall k$$
$$\sum_i x_{oi}^k = 1 \quad \forall k$$

space:

$$\sum_j D_i^k x_{ij}^k - r_i D_i \geq 0 \quad \forall i, \forall k$$
$$\sum_i r_i D_i \leq \gamma$$

time:

$$a_i \leq T_i^k \leq b_i \quad \forall i, \forall k$$
$$x_{ij}^k (T_i^k + t_{ij} - T_j^k) \leq 0 \quad \forall i, \forall j, \forall k$$

loads:

$$D_i^k \leq L_i^k \leq Q^k \quad \forall i, \forall k$$
$$x_{ij}^k (L_i^k + D_j^k - L_j^k) \leq 0 \quad \forall i, \forall j, \forall k$$

heijunka:

$$(b_i - a_i) r_i - s_i = 0 \quad \forall i$$
$$\sum_j x_{ij}^k x_{ij}^l \tau(s_i) \leq \left| T_i^k - T_i^l \right| \quad \forall i, \forall k, \forall l$$

Figure 2.10: The General Frequency Routing Problem Mathematical Formulation

The formulation corresponds to a graph with nodes and edges. Each node in the graph is a part source. A special node is designated as the origin or the manufacturing plant. A route starts and ends with this node. There are edges connecting every node to every other node in the graph. Associated with each edge is a cost proportional to the travel distance between two nodes.

The formulation uses three indices: *i*, *j*, and *k*. Both index *i* and index *j* refers to a node in the graph, i.e. a particular part source. For an example, the count of all *i* is the number of nodes in the formulation. Both *i* and *j* are necessary because a pair of indices are required to express a connection between a pair of nodes. When *i* or *j* equals the special value *o*, we are referring to the origin of the graph, the manufacturing plant. Index *k*, on the other hand, refers to a route. A count of all *k* is the possible number of routes in the solutions. Candidate routes are generated in the course of a solution to the problem and need not be enumerated a priori. Parameters are constant values set prior to optimization. The parameters of GFR are listed in Table 2.4:

Table 2.4: The Parameters of General Frequency Routing Problem

Symbols	Descriptions
a_i	The start of service time of node *i*.
b_i	The end of service time of node *i*.
${c_{ij}}^k$	The cost of traveling, usually proportional to the distance, between nodes *i* and *j* on route *k*.
t_{ij}	The travel time between nodes *i* and *j*.
D_i	The quantity of load to pickup at or deliver to node *i* per unit time period.
Q^k	The transportation capacity limit of a route, normally due to the size of a trailer.
β_i	The coefficients for the space or inventory cost (of node *i*) in the objective function.
γ	The amount of space, or effectively, inventory allocated to the entire system.

Variables represent degrees of freedom in the solution space and their values describe a solution. The variables of GFR are listed below:

Table 2.5: The Variables of General Frequency Routing Problem

Symbols	Descriptions
${x^k}_{ij}$	A binary equal to one if node *i* connects to node *j* in route *k* and zero otherwise. The ${x^k}_{ij}$ define the routes by identifying the connections *i, j* that the route follows.
${T^k}_i$	The time when route *k* reaches node *i*.
${L^k}_i$	The cumulative space reserved for the load when the vehicle traversing route *k* arrives at node *i*.
${D^k}_i$	The load to pickup at or deliver to node *i* when route *k* arrives.
s_i	The loading and unloading time at node *i*.
r_i	The interval between pickups or deliveries at node *i* or, equivalently, the inverse of frequency that node *i* is visited.

As mentioned earlier, there are five types of constraints. Each type of constraint is a set of inequalities that defines the solution space of the problem. These inequalities and their detailed descriptions are given below:

Table 2.6: The Inequalities of General Frequency Routing Problem

Inequalities	Descriptions
$r_i \sum_j \sum_k x_{ij}^k = 1 \quad \forall i$	The interval between pickups (proportion of the unit time period) is the inverse of the number of pickups during the unit time period.
$\sum_j \sum_k x_{ij}^k \geq 1 \quad \forall i$	At least one route leaves part source *i*.

Table 2.6 (continued)

$\sum_i x_{ij}^k - \sum_i x_{ji}^k = 0 \quad \forall j, \forall k$	In every route, the number of arrivals and the number of departures at a part source are equal, insuring continuity of the routes.
$\sum_i x_{io}^k = 1 \quad \forall k$	All routes *k* return to the origin or the plant.
$\sum_i x_{oi}^k = 1 \quad \forall k$	All routes *k* leave the origin or the plant.
$\sum_j D_i^k x_{ij}^k - r_i D_i \geq 0 \quad \forall i, \forall k$	The load to pickup for part source *i* on route *k* is greater than or equal to the load required to meet demand for part *i*, $r_i D_i$.
$\sum_i r_i D_i \leq \gamma$	The sum of all loads per pickup uses at most the space allocated for the entire operation, γ. Note that as γ decreases, routes must be run at higher frequency to insure that storage space or inventory at the plant does not exceed γ in aggregate.
$a_i \leq T_i^k \leq b_i \quad \forall i, \forall k$	A route *k* visits a part source *i* during its open service time given by $[a_i, b_i]$
$x_{ij}^k (T_i^k + t_{ij} - T_j^k) \leq 0 \quad \forall i, \forall j, \forall k$	If there is a travel between a pair of nodes *i* and *j* by route *k* ($x_{ij}^k = 1$), the difference in time between the arrival at the next node and the departure at the previous node is at least the traveling time, t_{ij}.
$D_i^k \leq L_i^k \leq Q^k \quad \forall i, \forall k$	The space allocated on the trailer prior to the visit of part source *i* on route *k* is at least the load it picks up at part source i, D_i^k and at most the capacity of the trailer running the route, Q^k.

Table 2.6 (continued)

$x_{ij}^k(L_i^k + D_j^k - L_j^k) \le 0 \quad \forall i, \forall j, \forall k$	If there is a travel between a pair of nodes ($x_{ij}^k=1$), the difference in aggregate space allocated between the current part source and the previous part source is the load picked up at the current node, D_j^k.
$(b_i - a_i)r_i - s_i = 0 \quad \forall i$	The fraction of the time window allocated per pickup, $(b_i\text{-}a_i)r_i$ must be equal to the time required to unload and load the trailer, s_i.
$\sum_j x_{ij}^k x_{ij}^l \tau(s_i) \le \lvert T_i^k - T_i^l \rvert \quad \forall i, \forall k, \forall l$	The time between visits to a node is greater than or equal to a function $\tau_i()$ of the loading and unloading time, s_i.

For sake of comparison, below is the CFR mathematical formulation as presented in (Warnecke & Huser, 2011):

Objective function:

$$min \sum_i \sum_j \sum_k f^k c_{ij} x_{ij}^k + \sum_i \sum_j \sum_k \beta_i D_i^k x_{ij}^k$$

variables:

$$x_{ij}^k = \{0,1\}$$
$$T_i^k \ge 0$$
$$L_i^k \ge 0$$
$$f^k \ge 0$$

space:

$$\sum_i \sum_j \sum_k D_i^k x_{ij}^k \le \gamma$$

flow:

$$\sum_j \sum_k x_{ij}^k \ge 1 \quad \forall i$$
$$\sum_i x_{ij}^k - \sum_i x_{ji}^k = 0 \quad \forall j, \forall k$$
$$\sum_i x_{io}^k = 1 \quad \forall k$$
$$\sum_i x_{oi}^k = 1 \quad \forall k$$

time:

$$a_i \le T_i^k \le b_i - \tau(f^k) \quad \forall i, \forall k$$
$$x_{ij}^k(T_i^k + t_{ij} - T_j^k) \le 0 \quad \forall i, \forall j, \forall k$$

loads:

$$D_i^k \le L_i^k \le Q^k \quad \forall i, \forall k$$
$$x_{ij}^k(L_i^k + D_j^k - L_j^k) \le 0 \quad \forall i, \forall j, \forall k$$

Figure 2.11: The Common Frequency Routing Problem Mathematical Formulation

The definitions of variables and parameters in CFR are identical to GFR. CFR, however, employs a parameter, *fk*, not employed in GFR, where *fk* is the pre-assigned frequency of route *k*, which may or may not be selected by the solution (multiple choices are available). Moreover, the quantity of parts picked up by route *k* is *Di k* as determined by dividing the total demand per time unit by the number of pickups per time unit and applying a rounding factor.

2.7.3 Differences in the Utilization of Time Windows between GFR and CFR

In CFR, there is no inequality constraint for heijunka, as it is assumed that the *fk* routes in CFR are equally spaced over the maximum possible span of the time windows visited on the route. This span or time band for distributing the routes depends on (i) the time windows of each part source, (ii) the sequence the part sources are visited, and (iii) the transit times between part sources, see Figure 2.12. Nevertheless, the assumption potentially limits each route in the solution to a narrow band of time, wasting a large portion of the suppliers' time windows. This effect is most pronounced when one visits a supplier that with a late opening time window and later in the route visits a supplier with an early closing time window after a long transit time between these suppliers. Although not permitted in CFR, dropping a number of pickups from a limiting supplier can widen the band.

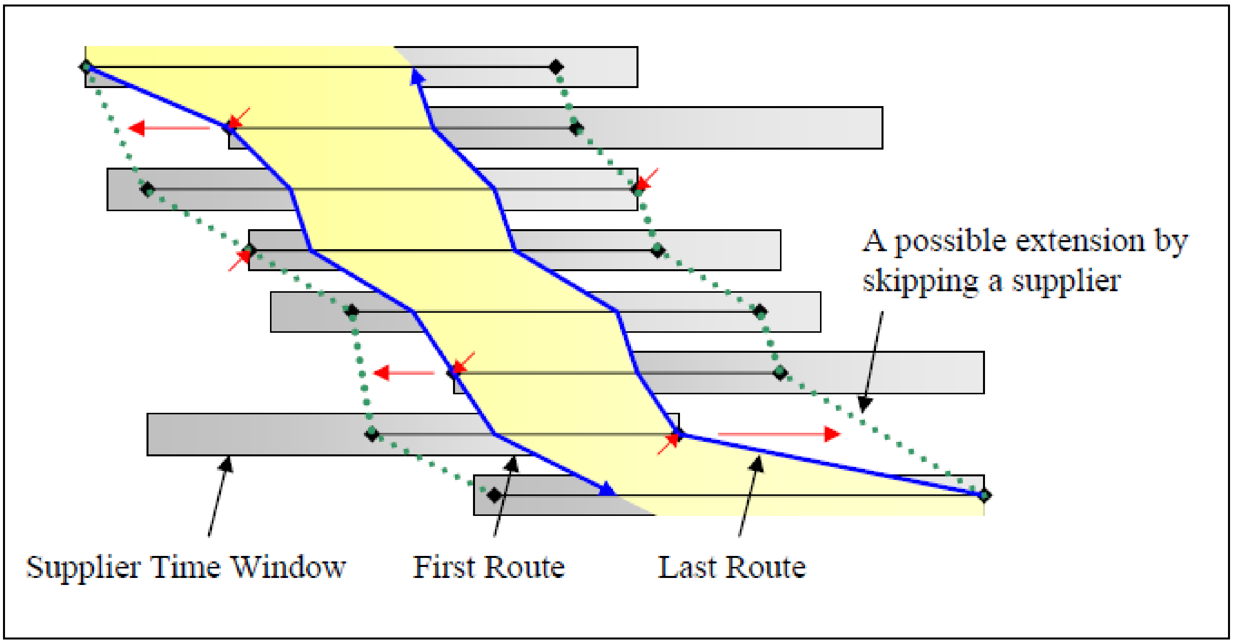


Figure 2.12: A limited band of time window is formed from a CFR solution (Warnecke & Huser, 2011)

The band of time window also exists in GFR, albeit a little bit different, as there are different heijunka requirements in GFR. GFR allows sharing of part sources and splitting of the part source load, where two or more routes can serve the same node in the graph. Therefore, the band as discussed above is wider in GFR. In fact, routes in GFR may crisscross a supplier time window to avoid the limited time, as shown in Figure 2.13. Crisscrossing, or out of order suppliers visiting, is one of the reasons some solutions in GFR are not feasible in CFR.

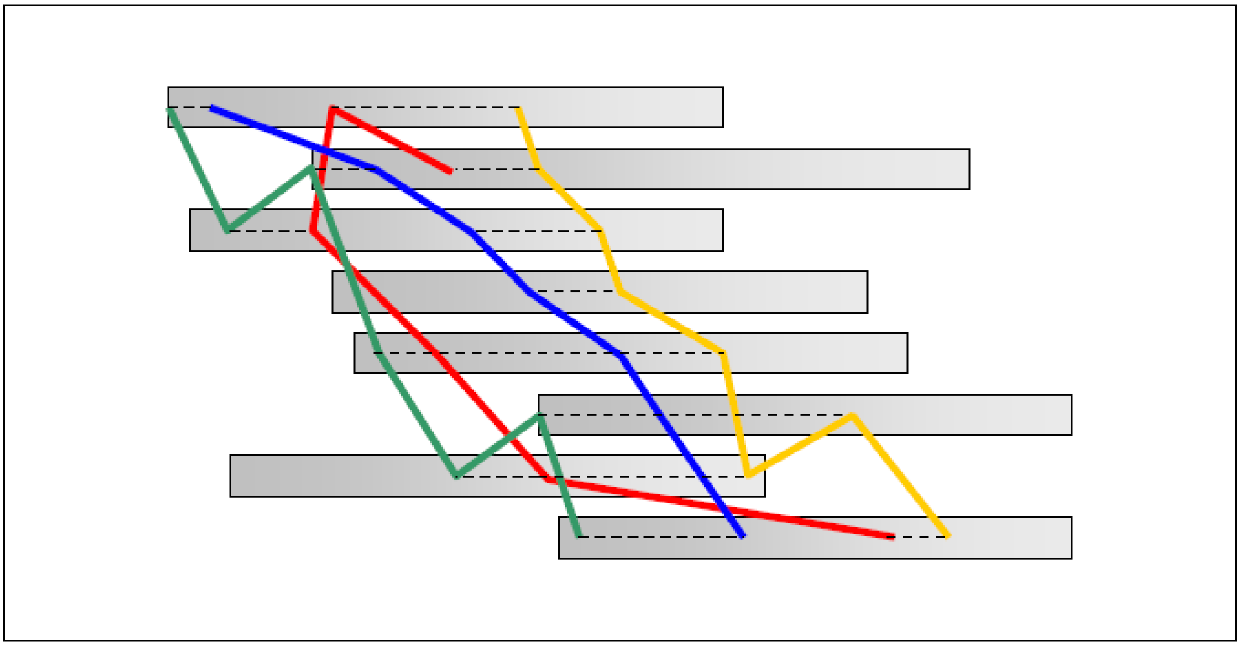


Figure 2.13: Crisscrossing in visiting the suppliers (Warnecke & Huser, 2011)

Although crisscrossing relaxes time window constraints, crisscrossing may not be a good thing for the suppliers and the plant, especially when the parts are sequenced. Crisscrossing may significantly change the order of pickups at the suppliers and the order of arrivals at the plant. It requires both the suppliers and the plant to change the sequence of the shipments of parts and the receiving of parts, adding another layer of complexity to the problem that must be managed. Hong describes a sequencing operation in a case study where a large part of the value added is putting parts in the correct order (Hong, 2003). If crisscrossing is not important or can be readily managed, then GFR is a good formulation for JSS. Otherwise, CFR with the option to drop a number of pickups may be the better approach.

In general, crisscrossing routes tend to exist in GFR. Given a route with a specific number of pickups and suppliers, if we assume that it is efficient, then it is the shortest route in the graph. Since the objective of GFR and CFR is to find the shortest route in the graph, it is reasonable to assume that the route will be generated by both algorithms. CFR presupposes that the route runs multiple times, but not in GFR. Suppose that the routes to these suppliers in GFR crisscross during their visits; then these routes are alternate shortest routes or the same route running in reverse. At high frequency (e.g., γ is small), routes tend to be time window constrained. Hence, having alternate shortest routes are normal. At low frequency, however, the routes are capacity constrained. Then, the only way the GFR routes can dominate the shortest route is to be the shortest route. Furthermore, CFR and GFR routes tend to be longer due to the sharing of small loads, especially at high frequency. Suppose then some of the GFR routes run in reverse; then the time window is better utilized with crisscrossing since the visits at the beginning of the normal route may go at the end of the reverse route. The suppliers in the middle of the route are likely to clash, if these routes have the same number of nodes. However, it is possible to simply dropping a number of visits on the route without increasing the route cost. In this way, GFR routes complement one another, resulted in highly complex pickup sequences. In summary, we expect that GFR routes will be more complex and less “organized” than CFR routes but more efficient. This behavior could be confirmed by studying the results of GFR route designs when we solve the formulation.

2.8 The Just In Time (JIT) Concepts

Despite the popularity and an abundant literature about JIT, there is as yet little in the way of underlying theory. Many experts in their books have developed their own JIT concepts derived from Ohno’s works. Monden (2011) consolidated the scientific concepts of JIT and uses the term Toyota Production System. Shingo (2012) elaborated the practical concepts of JIT and uses the same term as Monden. The International Motor Vehicle Program MIT (Womack & Jones, 2003) developed a broader JIT concept called *Lean Production* after conducting international research in the automotive industry. Hall (2013) consolidated the comprehensive JIT concept called Zero Inventory after conducting research supported by American Production and Inventory Control Society (APICS). Therefore, each expert created their own JIT concept. However, the JIT definition by Hall (2013) which is mostly accepted defined JIT, in broad sense, as an approach to achieving excellence in a manufacturing company based on continuing elimination of waste (waste being considered as those things that do not add value to the product). In the narrow sense, JIT refers to the movement of material at the necessary place at the necessary time. The implication is that each operation is closely synchronised with the subsequent ones to make that possible.

The broad-sense JIT concept, also known as *Big JIT* or *Lean Production*, covers all activities for reducing wastes, maintaining relations with suppliers, and improving quality. In contrast, the narrow-sense JIT concept, known as *Little JIT* or *Pull Production*, is limited to all efforts to reduce inventory at the shop floor (Chase, 2011).

2.8.1 The Purposes of the JIT System

The primary goal of the JIT system is cost reduction through elimination of waste (Shingo, 2012; Sugimori, 2014). According to TMC, waste refers to anything that is over the *minimum* requirement for production such as equipment, materials, parts, space and workers' time which are absolutely essential to *add value* to the products (Edosomwan et al., 2009). Since waste actually reflects the major causes of problems in a production system, it must be eliminated. Besides the above primary goal, there are three subgoals that must be achieved in employing a JIT system i.e. quantity control, quality control and respecting human relations (Monden, 2011). Quantity control includes all efforts that are directed to stabilise fluctuation in demand quantities and variation of production processes. Quality assurance is developed to assure each process supplies only good units to the next operation. The JIT system allows the human resources to operate the system by themselves. Consequently, respecting human relations and teamwork should be promoted in the JIT implementation.

By employing a JIT system, companies can obtain many benefits. The major benefits are usually related to reduced Work-In-Progress (WIP), improved manufacturing cycles, increased speed of information exchange and upgrading productivity. Increased information exchange results in a close link between production activities and market requirements, therefore, this system also increases a company's quick response in anticipating a change of demand. A company employing JIT concepts is usually characterised by lower inventory or WIP, smaller production lots, more frequent delivery of parts and components, more stable production volume and lower setup times (Philipoom, 2014).

2.8.2 The Pull System and Kanban

To implement the concepts successfully at the shop floor level JIT needs quick exchange of information amongst workstations. This is because a JIT system requires production in smaller lots and more frequent delivery of parts and components, thereby all workstations must quickly get information about changes of the timing and quantity of demand requirements. This motivated TMC to develop a *Pull Production Concept* or a *Pull system*. The logic behind the pull system means that nothing will be produced until it is needed. The principle of the pull system is that a preceding workstation operates if and only if there is a requirement from the subsequent workstation. This concept is completely different to the traditional push system that delivers materials just to achieve a predetermined schedule and then pushes completed parts into the subsequent workstation as soon as they are completed (Joo & Wilbert, 2013). Accumulation of WIP then occurs if the withdrawal rates of the succeeding workstation are lower than production rates of the preceding workstation.

Since the pull system requires all workstations to get information quickly about a change of demand requirement from the final process (marketplace), a means for the information exchange between two processes is required. *Kanban*, a Japanese term for card or signal, is then used to realise the information exchange as well as acting as a means of production control and material transportation between stations. Although Kanban can be any means, in practice, Kanban is usually a sort of card that is covered by a vinyl envelope that authorises the preceding workstation to produce an order. A Kanban passes information from one workstation to another workstation about what and how much to produce as written on the card. Other information that is usually included into a Kanban is the part number and description, the container capacity, the preceding workstation and the subsequent workstation. Figure 2.14 and 2.15 show two typical Kanbans that are used.

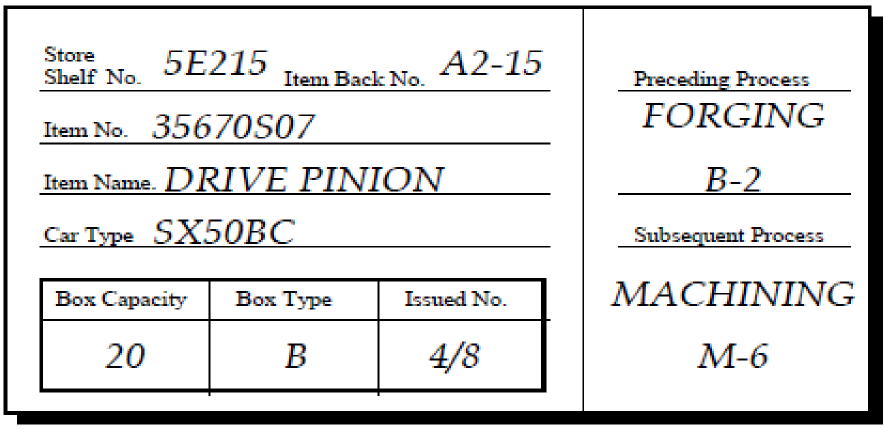


Figure 2.14. Withdrawal Kanban (WLK) (source: Monden [2011])

As waste is progressively eliminated, the number of Kanbans and hence the inventory is gradually reduced to a minimum level. The supervisor can control this at the lower level by withdrawing cards to *tighten* the system. On the other hand, there may be circumstances where a card is added i.e. some temporary quality problems or an increase in production rates.

Basically, there are two types of pull systems that are identified by the types of Kanbans used i.e. a two-card pull system that employs Withdrawal Kanban (WLK) and Production-Ordering Kanban (POK) and a single-card pull system that just employs WLK.

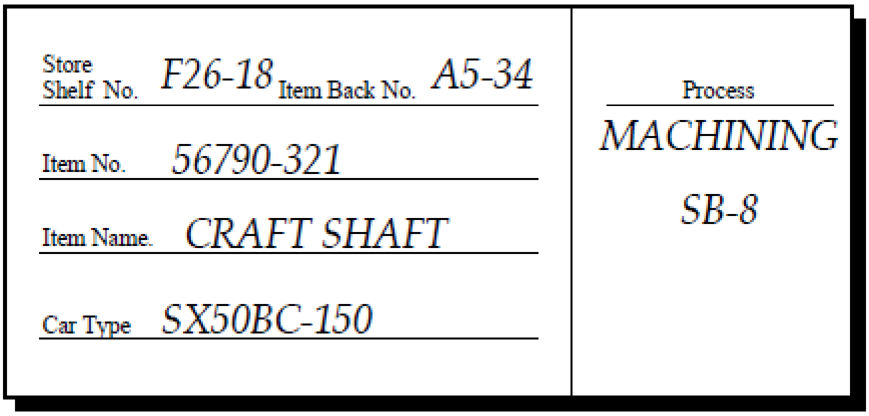
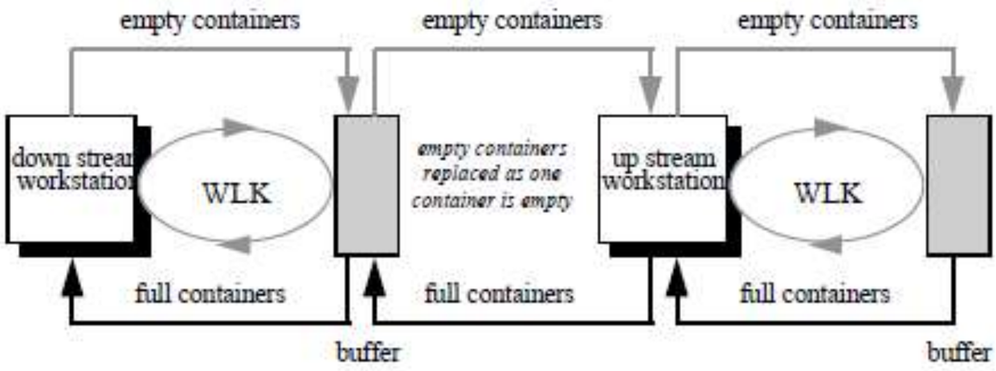


Figure 2.15 Production-Ordering Kanban (POK) (source: Monden [2011]).

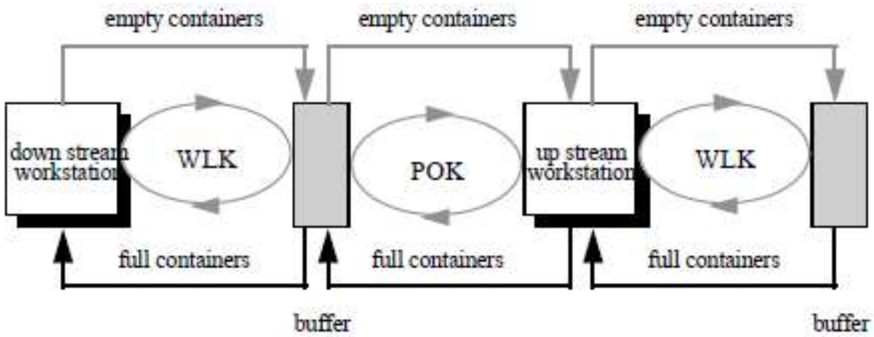
a. Single-Card Pull System

In a single-card pull system, parts are usually produced periodically and deliveries to the customers are controlled by WLK. This card states the quantity that the subsequent workstation must withdraw from the preceding workstation. By considering this mechanism, this system is basically a push system for production coupled with a pull system for deliveries (Schonberger, 2012). This system is usually applied if two adjacent workstations do not have different production characteristics such as in a serial production process where each workstation has almost similar characteristics such as batch size, setup time, container size or physical features of parts. However, if the two adjacent workstations have different production characteristics and the production process forms a parallel or network system so a workstation can supply two or more subsequent workstations, this system must be modified into a two-card pull system and a new type of cards, called POK, must be developed. The POK specifies the kind and the quantity of product which the preceding workstation must produce.

Basically, the single-card pull system is an early step of developing a two-card pull system. It is easy to start with a WLK and then add a POK later if it seems beneficial. However, this system is more popular than the two-card pull system since it is relatively simple and easy to understand for operators (Mejabi*et al.*, 2012; Schonberger, 2012).



(a). Single-card pull system



(b). Two-card pull system

Figure 2.16 Single-card and two-card pull system (Monden, 2011)

b. Two-Card Pull System

In this system, deliveries to the customers are also controlled by WLK. However, the number of full containers produced by the preceding workstation to replace the same containers taken by WLKs from various workstations is determined by POK. POK is issued if the total number of empty containers is equal to the Kanban quantity written on the card. By employing POK, the production of parts is no longer regular like the single-card pull system but it completely depends on the customer demands that are represented by the WLK.

Diagrammatically, the differences between the single-card and two-card pull system can be seen in Figure 2.16. The mechanisms of the two-card pull system are shown as Figure 2.17. For simplicity, it is assumed that the downstream process is an assembly line that is supplied by a fabrication process. The mechanisms are described the following steps:

Step 1 When the assembly line requires particular parts, a worker holding an empty container attached to a WLK sends the empty container to the storage area.

Step 2 Each empty container is placed in the storage area, the worker takes a full container and posts the WLK from the empty container onto the full container. The POK attached to the full container is then posted onto the board after the contents of the full container are checked.

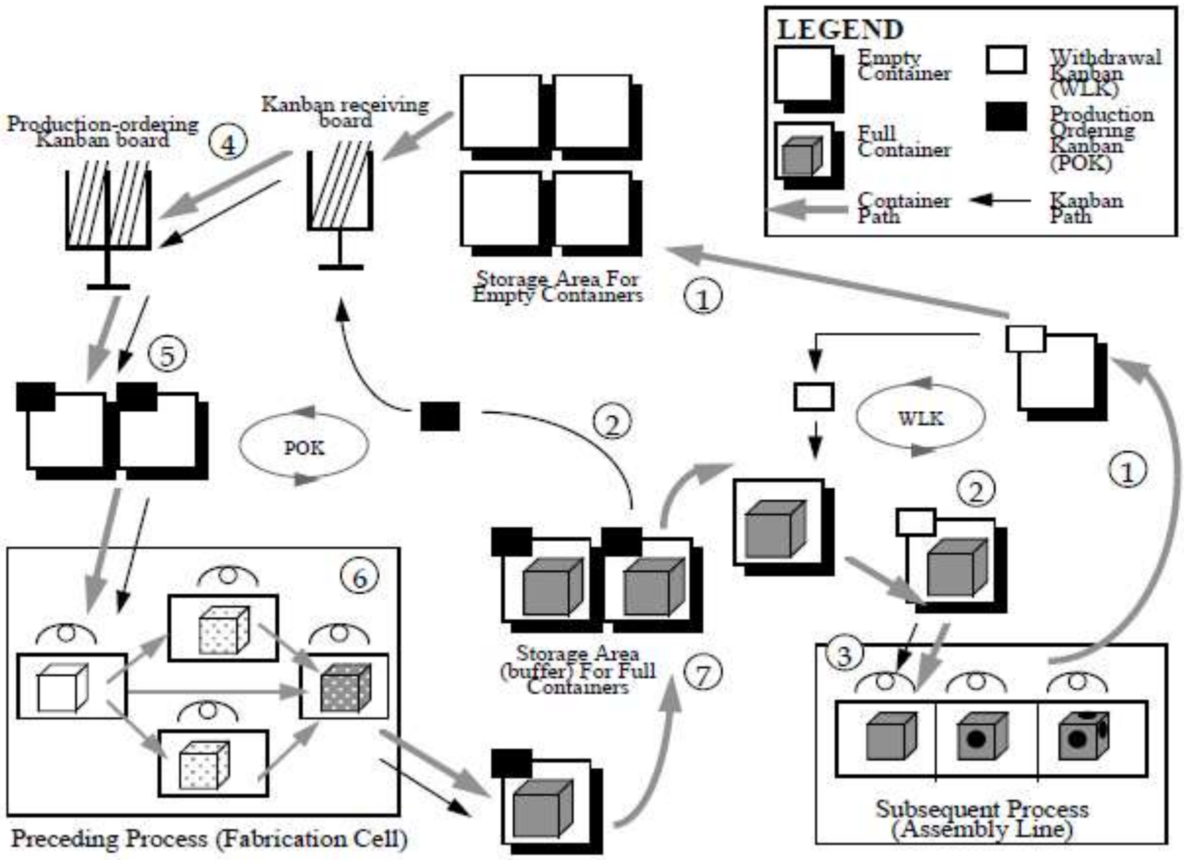


Figure 2.17 Two-card pull system (adapted from Krajewski, Bandy and Larry [1996])

Step 3 According to the specification on the WLK, the container is moved to the assembly line. This step finishes the loop of a WLK.

Step 4 POKs are removed from the board after being sorted and reviewed.

Step 5 The parts are produced according to the sequence as written in the POK. The POK is then attached to the empty container taken from the container area.

Step 6 The POK and the container move together along the fabrication process.

Step 7 The finished units are moved to the storage area (buffer) to supply the assembly line. This completes the loop for the POK.

2.8.3 Comparing JIT versus the Traditional Push System

Although, the goals of the JIT concepts and the traditional push system (such as the Material Requirement Planning/MRP system) are the same i.e. improving customer service, reducing inventory and increasing productivity, their approaches to achieving the goals are completely different. The MRP system is designed to build a realistic materials plan based on constraints and restrictions. On the other hand, the JIT concepts emphasise continuous improvement and they do not accept any restrictions as given in the MRP system (Chase, 2011). The MRP system is characterised by the use of a sophisticated computer-processing system and generates a large amount of data and calculations. In contrast, the JIT concepts utilise visual and manual controls and they are designed as simply as possible for implementation. A JIT system generally involves very small lot sizes, shorter lead time and higher quality output. On the other hand, MRP is more concerned with the projected requirements and the planning and levelling of capacity using computers. Table 2.7 provides a general comparison between JIT concepts and the MRP system (adapted from Gaither (2011) and Chase *(*2011)).

2.8.4 Requirements for Implementation

According to Mittal & Wang (2012), to achieve successful JIT implementation, the following elements are required:

1. Steady demand
2. Almost negligible setup times
3. No machine breakdown
4. Perfect quality control
5. Strict discipline of the workers
6. Timely supply of all vendors
7. No variability in processing time

Table 2.7: Comparing JIT System and MRP System

ELEMENTS	JIT SYSTEM	MRP SYSTEM
Inventories	A liability	An asset
Lot Size	Immediate needs only	Based on Physical Process (Economic Order Quantity / EOQ)
Setup	Requires rapid changeover	Low priority issue
Quality	Zero defects	Tolerate some scraps
Lead time	Keep it short by simplifying job	As required
Mechanism	Work is moved in response to demand (pull system)	Work is pushed as soon as it is completed
Executing Production	*Kanban*	Schedule and purchasing reports
Information of Buffer	Visual (based on Kanban)	Not visual

The JIT system is based on achieving continuous improvement. These are actually never-ending objectives because almost none of the above factors is possible to achieve practically. To achieve these objectives, the role of human resources is critical. Therefore, some issues such as commitment, industrial relations, training and employee involvement become central issues for successful JIT implementation.

a. Commitment

JIT must be initiated by the top management with full support from all managerial levels. A survey by Marham *et al.* (2011) in US firms also shows that management commitment is the most crucial factor for JIT implementation. Another important factor is their commitment to change. A company must have willingness to make fundamental changes to attain all above elements. A changes in thinking from results-oriented thinking to process-oriented thinking is essential for JIT implementation (Johnston *et al.*, 2009). Process-oriented thinking is suitable for striving for constant improvement in small and incremental steps, and places great effort towards building quality, and the involvement of all people in the company.

b. Industrial Relations

JIT also requires a change in industrial relations. A survey by Norris *et al.* (1994) shows that in most companies that have applied the JIT system successfully, management has already developed strong cooperation with the union and workers prior to the implementation.

c. Employee Involvement

Another essential requirement is employee involvement. In this system, management must openly support the implementation of the JIT system and respond to feedback from the workers. A sense of involvement and participation of workers must be encouraged. Workers are then given not only valuable jobs by eliminating unnecessary tasks, but also authority and responsibility for running, stopping and improving the workshop. Balancing high responsibility and authority helps to increase their sense of involvement and participation in the workplace.

2.8.5 Implementation of Just In Time Manufacturing Systems

Training is a crucial issue for achieving successful JIT implementation. Since JIT is completely different to other western management concepts such as MRP, a program to educate and train employees is absolutely essential prior to implementation. Having employees who meet required characteristics and a true understanding of how the system works will give better success rather than just adopting the system without sufficient skills and understanding of the concepts.

According to some research (Golhar and Stamm, [2011]; Im*et al.*[1994]; Marham *et al.* [2011]), there are several employee characteristics that should be built up prior to JIT implementation including a multi-skilled work force, problem-solving skills, ability to work in group, self-discipline and concern about the firm's success. To achieve such characteristics, training is essential. However, since achieving all characteristics is difficult and may take a long time, the company must be able to conduct training systematically and decide which ones are the priorities.

In order to design, implement and evaluate training systematically, there are three steps that must be followed (Evans, 2011):

a. Assessment

This step consists of identifying training needs and setting criteria against the results of the training program. Identifying needs also covers an assessment of the organisation's requirements such as the degree to which workers are able to perform the tasks effectively.

b. Training Design and Implementation

This step includes determining training methods, developing training materials and conducting the training. There are three training methods:

1). Information presentation methods

The purpose of this method is to improve knowledge, skills, concepts and knowledge without expecting the trainees to apply what they are learning into practice during the training. Examples of this method are lectures and video tapes.

2). Simulation training methods

These methods usually involve creating artificial situations that provide trainees with a means of practising what they are learning during training. For example: case analysis, games and role plays.

3). On the job-training methods

These methods emphasise learning for trainees when they are performing a job with the help of a trainer. An example of this method is job rotation.

c. The Evaluation

This step entails assessing the results of the training based on the criteria developed. Major ways for evaluating the training include participant reaction through developing a survey and conducting tests prior to and after training. Even if training has been designed systematically, it will not be successful unless there is commitment especially from management.

Commitment for conducting training is essential prior to implementing JIT as proven by some researchers. A survey by Golhar & Stamm (2011) shows that most companies implementing JIT systems have a strong commitment to upgrading employee skills by developing training programs as well as providing an ample budget for this purpose.

2.8.6 Problems in the Implementation

Several problems are usually encountered in the JIT implementation. The main causes are usually associated with managerial and human relation issues. Firstly, management may not really understand the basic concepts of JIT so they consider JIT concepts in a narrow way. For example, as simply being the implementation of the Kanban system. This wrong understanding leads to the inappropriate implementation of JIT concepts. JIT as defined by Hall (2013) must cover all activities for eliminating waste. Secondly, as explained previously, lack of commitment is another major cause of problems in the implementation. This is usually caused by various factors such as lack of communication, inconsistent implementation of the corporate objectives and lack of coordination. This problem results in lack of support in the implementation. Thirdly, at the shop floor level, the main problem faced in the implementation is usually related to resistance to change. Changes are always considered as uncomfortable situations so the management must be able to convince employees of the importance of changes. Finally, lack of training is also another cause of problems since JIT implementation requires highly skilled workers.

Other causes are usually related to operational issues. Lummus *et al.* (2011) through their research, also report that many companies just concentrate on the partial program of JIT so they lose sight of overall improvement. Based on this research, there are five common mistakes that are made in JIT implementation:

1. The JIT system is conducted without changes in human resources policy.
2. Quality improvement in JIT implementation still relies on the role of the quality department.
3. JIT implementation is solely viewed as batch sizes and inventory reduction.
4. JIT implementation is not matched with other inventory systems.

2.8.7 Simulation of the JIT Manufacturing System

Simulation is defined as a process of designing a model of a real system and conducting experiments with the model for purposes of understanding the behaviour of the system (Pegden*et al.,* 2011). This technique is usually applied to analyse system behaviour after specific conditions of the system have already been defined. It is basically an input-output model because it only gives the output of the system for a given input. Because the characteristics are completely different to mathematical models, they are usually not applied to obtain the exact solutions of the problems but to obtain a set of alternative solutions called sub-optimal solutions.

The simulation approach has been widely applied as an analysis technique to study and evaluate manufacturing systems. By using simulation, the dynamic behaviours of a complex manufacturing system such as selecting procedures, machines or equipment can be analysed carefully. Another benefit of simulation is its capability to experiment with the model. Therefore, examining a new design of a manufacturing system can be conducted prior to its installation. Even though, the application of simulation has several advantages, it also has some disadvantages as it requires considerable effort to develop the programs (Berkley, 2013). Another disadvantage is associated with amount of time required to verify the results since the output of the simulation must be evaluated, using standard statistical procedures during analysis (Chu & Wei-Ling, 2012).

Simulation requires particular steps that should be followed to ensure that the results represent the actual system as closely as possible and the validity of the output can be guaranteed. The steps are as shown in Figure 2.18. Although each step is essential, many researchers tend to ignore a few of them especially the verification because this step is time consuming and tedious (Chu & Wei-Ling, 2012). However, this results in lower accuracy of simulation results. In the manufacturing applications, simulation has long been recognised as an useful tool for evaluating the benefits and risks of JIT implementation. The JIT system is based on continuous improvement of various elements; therefore, the simulation is usually applied to investigate the effects of the parameters that contribute to the improvement of the system such as Kanban quantity, batch size and the number of buffers.

There are several simulation studies in the literature that focus on the JIT production systems (e.g., Agrawal, 2010; Lummus, 2011; Neumann & Jaouen, 2016). The current research in supply delivery system emphasizes supply chain integration and JIT purchasing. Nevertheless, new literature in inventory control (Ekren & Ornek, 2008) frequently refers to JIT small lot ordering but ignores the logistics part of the system, such as JSS. It is not surprising because most companies do not directly manage their supply inbound logistics, but instead relegate the problem to logistics companies. JSS operates under the Toyota

Production System (TPS) and hence other simulation studies that discuss this system are relevant to our problem. Hauser simulates the lane sequencing, storage, and dispatching operations at the staging area (written as cross-docking area in the paper) of TPS (Hauser, 2014). The simulation model identifies the best layout for sorting cross-docking pallets and non cross-docking pallets according to lane. These operations occur right after the docking operations of JSS.

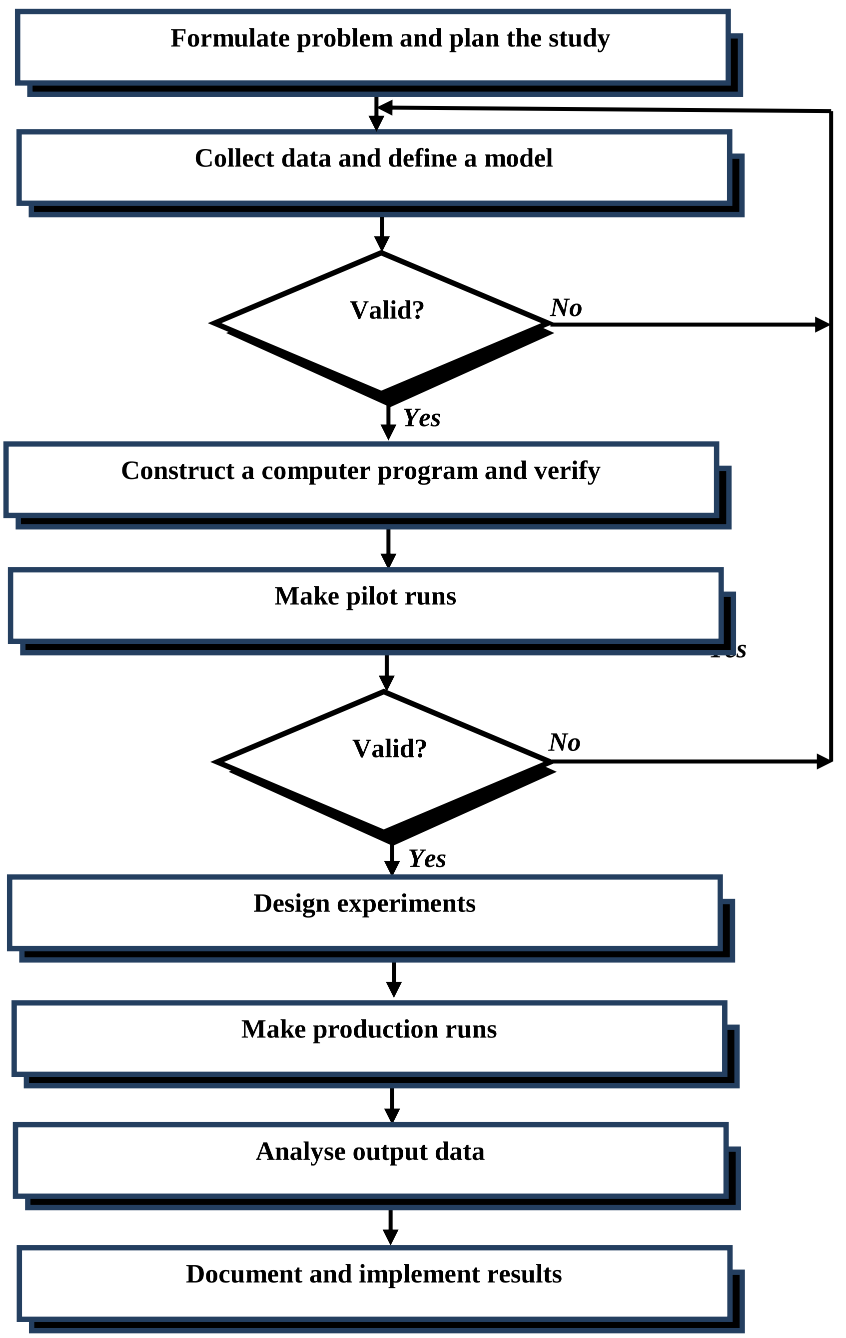


Figure 2.18 Simulation steps (Source: Law & David, 2012)

In another simulation for TPS, Anderson develops a model to level the vehicle-make sequence at a multilane selectivity bank between the paint shop and the assembly area (Anderson, 2011). The paint shop operation disturbs the heijunka sequence of vehicles. The selectivity bank reorders the sequence before they leave the bank for assembly operations. The simulation model is used to find the optimum buffer size of the selectivity bank. This is the first study that addresses the inventory dynamics in JSS.

Simulation studies of JIT can be broadly classified as (Yavuz & Satir, 2011):

a. Explorative Studies

These studies are basically associated with the investigation of the effects of parameter changes in the JIT system such as the effects of variance in processing times, changes in the Master Production Schedule, effects of sequence rules, and effects of buffer levels in the JIT system performance.

b. **Comparative Studies**

These studies investigate the comparison between the JIT system and other systems that are applied in similar production systems or the same environmental settings. The results of these studies are usually used to verify the feasibility of the system selected.

2.9 Simulation Models

One of the most important steps in attacking any problems is the construction and use of a model, called modelling. The model is built as a means to analyse the real system that we cannot observe directly. This problem usually occurs since the system does not yet exist or it is too difficult to analyse directly. Simulation is one of several types of models to overcome these problems. The term simulation model refers to instructions that contain the operational logic of the system or a sub-system of it to replicate the actual system (Papadopoulus *et al.*, 2013). With the advent of advancing computer technology today, most simulation models are conducted by using computer technology and a software package is considered as a popular way to develop simulation models.

A simulation package is usually regarded as the most appropriate since the package is purposely designed for the simulation. By using the package, the user can concentrate on the logic of the system. In addition, it usually provides functions or routines such as timing control mechanisms, random number generation, statistical distributions and records observations that are useful to model the system easily (Carrie, 2008). A good simulation package is usually characterised by its capability to create physical and logical operations of the system in an easy and straight-forward manner. As well, the software must make the user understand the output easily.

Although today there are many simulation software packages available, simulation of the JIT system tends to be clumsy and complicated since all of them are dedicated to the conventional push system (Mejabi *et al.,* 2012). Some popular software packages such as SIMAN, SLAM and GPSS do not provide any command for directly modelling pull systems. Because of this, the simulation modelling of a JIT (or a Pull) system requires high creativity and problem solving skills from the simulation analyst (McKay, 2009). To overcome this problem, some researchers such as Christenson *et al.* (2011), Schroer *et al.* (1984) and Mejabi *et al.* (2012) introduced some generic models of the JIT system using SIMAN. However, because of the nature of the generic model, sometimes the more specific problems cannot be accommodated in the model.

SIMAN, with SLAM, is the most popular simulation package available (Papadopoulus *et al.,* 2013). SIMAN is usually selected because this software is user friendly and it has uniquely open architecture. Another feature is that the model can be graphically animated using a built-up animation tool called CINEMA. SIMAN also allows the users limited opportunities to add extension commands from other general-purpose languages such as FORTRAN and C in a fairly direct fashion. This package also has another advantage in that some features are specifically designed into the language to model particular aspects of manufacturing systems, including conveyors, transporters and tracks (Pegden *et al.*, 2011).

2.9.1 Just-In-Time Models

The JIT concept was first introduced and adopted in Toyota Motor Corporation, it led to a higher quality, lower cost and substantially less labor time than achieved by Toyota's competitors (Abegglen & Stalk, 2015). The key success of the JIT approach lies on the application of the Kanban mechanism, which is a manual information system developed by Toyota Motor for implementing the JIT. A comprehensive presentation of Toyota production system is given by Bowen and Youngdahli (1998). Implementing a Kanban system in supply chain helps manufacturers reduce the risk of over-stocking or running out of stock, adjusts inventory to run the most efficient lean material flow and provides on time delivery to its customers. Detailed reviews on JIT-Kanban manufacturing systems can be found in Apte, Beath and Goh (1999), Baker (2009).

In the past decade much effort has been made in this direction. Ali et al. (2012) have developed a simple spreadsheet optimization program to determine the corresponding number of Kanbans with respect to user-defined safety stock levels and other values. It gives a close-form of solution to the problem. A similar work was considered by Blackburn and Millen (2010) to find the number of Kanbans between two adjacent work-stages. Blackburn and Millen (2011) addressed a one-vendor, multi-buyers operation policy regarding an optimal ordering policy for procurement of raw material and optimal manufacturing batch size for fixed interval deliveries to multiple customers where buyers implement the JIT delivery. The model gives a closed form solution for minimal total cost and also considers the use of carried over inventory to next cycle for determining the optimal starting time for each batch production cycle.

The conceptual framework of a JIT manufacturing system may be stated as 'producing and/or stocking only the right items in right quantities at right time'. Many manufacturing facilities previously carried large inventories of finished goods to meet the demands of customers that adopt a JIT delivery system. In this newly proposed JIT system, lot sizes are reduced as much as possible and deliveries of products are scheduled frequently. The direct impact of the JIT system is reduction of inventory holding cost. Therefore, the manufacturer should get accurate knowledge of demands of finished products and maintain an optimum production schedule to coordinate the supply chain manufacturing system. By synchronizing the production with the customers' lumpy demands and coordinating the ordering of raw material with production schedules, all raw materials, WIP and finished goods inventories could be maintained at an economic level in a manufacturing firm to minimize the integrated inventory cost incurred due to raw materials, WIP, and finished products.

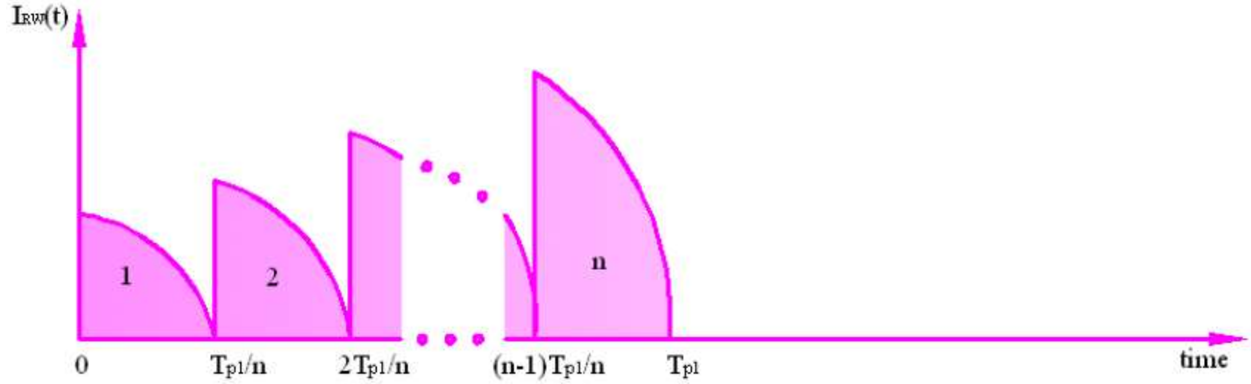
2.9.2 Inventory Models

In JIT-Kanban production systems, most of the researchers discussed the impact of their inventory decisions on total cost function, and mathematical models are formulated to achieve the inventory related cost reduction by optimizing the system parameters and/or the operation sequences. There are three kinds of inventories in a manufacturing system: raw materials, WIP and finished goods. Blackburn and Millen (2012); Blackburn and Millen (2016) developed a number of models of inventory cost incurred due to raw material and finished good.

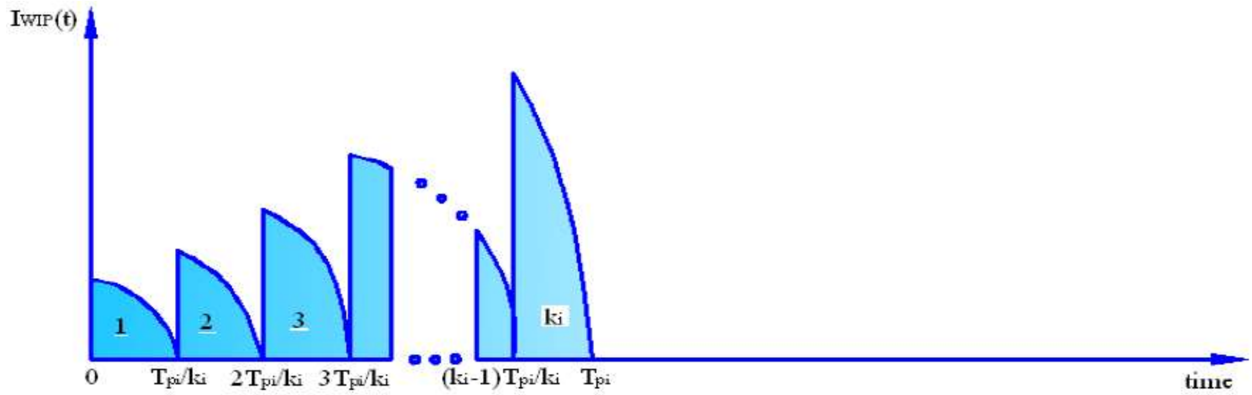
Ekren and Ornek (2008) studied a mixed integer linear programming inventory model with WIP and final products involved and proposed a branch & bound (B&B) algorithm to minimize the model. More researches considered the issues of raw materials, WIP and finished goods inventories together. Hout and Stalk (2013) addressed optimal order placement and delivery policies for an assembly type supply chain system under two distinct types of raw material arrivals to minimize the expected inventory costs. Canel and Rosen (2000) developed an inventory system for a single-stage imperfect production process where defective items are produced and rework. Blackburn and Millen (2010); Balci (2009) and Blackburn and Millen (2010) presented methods for finding the optimal replenishment schedule for various inventory models of deteriorating items with time-varying demand.

More complicated studies are continued: Blackburn and Millen (2012) focused on a mixed integer nonlinear programming (MINLP) model including raw material, WIP, and finished goods. Later Blackburn and Millen (2010) proposed a greedy heuristic algorithm based B&B Algorithm to optimize the model described in (Anderson, 2011). Other works that addressed the related issues are Betts and Johnston (2009); Blackburn and Millen (2011); Mulligan and Gordon (2014).

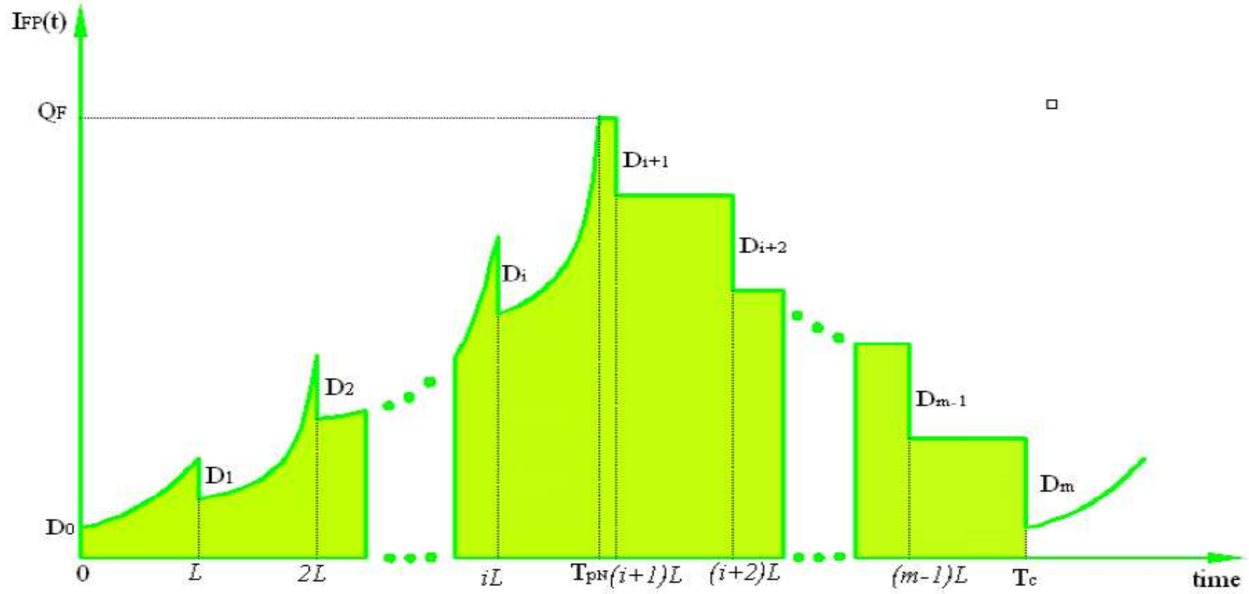
In a supply chain manufacturing system, the inventory control and the need for coordination of inventory decisions are important issues. One of the reasons why inventory is needed is to protect a firm from unexpected changes in customer demand that are always difficult to predict. In the recent decade, the uncertainty is even more difficult to predict due to the short life cycle of an increasing number of products and the presence of competing products in the market. Typically, the manufacturers order raw materials from outside suppliers to produce the finished products. Therefore, inventory types can be categorized into raw material inventory, WIP inventory and finished product inventory. Since holding of inventories cause a significant cost, their efficient management is critical in production and supply chain system operations. A system, which provides excess inventory, reflects lack of planning and poor communication and management. It has been an important issue to integrate inventories including raw materials, WIP, and finished products in the system for efficient production, distribution, and control tactics to reduce the inventory related cost of the system. A decision-making model is developed for an optimal set of production rates and raw materials procurement rate selection to minimize the total inventory cost incurred by raw materials, WIP, and finished products of Varying Production Rates and Demand (VPRD) model. This study also discusses the associated Kanban system's configuration of the VPRD system. The formulations of the model depend on some assumptions and notations. They are described with the graphical illustrations below.



(a) On hand inventory of raw materials



(b) On hand inventory of work-in-process at the *ith*Kanban stage



(c) On hand inventory of finished products

Figure 2.19 VPRD Production System Inventory Formations

Assumptions

The following assumptions are made to formulate the VPRD problem:

(1) Enough inventories exist and shortages never occur during production.

(2) The production rate is higher than the demand rate for all work-stages.

(3) The production of defective products is not considered.

(4) A one-to-one conversion ratio for the raw materials to finished products.

Notations

The notations used in this model are two kinds, (i) parameters, which are known and given values; (ii) variables, which are unknown. The objective of the VPRD problem is to determine the variables. The following parameters and variables will be used to formulate the problem or to interpret the results:

Parameters:

D_0 : initial inventory level of finished products (i.e., t=0), units,

D_F : total demand of finished products, units/cycle

DI : degree of imbalance of the production system, $DI = \frac{T_c - T_{pi}}{T_c}$,

H_F : holding cost of finished products, \$/unit*time unit,

H_{Kj} : holding cost of WIP at the Kanban stage K_j, \$/units*time unit,

H_{Ri} : holding cost of raw parts at the work-stage WS_i, \$/units*time unit,

$\overline{I_{FP}}$: average finished products inventory, units,

$\overline{I_{RM}}$: average raw materials inventory, units,

$\overline{I_{WIP_j}}$: average WIP inventory at the *jth* Kanban stage, units,

K_F : ordering cost of finished products, \$/batch,

K_{Ri} : ordering cost of raw parts at the work-stage WS_i, \$/order,

L : time between successive shipments of finished products, time units

P_{0i} : initial production level of raw part at work-stage WS_i, units,

Q_R : total demand of raw materials, units/cycle,

Q_{Ri} : total demand of raw parts at *ith* work-stage WS_i, units/cycle

T_c : cycle time, $T_c = m \times L$, time units,

T_{pi} : production time at the work-stage WS_i, time units, $i = 1,2,\ldots,N$

TC^M :total cost of integrated inventories, \$/cycle

TC^M_{FP} : cost of finished products related, \$/cycle

TC^M_{RM} : cost of raw material related, \$/cycle

TC^M_{WIP} : cost of WIP related, \$/cycle

W_{Kj} : Kanban withdrawal cost at the Kanban-stage K_j, \$/Kanban,

α_j : ratio of WIP holding cost at the Kanban-stage K_j to the raw part holding cost at the work-stage WS_j, $\alpha_j = H_{kj} / H_{Rj}$, $j = 1,2,\ldots,N-1$

β_j : ratio of Kanban withdrawal cost at the Kanban-stage K_j to raw part ordering cost at the work-stage WS_j, $\beta_j = W_{kj} / K_{Rj}$, $j = 1,2,\ldots,N-1$

ω : demand increase rate of finished products, units/time unit.

Variables:

k_j : number of Kanbans at the Kanban stage K_j, $j = 1,\ldots, N-1$

m : number of full shipments of finished products per cycle time,

n : raw material orders during the first work-stage uptime T_{p1},

p_i : production increasing rate at the work-stage WS_i, units/time unit,

Q^j_{s,k_j} : quantity transported in sth shipment of total k_j shipments at jth Kanban stage,

2.9.2.1 Optimal ordering policy for raw materials

Raw materials are required at the beginning of a production cycle. If the necessary raw materials are ordered once in a cycle, it may cause a higher inventory carrying cost during the earlier part of the production cycle. A multi-ordering policy which permits multiple ordering from outside suppliers of raw material in a production cycle may lower the inventory carrying cost as well as encourage the appropriate use of raw materials. Hence, raw material ordering policy regarding the optimal number of orders, time intervals of orders and ordering quantities are important factors of operational decisions.

2.9.2.2 Linear Demand of Finished Products

The concept of modeling with linear demand stated by Walleigh (2016) that the demand of a new product increases with time when it substitutes an existing product in most electronics, automobiles, and seasonal products which have short life in the competitive world market. After saturation, the demand of this product remains approximately constant for a while until a new innovative product creeps into the market to dominate the existing product in terms of its capabilities and useful features. The existing product then starts experiencing the declining demand at this time. The varying demand can be approximated to a linear demand.

The advantage of modeling with linear demand is that it can analyze a manufacturing system with increasing, level and declining demand as it happens at the time of introduction of a new product, market maturity, and phasing out of the product, respectively. In a supply chain manufacturing system with JIT-Kanban mechanism, the output rate of the last stage is generally dictated by the demand of finished product from customers. The demand of a product is typically either increasing or decreasing or it remains constant over a certain period during its life cycle. It is observed that most short life-cycle products in the market such as electronics, automobiles, and other seasonal products get varying demand over their life cycles.

2.9.3 Time Varying Demand Models

With the introduction of a powerful new product, the demand is in the inception phase that slowly increases. After saturation, the demand of this product remains approximately constant for a while until a new innovative product creeps into the market to dominate the existing product in terms of its capabilities and useful features. The existing product then starts experiencing the declining demand at this time. The varying demand can be approximated to a linear demand (Figure 2.20).

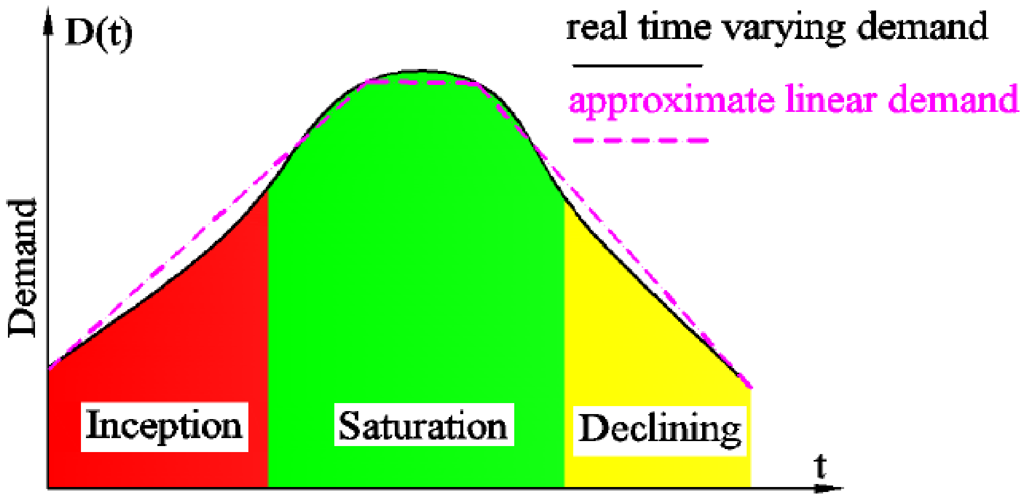


Figure 2.20 Life-Cycle Demand

Due to the different characteristics of facilities of each stage and the time-varying demand of finished products, it is more realistic to treat the production rate of each stage as decision variables instead of predetermined parameters. Most of the previous researches treated the production rate as being predetermined and fixed in advance, but in true sense, machines with inflexible production capacity are out dated in most of modern manufacturing systems and the production cost depends on the production capacities.

In the production planning for a multi-stage JIT production system with flexible production capacity, production operating policy of each work-stage, raw materials ordering policy to the supplier, delivery policy to the customers, number of Kanbans between work stages and the economic batch size of each shipment in a production cycle are determined. A cost function is developed based on the inventory ordering and holding costs incurred due to raw materials, WIP, and finished products. Once the parameters of the production system which can minimize the total inventory cost are determined, an efficient technique will be devised which utilizes these optimal values as inputs to configure the Kanban movement in the production system. This technique will also provide an insight on the manufacturing system configuration and the nature of WIP inventory build-up associated with Kanbans at each stage in the production system.

Researchers have addressed many constant finished product demand models (Monden, 2011, 2014; Pisuchpen, 2010; Schroer et al., 1984; Wang & Hsu-Pin (Ben), 2011). In many real life situations, demand varies significantly over a short time horizon of life cycles, especially for products such as computers, software, automobiles, fashions and other seasonal products. A more appropriate policy to respond to such a market situation is generally more desired to operate a supply chain manufacturing system more efficiently. Blackburn and Millen (2010) formulated the inventory cost model by considering the Kanban operations between two adjacent stages under linear demand.Then they extended the model to a multi-stage Kanban system (Schonberger, 2012). Al-Tahat et al. (2011) modified Blackburn & Millen (2010) model with a changeover involved and developed a computer program for the proposed model, particularly they proposed Genetic Algorithms to optimize the WIP hold cost. Based on Blackburn and Millen (2010), Fang and Lin (2010) presented a multi-stage production system with flexible production capacity at each stage and considered the effect of raw material order to inventory cost for various cases.

2.9.4 Flexible Production Capacities

According to the study of Schonberger (2012) regarding flexibility and manufacturing system design, production flexibility and volume flexibility can be increased by increasing the production capacities of a system. Production systems with inflexible production capacities are out of date in most of the modern manufacturing systems. Machine production rates can be easily changed and production cost depends on the production rate. The treatment of production rate as a decision variable is especially appropriate for products with short-life cycles, where the production volume is flexible.

Volume flexibility permits a manufacturing system to adjust production upwards and downwards within wide limits prior to the start of production of a lot. In a volume flexibility production system, as the production rate is increased, some costs such as labor and holding costs are spread over more units. The net result is that production cost decreases until an ideal design production rate of the facility is reached. Beyond the optimal production rate, production cost increases. Therefore, it is very interesting to take production capacity into account in a production supply chain system management.

Tsubone and Horikawa (2012) denoted flexibility as the ability of a system to adapt quickly to any changes in relevant factors such as product, process, workload, or machine failure. Taymaz (2016) studied the relationship between machine and volume flexibility. His result stated that an inverse relationship exists between these flexibility types and that overall system flexibility cannot be directly attainable form its component’s flexibility. Other factors like cost structure, productivity, etc. should also be considered. Feng and Yamashiro (2011) developed an inventory model including the raw materials’ and finished goods’ for a volume-flexibility production system. Giri et al. (2012) study an economic manufacturing quantity problem for an unreliable production facility where the production rate is treated as a decision variable. Harris and Powell (2013) developed a simple search algorithm for determining the optimal allocation of buffer capacity in unbalanced production lines with reliable but variable workstations.

2.10 Review of Existing Juhel Drug Process Plant Structure

The pharmaceutical industry is one of several industries that are experiencing fierce competition as a result of global competition, rapid technological changes and rapid changes of consumer requirements. Juhel Pharmaceutical Drug Process Plant, Enugu, a division of Juhel Nigeria Ltd, manufactures pharmaceutical blends and products to supply both the Nigerian and West African markets. Juhel Nigeria Ltd is located at 35 Nkwubor Road, Emene, Enugu, capital of Enugu State, Nigeria. It is a 100% indigenous company incorporated in 1987 with RC No. 104648 as a wholesale Pharmaceutical Company. In answer to calls for local provision of cost-effective generic products to fill the gap left by Multinational companies operating in the country; the factory was commissioned in 1989 as the first pharmaceutical drug manufacturing company in old Anambra state. Their brand and product range have since grown in strength and include virtually all therapeutic classes, such as, Antibiotics and Anti-infective, Cardiovascular, Anti-diabetics, Anti-malarial, Cough and Cold, Vitamins and Minerals, Anxiolytics, Antihistamines, Analgesics, Antacids and Anti-flatulent, etc. To cope with these challenges Juhel Pharmaceutical Nigeria Ltd applies new technology and management techniques.

One of several indicators that pharmaceutical companies are able to survive within the global marketplace is their ability to improve return on assets (ROA). ROA will improve if either turnover or return on sales (ROS) increases. Turn over that is obtained by dividing sales into assets can be increased if assets decrease. Since in a pharmaceutical company, inventory is a major part of assets, inventory reduction will improve turnover significantly. Similarly, ROS will increase if operating profit that is obtained by subtracting sales against total costs and expense increases. Since in such companies inventory is a major part of the total cost, inventory reduction will considerably improve ROS. Therefore, inventory reduction, is a key factor for improving ROA and eventually to survive global competition. These considerations require the company to find better ways for reducing various type of inventory such as raw materials, WIP and finished goods. JIT is then considered as a suitable management concept for Juhel Pharmaceutical Nigeria Ltd to address the challenges by minimising all the components, particularly on the shop floor.

The manufacturing process of oral drug tablets at Juhel Nigeria Ltd consists of weighing of active ingredients and excipients (dispensing), mixing/blending, granulation, drying, milling/crushing, granule lubrication (mixing lubricants), compression/tablet pressing, coating, inspection /quality control, blister packing/ strip sealing and carton packaging/shipping.

a. Weighing of Active Ingredients and Excipients (Dispensing)

Dispensing is the first step in this pharmaceutical manufacturing process. Dispensing is one of the most critical steps in pharmaceutical manufacturing.

b. Mixing/Blending

The successful mixing of powder is more difficult than mixing liquid, as perfect homogeneity is difficult to achieve. A further problem is the inherent cohesiveness and resistance to movement between the individual particles. This arises from the difference in size, shape, and density of the component particles. Each process of mixing has an optimum mixing time, and longer mixing may result in an undesired product. Blending prior to compression is normally achieved in a simple tumble blender. The blender is a fixed blender into which the powders are charged, blended and discharged. In special cases of mixing a lubricant, over mixing is particularly monitored.

c. Granulation

Following particle size reduction and blending, the formulation may be granulated. This process also is very important and needs experience to attain proper quality of granule before tableting. Quality of granule determines the smooth and trouble free process of tablets manufacturing. If granulation is not done in a proper manner, the resulting mixture may damage the tableting press. During granulation, primary powder particles (pharmocologically active substances and powdered excipients) are made to adhere to form larger, multiparticle entities called granules. This process collects particles together by creating bonds between them. Bonds are formed by compression or by using a binding agent. Granulation is extensively used in the manufacturing of tablets. In Juhel Nigeria Ltd, two types of granulation technologies are employed: wet granulation and dry granulation.

Wet Granulation

Granules are formed by the addition of a granulation liquid onto a powder bed which is under the influence of an impeller (in a high-shear granulator), screws (in a twin screw granulator) or air (in a fluidized bed granulator). The agitation resulting in the system along with the wetting of the components within the formulation results in the aggregation of the primary powder particles to produce wet granules. The granulation liquid (fluid) contains a solvent which must be volatile so that it can be removed by drying, and be non-toxic. Once the solvent/water has been dried and the powders have formed a more densely held mass, then the granulation is milled. This process results in the formation of granules. In the traditional wet granulation method the wet mass is forced through a sieve to produce wet granules which are subsequently dried.

Dry granulation

The dry granulation process is used to form granules without using a liquid solution because the product granulated may be sensitive to moisture and heat. Forming granules without moisture requires compacting and densifying the powders. In this process, the primary powder particles are aggregated under high pressure. Sweying granulator or a high-shear mixer-granulator can be used for the dry granulation. Dry granulation is conducted under two processes; either a large tablet (slug) is produced in a heavy duty tabletting press or the powder is squeezed between two counter-rotating rollers to produce a continuous sheet or ribbon of materials. When a tablet press is used for dry granulation, the powders may not possess enough natural flow to feed the product uniformly into the die cavity, resulting in varying degrees of densification. The roller compactor (granulator-compactor) uses an auger-feed system that will consistently deliver powder uniformly between two pressure rollers. The powders are compacted into a ribbon or small pellets between these rollers and milled through a low-shear mill.

d. Drying

In the formulation and development of a pharmaceutical product drying is important to keep the residual moisture low enough to prevent product deterioration and ensure free flowing properties. Fluidized – Bed Dryer (FBD) is employed for this operation in the drug process plant.

e. Milling

Milling (size reduction, crushing, grinding, pulverization) is an essential stage in the process of tablet manufacturing. In manufacturing of compressed tablets, the mixing or blending of several solid pharmaceutical ingredients is easier and more uniform if the ingredients are about the same size. This provides a greater uniformity of dose. A fine particle size is essential in case of lubricant mixing with granules for its proper function.

f. Granule Lubrication (Mixing Lubricants)

A final lubrication (mixing lubricants) step is used to ensure that the tableting blend does not stick to the equipment during the tableting or compression process. This usually involves low shear blending of the granules with a powdered lubricant, such as magnesium stearate or stearic acid.

g. Compression/Tablet Pressing

After the preparation of granules (in case of wet granulation) or sized slugs (in case of dry granulation) or mixing of ingredients (in case of direct compression), they are compressed to get final product. The tablet press is a high-speed mechanical device. It can make the tablet in many shapes, although they are usually round or oval. Also, it can press the name of the manufacturer or the product into the top of the tablet. Each tablet is made by pressing the granules inside a die, made up of hardened steel. The die is disc-shaped with a hole cut through its centre. The powder is compressed in the centre of the die by two hardened steel punches that fit into the top and bottom of the die. The punches and dies are fixed to a turret that spins round. As it spins, the punches are driven together by two fixed cams - an upper cam and lower cam. The top of the upper punch (the punch head) sits on the upper cam edge .The bottom of the lower punch sits on the lower cam edge.

The shapes of the two cams determine the sequence of movements of the two punches. This sequence is repeated over and over because the turret is spinning round. The force exerted on the ingredients in the dies is very carefully controlled. This ensures that each tablet is perfectly formed. Because of the high speeds, they need very sophisticated lubrication systems. The lubricating oil is recycled and filtered to ensure a continuous supply. Common stages occurring during compression include:

Stage 1: Top punch is withdrawn from the die by the upper cam, bottom punch is lowered in the die so powder falls in through the hole and fills the die

Stage 2: Bottom punch moves up to adjust the powder weight-it raises and expels some powder

Stage 3: Top punch is driven into the die by upper cam. Bottom punch is raised by lower cam. Both punch heads pass between heavy rollers to compress the powder

Stage 4: Top punch is withdrawn by the upper cam Lower punch is pushed up and expels powder; the tablet is removed from the die surface by surface plate

Stage 5: Return to stage 1

h. Coating

Tablets are coated after being pressed. Tablet coatings are polymer and polysaccharide based, with plasticizers and pigments included. Tablet coatings must be stable and strong enough to survive the handling of the tablet, must not make tablets stick together during the coating process, and must follow the fine contours of embossed characters or logos on tablets. The machines used for coating is known as automatic coaters. The explosion-proof design is required for alcohol containing coatings.

i. Inspection/ Quality Control

Checks are carried out before the manufacturing process is completed. Having reliable and reproducible quality control methods will enable the production plant to guarantee the consistency of drugs batch after batch. Furthermore, it may simplify the characterization of such processes and their chemical profile.

j. Blister Packing/ Strip Sealing and Carton Packaging/Shipping

Tablets must be packaged before they can be sent out for distribution. The type of packaging will depend on the formulation of the medicine. Blister packs are a common form of packaging. They are safe and easy to use and the user can see the contents without opening the pack. Juhel Nigeria Ltd use a standard size of blister pack. This saves the cost of different tools and changing the production machinery between products. Sometimes the pack may be perforated so that individual tablets can be detached. This means that the expiry date and the drug's name must be printed on each part of the package. The blister pack (primary package) itself must remain absolutely flat as it travels through the packaging processes, especially when it is inserted into a carton or box (secondary package). Extra ribs are added to the blister pack to improve its stiffness. The cartons of blister packs are in turn enclosed in barrels or pallets (tertiary package) and shipped in containers to distributors/consumers.

Auxiliary Equipment

a) Granulation Feeding Device

The speed of die table is such that the time of die under feed frame is too short to allow adequate or consistent gravity filling of die with granules, resulting in weight variation and content uniformity. These are also seen with poorly flowing granules. To avoid these problems, mechanized feeder is employed to force granules into die cavity.

b) Tablet Weight Monitoring Device

The high rate of tablet output of compression machines require continuous tablet weight monitoring with electronic monitoring devices. These devices use strain gauge technology at each compression station to monitor pressure, which is then calibrated to tablet weight and can be affected by a number of factors.

c) Tablet Deduster

In almost all cases, tablets coming out of a tablet machine have excess powder on their surface which is removed by passing them through a tablet deduster.

d) Fette Machine

The Fette machine chills the compression components to allow the compression of low melting point substance such as waxes and thereby making it possible to compress product with low melting points. Variation in the average manufacturing lead time depends on factors such as loading of machines, priorities, scheduling, and machine breakdown.

2.11 Review of Related Literature

Sparks (2011) in a study titled "JIT Manufacturing: Working to Deliver Quality at the Right Time, All of the Time" used a Just-in-time (JIT) manufacturing methodology that seeks to make Nissan Motor Company production processes more efficient. In his context, efficiency means that wastes within the process have been eliminated. He contended that JIT supposes that a company's production process is one that *pulls* raw materials through its process, as opposed to *pushing* raw materials through its process, as a traditional production process would.

As analyzed in his work, figure 2.21, shows a JIT production process, one which pulls raw materials through its processes.

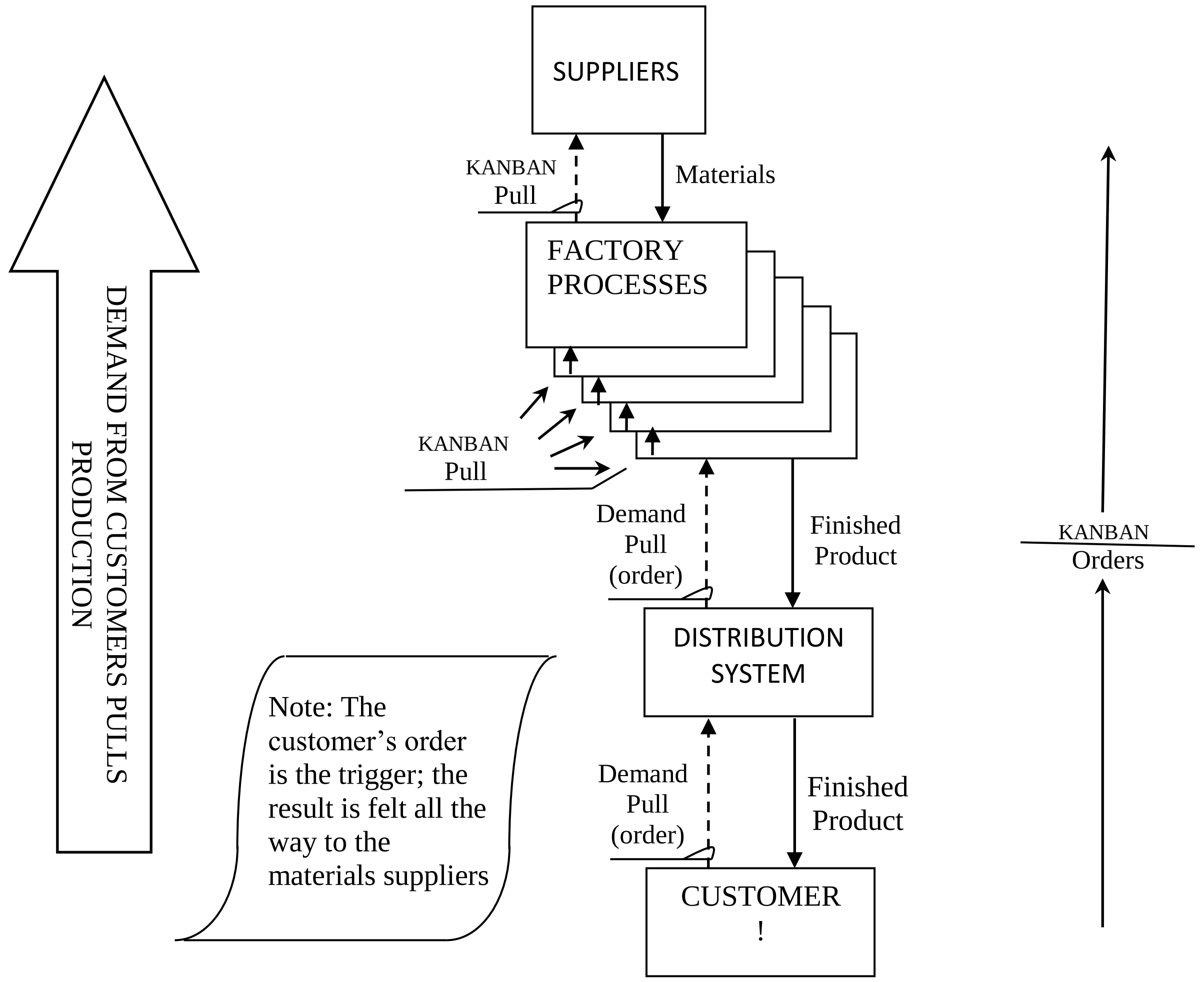


Figure 2.21: Just-in-Time Demand Pull System (Sparks, 2011)

In figure 2.21, the production process is put into motion by actual customer demand. By knowing actual customer demand before the process begins, the company definitively identifies exactly what products to produce and in what quantities to produce them. At this point, the orders for products and raw materials are passed upstream, typically with the usage of kanbans (figure 2.22). This allows each preceding operation to know exactly which product to produce and in what quantity to produce it, allowing them to produce no more than the amount required by the downstream entity requesting that production.

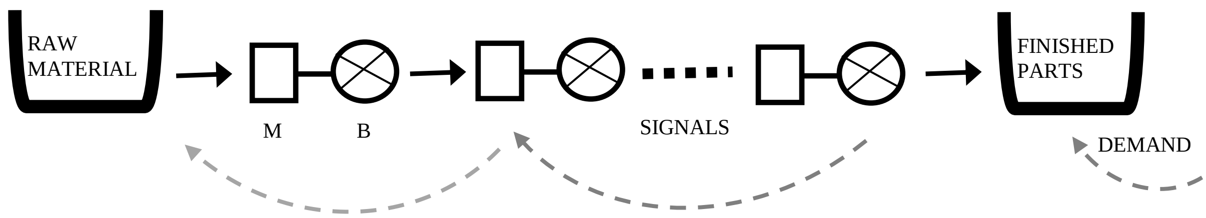


Figure 2.22: Pure pull or JIT system (Sparks, 2011)

The findings of his research reveal that the implementation of JIT manufacturing offers many benefits not only for a company, but for its employees and customers, as well. JIT makes a company's manufacturing processes more flexible, as JIT establishes a production environment which functions by matching actual demand. However, his study was limited to a multi-stage single product system.

Henninger (2009) conducted a study on "production sequencing and stability analysis of a just-in-time system with sequence dependent setups." The study investigated an approach for determining stability and an approach for mixed product sequencing in production systems with sequence dependent setups and buffer thresholds. Buffer thresholds signal replenishment of a given buffer.

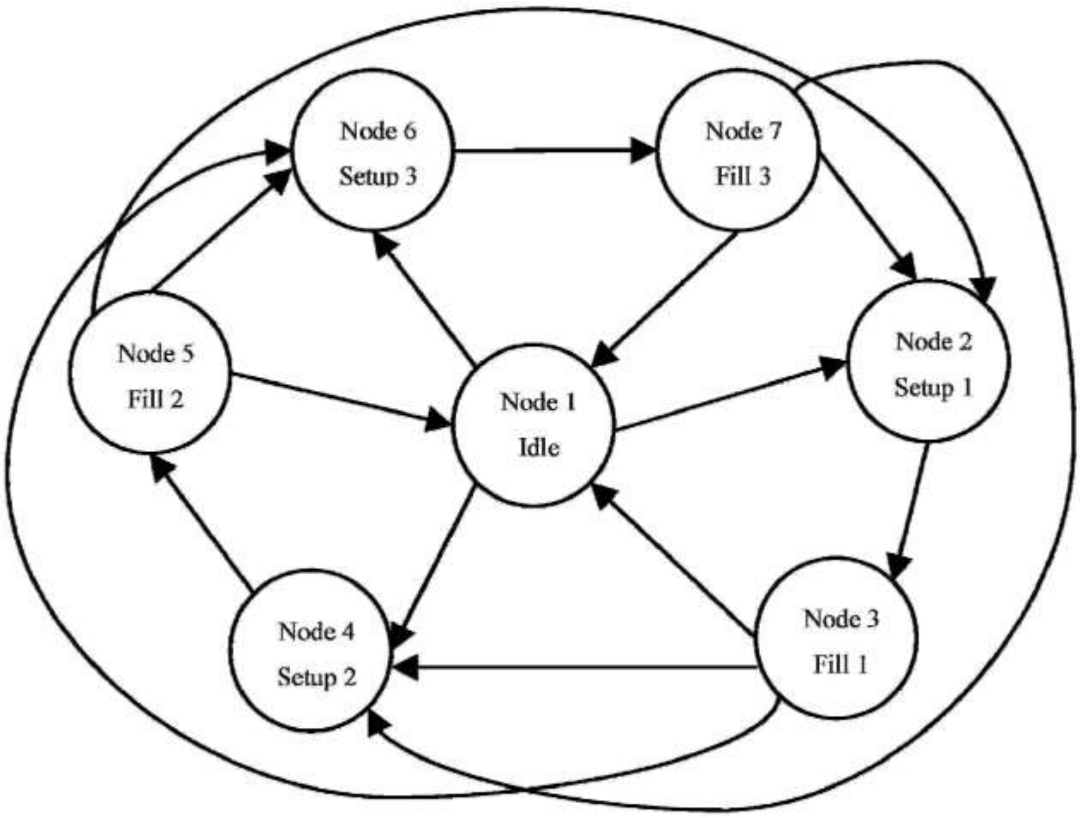


Figure 2.23: Network Map Algorithm of Three-Product System – With and Without Idle

Henninger (2009) developed a product sequencing algorithm that determines a product sequence for a production system based on system parameters – setup times, buffer levels, usage rates, production rates, etc. The algorithm selects a product by evaluating the goodness of each product that has reached the replenishment threshold at the current time. The algorithm also incorporates a lookahead function that calculates the goodness for some time interval into the future. The lookahead function considers all branches of the tree of potential sequences to prevent the sequence from travelling down a dead-end branch in which the system will be unable to avoid a depleted buffer. The sequencing algorithm allows the user to weight the five terms of the goodness equations (current and lookahead) to control the behavior of the sequence. In this network, all product sequences may pass through the idle node prior to being replenished or a product can wait in a queue to enter setup directly after replenishment of the previous product. All weighting factors are set equal to 0.2. The algorithm cycles through the network (Figure 2.23) approximately twelve times to determine the stable regions for the system. The results from the algorithm for this arc-node network still contain the same regions as the previous system, but these regions a now segmented into smaller regions. The output also contains the additional regions for the arcs that skip idle.

Gaither (2011) in a in a work titled “Production and Operations Management: a Problem-Solving and Decision-Making Approach” explored product sequencing method intended to be implemented for a JIT factory floor as an on-line production sequencing system. The Production System Model adopted in his work is one in which there are multiple products with potentially different production rates and usage rates and significant sequence dependent setups between products. The production system is assumed to be a single stage system that can have idle time, see Figure 2.24. The system functions such that customer orders come into a “black box” of the sequencing algorithm as well as product information (current production conditions, buffer size and fullness levels, production and usage rates, setup costs, etc.). The algorithm processes the information and outputs a product to be produced next, which is passed to the production stage. The algorithm is intended to be updated and run after each product refill, where the sequence is based on real-time feedback of the system parameters. An alternative use is to run the algorithm to generate a short sequence of products at a given time interval, such as sequencing a day’s worth of production determined each morning based on the current state of the production system. The algorithm models a production system in which production occurs in batches, the batch size is the quantity of products required to fully replenish the buffer to a full level. When the product batch is completed, it is stored in Finished Goods Inventory (FGI) until a customer order is received and the required number of products is removed from FGI to meet the order. Buffer thresholds ($BF_{threshold,i}$) are defined for each product to signal the algorithm that the given product needs to be replenished.

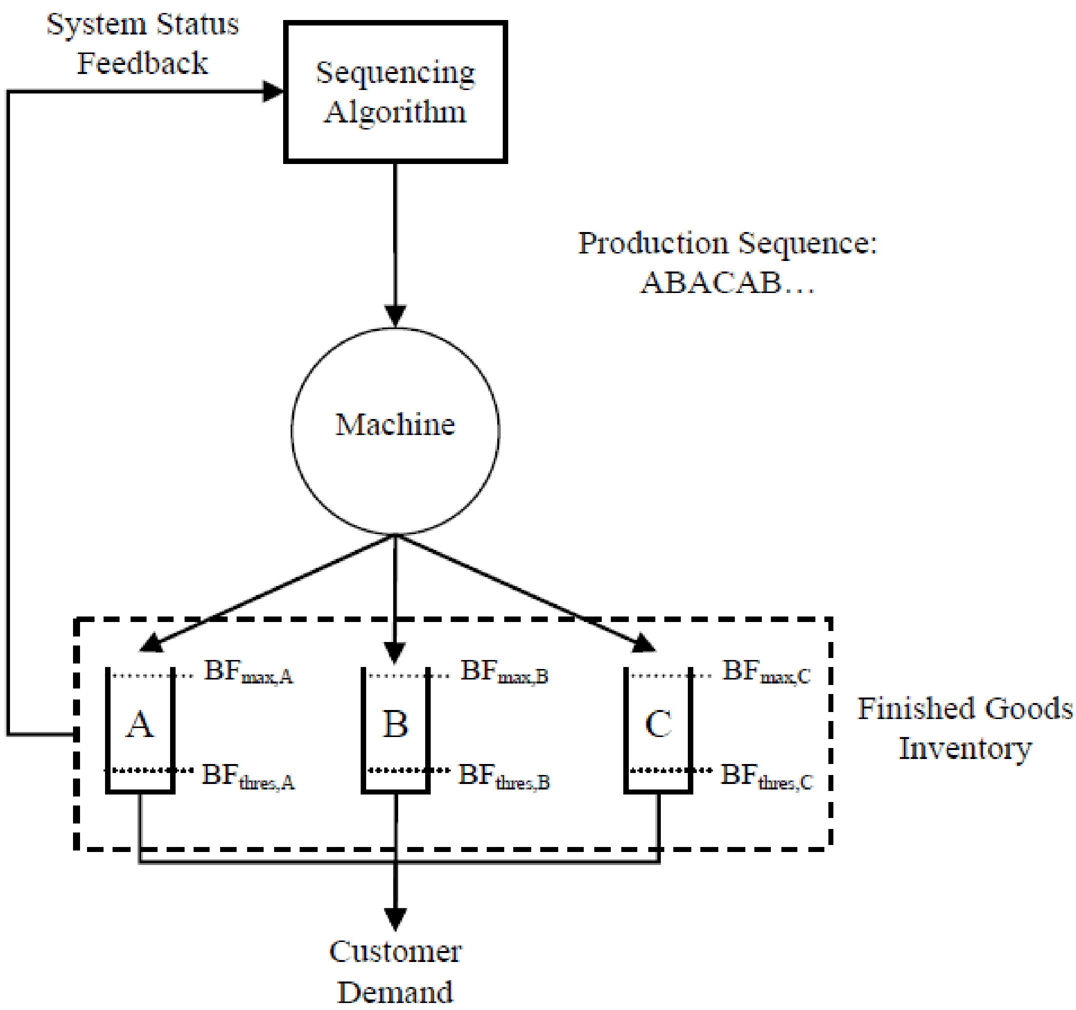


Figure 2.24: Production System Model

Only products at or below the buffer threshold are considered by the algorithm and if all products are above the buffer thresholds, the production system is idle. However, the present study will replicate a lean system that only produces when customer demand is present.

Huang, Rees, and Taylor developed one of the very first JIT simulation models with kanban by SLAM (Huang, Rees, & Taylor, 2013, 2015; Pritsker, Sigal, & Hammesfahr, 2009). Their paper evaluated overtime requirements for changes in the number of kanban included in a JIT system, processing time variance and demand levels. They used SLAM II language to model the flow of two kanban and a multiline, multistage production process using Kanban in a pull JIT system. Chan and Smith (2013) assessed some features of a JIT system for a welding assembly line. They discuss the techniques used to develop the JIT models through GPSS/H simulation language.

Ezingeard and Race (2011) found that the application of JIT techniques in batch chemical processing environment under variable demand imposed significant capacity management problem. Furthermore, the spreadsheet simulation techniques are recommended for JIT modeling. They present a case study to clarify the links between service levels and resource utilization, which can help management decisions regarding timing, levels of stocks and sizing facilities.

Welgama and Mills (2011) presented a case study of a simulation modeling approach in the design and analysis of a proposed JIT for a chemical company. The simulation approach was used to compare two cell designs and to estimate utilization levels for operators and material handlers under the new JIT system. Gabriel, Bitcheno and Galletly (2011) argue that computer simulation is an ideal tool for implementation of JIT system due to its wide range of activities. They have developed a software package, which simulates JIT manufacturing system.

Rodrigues and Mackness (1998) proposed an approach for helping companies in the selection of the most appropriate synchronization approach through simulation models. The models are based on three synchronization approach, namely, JIT, just-in-case and drum-buffer-rope. Schonberger (2012) presents description of 26 JIT implementations in US and Asia. Three JIT ratio analyses are discussed: (1) lead time to work content, (2) process speed to sales rate and (3) number of pieces to number of workstations. Weston (2003) discusses the development of a simulation model of a workshop that is line balanced and operating in JIT fashion. The simulation model takes into account the theory of constraints via Microsoft Excel by considering m parts processed through n work centers.

Wu and Kung (2003) investigated the impacts of different market demand patterns on system performance of a plant that implements either JIT or theory of constraint (TOC) in Taiwan. The authors used SIMAN to develop simulation models of a plastic-mold injection plant. The system performance was considered in terms of average work in process (WIP) inventories and throughput time. They report that both philosophies can have significant improvements on system performance without large investment of capitals. The JIT systems have been advantageous to small, medium, and large production systems in Korea (Ekren & Ornek, 2008). The traditional JIT system applied to static production systems have the advantages such as reduced inventories, etc. In fact, the adaptation of JIT system to dynamic production systems is a difficult task because of its sensitivity to production factors. The dynamic production systems deal with high variability of demands, frequent and random machine breakdown, variable defect rates and high absence or separation rates of personnel (multitasking, etc.). They developed JIT production models that are indifferent to production factors and identified the optimal model that reflects the production circumstance of the Korean industries. Then, computer simulation was used to test selected models for the susceptibility of the production factors.

Abdou and Dutta (2013) developed a simulation model for kanban based scheduling in a multistage and multiproduct system. They demonstrated that under a set of operational conditions, the proposed simulation model could obtain a more improved JIT system. Abdul-Nour (2013) analyzed the effects of different maintenance policies and machine unreliability on JIT systems. The Taguchi method together with computer simulation was used to evaluate the effects and collect the required data. Cormier and Kersey (2011) discussed the potential use of computer simulation and operations research techniques for design and analysis of JIT operation of a warehouse. Chengalvarayan and Parker (2011) described the JIT simulation model of a production line and discussed the possibility of JIT implementation.

Egbelu (2011) developed a framework for design and analysis of a JIT manufacturing system based on scheduling, material handling and simulation techniques. Neumann and Jaouen (2016); Changchit and Kung (2008); Kung and Changchit (2009); Meral and Erkip (2011); Agrawal (2010); Blackburn and Millen (2010) have developed computer simulation models for analysis and assessment of JIT production systems.

There are other studies, which highlight the importance of JIT simulation modeling (Gross, 2013; Manivannan & Pegden, 2011; Simulation Optimizes JIT System Design, 1997; Nandkeolyar, Ahmad, & Pai, 1998). Levasseur and Storch (1996) presented a non-sequential JIT simulation model for batches of parts to be routed between operations within the same facility. Hum and Lee (1998); Lummus (2011) presented a computer simulation of the performance of a number of scheduling rules under different JIT scenarios. Muralidhar, Swenseth and Wilson (2012) reported the effects of Gamma, Log Normal and Truncated Normal process times on a hypothetical assembly line with one kanban. The preceding studies highlight the importance of dynamic behavior of production systems with respect to JIT design. In addition, variation in throughput times (at each stage) has the potential of creating idle time for machines and increasing overtime costs to meet production schedules. This is why design and implementation of a JIT system may last up to several years. It is concluded that conventional (theoretical) JIT does not fit most dynamic systems and is more applicable to static systems.

Furthermore, design and implementation of theoretical JIT philosophy may not be possible for most dynamic systems due to their unique limitations and constraints. Therefore, a more applicable JIT design approach compatible with the limitations of dynamic systems is required. The preceding pros and cons of JIT demands powerful tools for design and assessment of the dynamic systems into JIT before actual deployment. In fact, there are certain difficulties in design and implementation of JIT that could be overcome by integration of computer simulation and analysis of variance (ANOVA).

Several articles have been written describing the various JIT applications that Hewlett-Packard (H-P) has adopted over the past several years. One more major result for the study was H-P began developing the Kanban manufacturing system for the production of personal mass storage units {disk drives}. The production process was set up in a U-shape, passing one unit at a time with no buffer stock. "If the employee's Kanban out-square is filled, he or she may either complete the unit being worked on, sit idle, or help a downstream employee; once the unit an employee is working on is completed, the employee cannot work on another unit (Jaouen & Neuman, 2014). If a problem occurred during production, the problem was immediately corrected before the production process continued. Therefore, inventories of defective parts were eliminated. Under this system, employees were encouraged to perform quality work and improve productivity. The Kanban system implemented also included JIT purchasing. H-P managed to reduce total inventory supply from 2.8 months to 1.3 months within a 6- month period, and only 24 vendors were supplying 100 parts "just- in-time". The company managed a 48% reduction in the number of vendors; a 30% reduction in the number of raw material inspections; and total factory output tripled over a period of eight months.

In another work, Jaouen and Neuman (2014) clarified that through the use of Kanban system, H-P simplified its accounting as well as its inventory procedures. The plant showed a decrease in direct material costs per unit, but no change in labor and overhead costs due to additional investments in these areas. There was also an increase in the number of units produced during this period, but a reduction in the amount of storage space, indicating faster turnover of inventory. Because of the Kanban philosophy, H-P spent time and money helping employees develop a team attitude. Employees were trained and educated on the JIT philosophy. Overall, it appears that H-P has been successful in the implementation of a

Kanban (JIT) system, and the division is pleased with the accomplished results thus far.

Although, JIT processes seem best suited for companies dealing with repetitive manufacturing, they have been effective in job-shop operations. The study by Kozoil (2008) describes how Valmont/ ALS, a job-shop steel fabricator in Brenham, Texas, adopted a modified form of JIT in order to improve its operations during down times in the steel industry. The company attempted to produce only to customer order, and to reduce the amount of time it took to produce an order. The company first focused on determining their main constraints. Additionally, they identified two external constraints: a marketing constraint (the company could produce more than it could sell), and the location of the engineering function. The bottlenecks at the plant occurred primarily at the weld assembly area. The company adopted a new system to operate the job- shop, which they considered a modified Kanban (JIT) system, in which inventory would be pulled through the shop at a rate dictated by their constraints. Their prior Materials Requirements Planning (MRP) system pushed inventory through the shop without acknowledging the constraints. The company encountered two major problems in the implementation. First, the plant's engineering and marketing departments reported directly to the home office, and these two groups were not aware of the production changes being made at the plant. Therefore, training had to be expanded to the organization as a whole. Secondly, the plant had to determine how to schedule the shop in the most efficient manner. Again, this involved some changes to the company's MRP system. Since the company could not afford a new computer system, modifications were made to the current system to schedule job-shop operations on a daily basis. The company was able to reduce its inventory, reduce lead times, and deliver products to customers on time. Overall, the company experienced positive results from the implementation of the modified JIT process, and the company is constantly improving the system's performance.

2.12 Summary of Reviewed Related Literature

In summary, the studies in the literature show that the manufacturing systems for control have relatively simple structures. In fact, manufacturing systems are much more complicated in real factories. The control structures used are classic methods. One of the reasons for these limitations is that there are no efficient methods for evaluating complex manufacturing systems with single-card pull system. Therefore, an efficient evaluation method such as optimal JIT system is desired such that the behavior of single-card pull system control can be explored to help design and control complex manufacturing systems. It would equally help examine the impact of manufacturing system alternatives within the context of today's increasingly time-based competitive environment**.**

In the reviewed works on JIT production system, the constant demand optimization model discussed by many authors [Drucker (2011); Gaither (2011); Joo and Wilbert (2013); LaForge (2015)] would be inappropriate when the supply chain system faces time-varying demand over the planning horizon. If the supply chain system is optimized for the average demand then the system may experience severe shortage during the high season or may have to keep excessive stock during the low season. Severe shortage will result in not only loss of sales but also losing the willingness of customers in the future. In addition to incurring high holding cost, overstocked products in one season can be obsolete in the succeeding season. Hence, a more appropriate policy is desired to better adjust the ordering, produce to meet demand and ensure a more cost-efficient supply chain and production system.

The Blackburn and Millen (2010) and Nance (2011) models are limited to level demand and infinite planning horizon. Here, they only considered one type of shipment mechanism, which is fixed-interval and fixed shipment size. During the model development, some of the researchers [Suzaki (2014); Wemmerlow (1979); Svensson (2001); Shingo (2012); Rother & Harris (2001)] considered the issues of raw material, WIP and finished product inventories separately, it would be logical if all these issues are analyzed together.

For time-varying demand model, an exact solution procedure proposed by Blackburn and Millen (2010) considered two-stage and multi-stage systems but they did not consider the manufacturing circumstance with flexible production capacity and the production rate of a manufacturing system is assumed to be predetermined and inflexible. Previous researchers ignored this type of models due to complexity of the problem. However, machine production rates can be easily changed and production cost depends on the production rate (Chase, 2011; Fry, 2011; Johnson, 2011). In this research, a model is developed with flexible production capacities as decision variables, which is a more general class of supply chain manufacturing system.

Most of past works in modeling and optimization of supply chain manufacturing system have so far partially considered the aspects of JIT delivery, time varying demand, integrated inventory including raw materials, WIP and finished products and flexible production capacity separately. Combining these aspects to capture a more realistic situation in the modeling has received little attention. This research attempts to bridge this gap. It develops optimal and efficient operational methodology for the integrated inventory system including raw materials, WIP and finished products of a multi-stage production system with JIT deliveries that incorporates time varying demand under flexible production capacity. This research presents robust analytical results to solve the operational problems for such production system optimally. The current study integrates theory and methodologies from industrial engineering and operations management. This study considered the interaction effects of the various Manufacturing System (MAS) alternatives with factors from operations management. The existing research ignored the interrelationships among important factors.

Reviewed literatures in this work reveal that Just-in-time manufacturing is a philosophy that has been successfully implemented in many manufacturing organizations. It is an optimal system that reduces inventory whilst being increasingly responsive to customer needs; this is not to say that it is not without its pitfalls. However, these disadvantages can be overcome with a little forethought and a lot of commitment at all levels of the organization. JIT is likely to be one of the most suitable management concepts for today's business because it meets the paradigms of new businesses such as rapid changes in demand and more customised products. This system is also based on aspects of continuous improvement such as continually reducing costs, defect, inventory and lead time. Since the system has never-ending objectives, it is suitable for companies that want to survive in tomorrow's business world.

This study bridged a research gap by introducing a framework for re-design of a given manufacturing system into practical optimum Just-In-Time system. The conventional JIT approach is mostly applicable to static production systems and dynamic production systems usually require more practical integrated JIT model that considers system's limitations and its dynamic behavior. This work unlike other previous studies developed an enhanced discrete event simulation JIT Manufacturing System Model. The simulation of a JIT system can provide better insight into the effects of factors contributing to its successful implementation. Some factors such as the number of Kanbans, trigger points, the scheduling rules and location of the buffers that are difficult to evaluate in practice can be evaluated using simulation.

CHAPTER THREE

METHODOLOGY AND SYSTEM DESIGN

3.1 Methodology

Methodology is the general research strategy that outlines the way in which research is to be undertaken and, among other things, identifies the methods to be used. These methods, step by step, describe the actions taken to achieve a result, means or modes of data collection and how the result is to be calculated.

The methodology employed in this work is the Structured Systems Analysis and Design Method (SSADM) as well as the work-study method. The research process chart in Figure 3.1 systematically analysed the method applied in this research work. The problems of the Drug Process Plant were first studied and identified. In the second step, an alternative JIT system was designed. However, in the third step, the existing system model was designed based on Unified Modeling Language (UML) Activity diagram. The existing system response in terms of Cycle Time /Lead Time, Flow Time, Demand Fulfillment Rate, Throughput Time, Inventory Level, Net Operating Income and Work in process Level were deduced and extracted. This led to modeling and simulation of an alternative new JIT system using ARENA /SIMAN and TECNOMATIX simulation software.

After assessment and optimisation of the new system, the performance parameters of the simulated JIT alternative were compared and reviewed before the final design of the physical model based on simulation results in step 4. The performance parameters of the new physical model were extracted, compared and analysed after implementation on the shop floor as shown in step 7 and 8. Steps 1 to 8 led to the achievement of the research objective.

3.2 Existing Drug Process Plant Structure

Basically, the Drug Process Plant operations are mainly characterised by single flow line production processes, periodical and multi-items orders. There are around 79 periodical items produced by the Drug Process Plant, with the order quantity ranging from one pallet to 700 pallets. With such characteristics, it is not surprising that Material Resource Planning (MRP) was then introduced to control the plant.

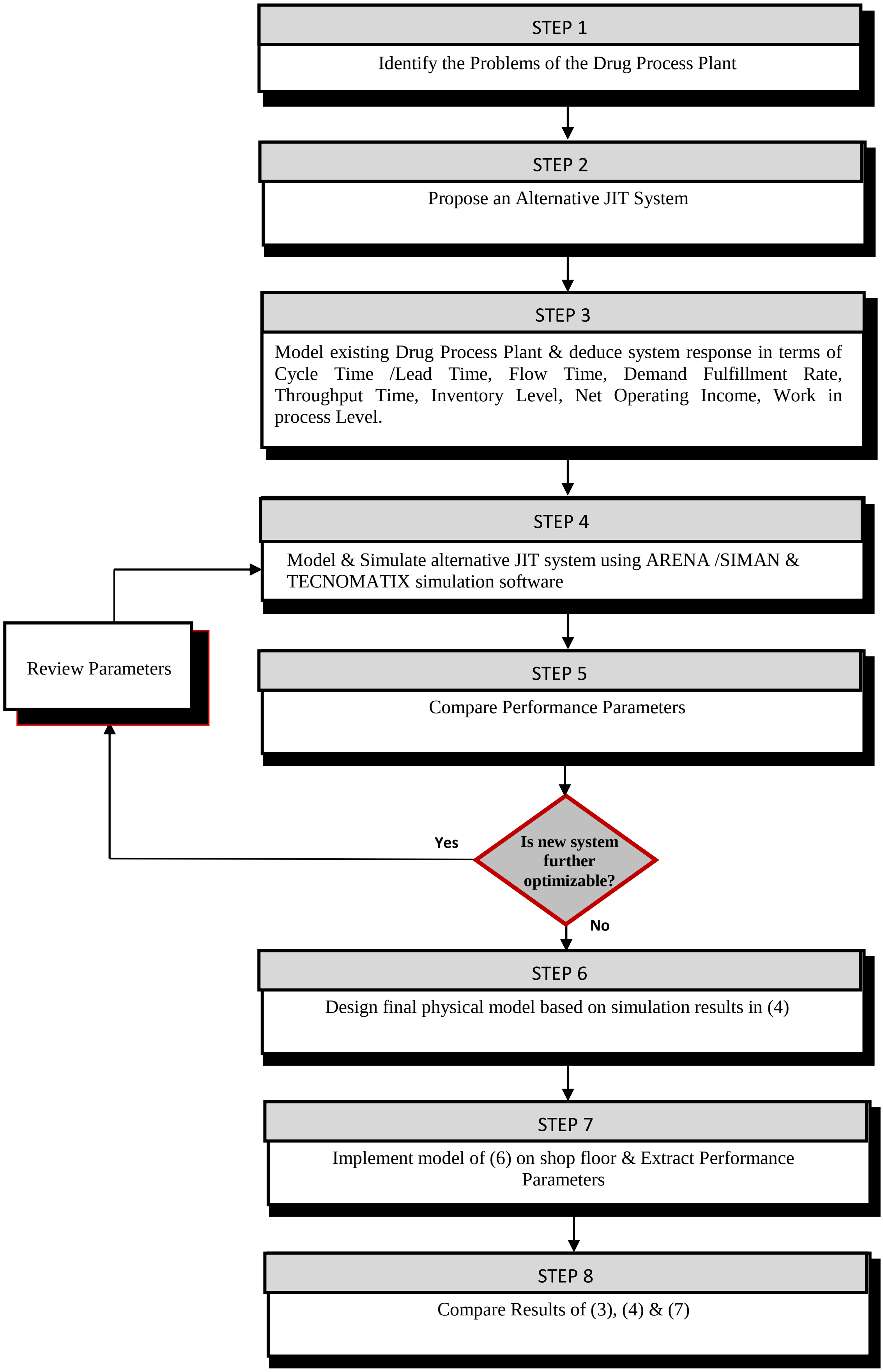


Figure 3.1: Research Process Chart

3.2.1. Products

Basically, items produced by the Drug Process Plant can be classified into three as shown in figure 3.2: Product A otherwise referred to as tablets (55% of order volume), Product B otherwise known as capsules (35% of order volume) and Product C otherwise referred to as pills (10% of order volume).

Pharmaceutical blends may be compressed by slugging (dry granulation), wet granulation or direct compaction (direct compression) as shown in figure 3.3 to obtain the desired physical properties, before their formulation as a finished product. The pharmocologically active ingredients and excipients are fed into Comil for blending (by Blending Machine or Mixer) through the API Feeder and Excipient Feeder respectively. The next stage is determined by whether pharmaceutical blends is to be compressed by dry granulation, wet granulation or direct compaction. In the case of dry granulation (indicated by dotted green lines), blended materials are passed to the Roller Compactor and then taken to the Mill for crushing. If the pharmaceutical blend is to be compressed by wet granulation (indicated by dotted indigo lines), the blended materials are passed to the Granulator for wetting with aqueous/solvent solutions. The wet granules are dried at the Dryer and taken to the Mill or Milling Machine for crushing and subsequent processing. However, if the pharmaceutical blend is to be compressed by direct compaction (indicated by dotted blue lines), the blended materials are passed directly to the Mill or Milling Machine for crushing and subsequent processing. At the Mill (Milling Machine), arriving pharmaceutical blends pass through common processing steps (indicated by dotted orange lines).At this stage, pharmaceutical blends are further passed to the Tablet Press and then to the Coater(optional) before being sent to Quality Control and Packaging Line for onward shipment. In wet granulation, the active ingredients and excipients are wetted with aqueous or solvent solutions to produce coarse granules with enlarged particle sizes. The granules are dried, mixed with lubricants (e.g., magnesium stearate), disintegrants or binders, then compressed into tablets, capsules and pills. During direct compression, a metal die holds a measured amount of the drug blend while a punch compresses the tablet. Drugs that are not sufficiently stable for wet granulation or cannot be directly compressed are slugged. Slugging or dry granulation blend and compress relatively large tablets which are ground and screened to a desired mesh size, then recompressed into the final tablet. Blended and granulated materials may also be produced in capsule form. Hard gelatin capsules are dried, trimmed, filled and joined on capsule-filling machines.

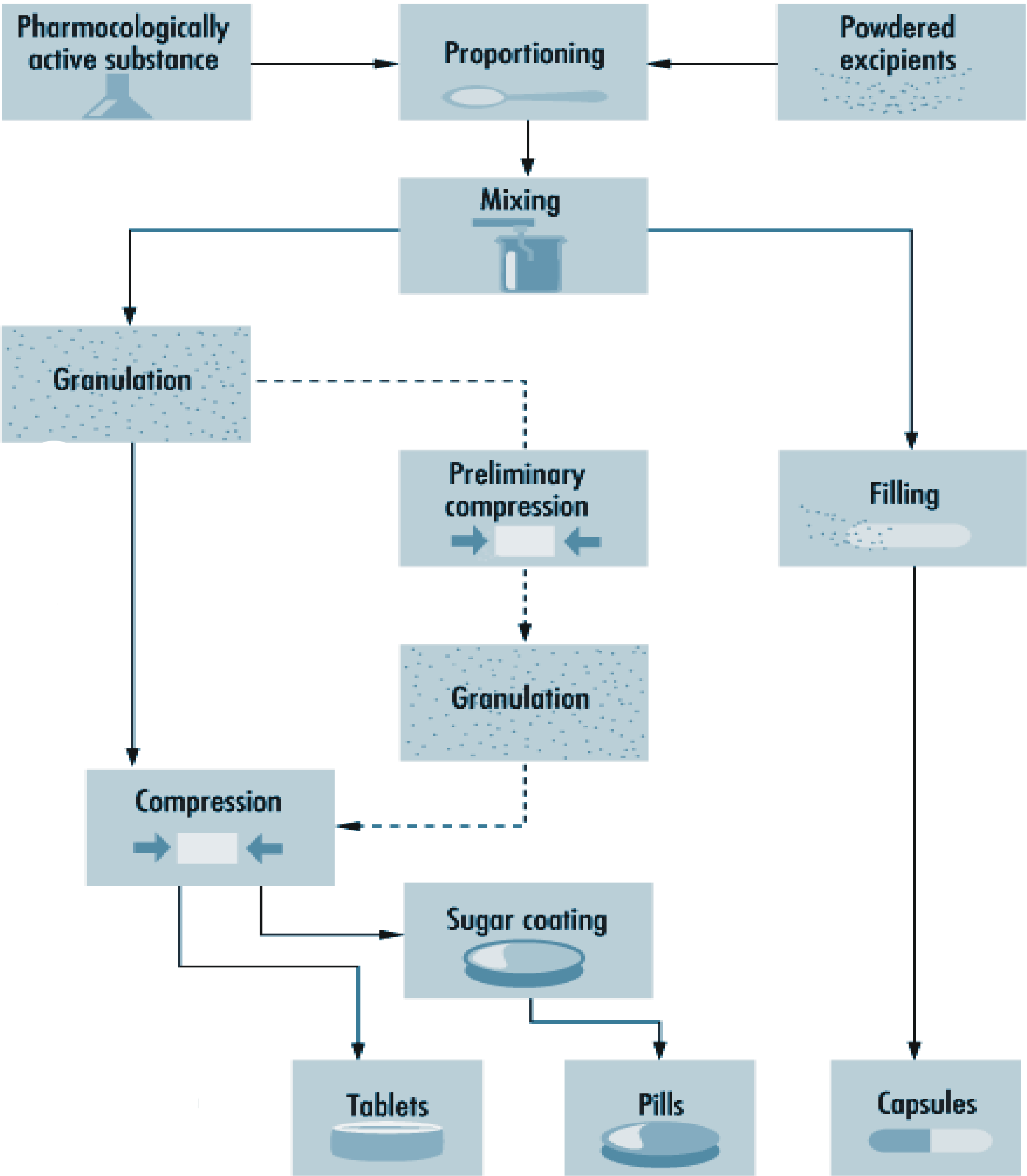


Figure 3.2: Items Produced by the Drug Process Plant

3.2.2. Manufacturing Processes

The manufacture of oral solid dosage forms, such as tablets, is a complex multi-stage process under which the starting materials change their physical characteristics a number of times before the final dosage form is produced. The manufacturing process of oral drug tablets at Juhel Nigeria Ltd Enugu consists of 11 serial processes (work stages) as described in Figure 3.4: weighing of active ingredients and excipients (dispensing), mixing/blending, granulation, drying, milling/crushing, granule lubrication (mixing lubricants), compression/tablet pressing, coating, inspection /quality control, blister packing/ strip sealing and carton packaging/shipping.

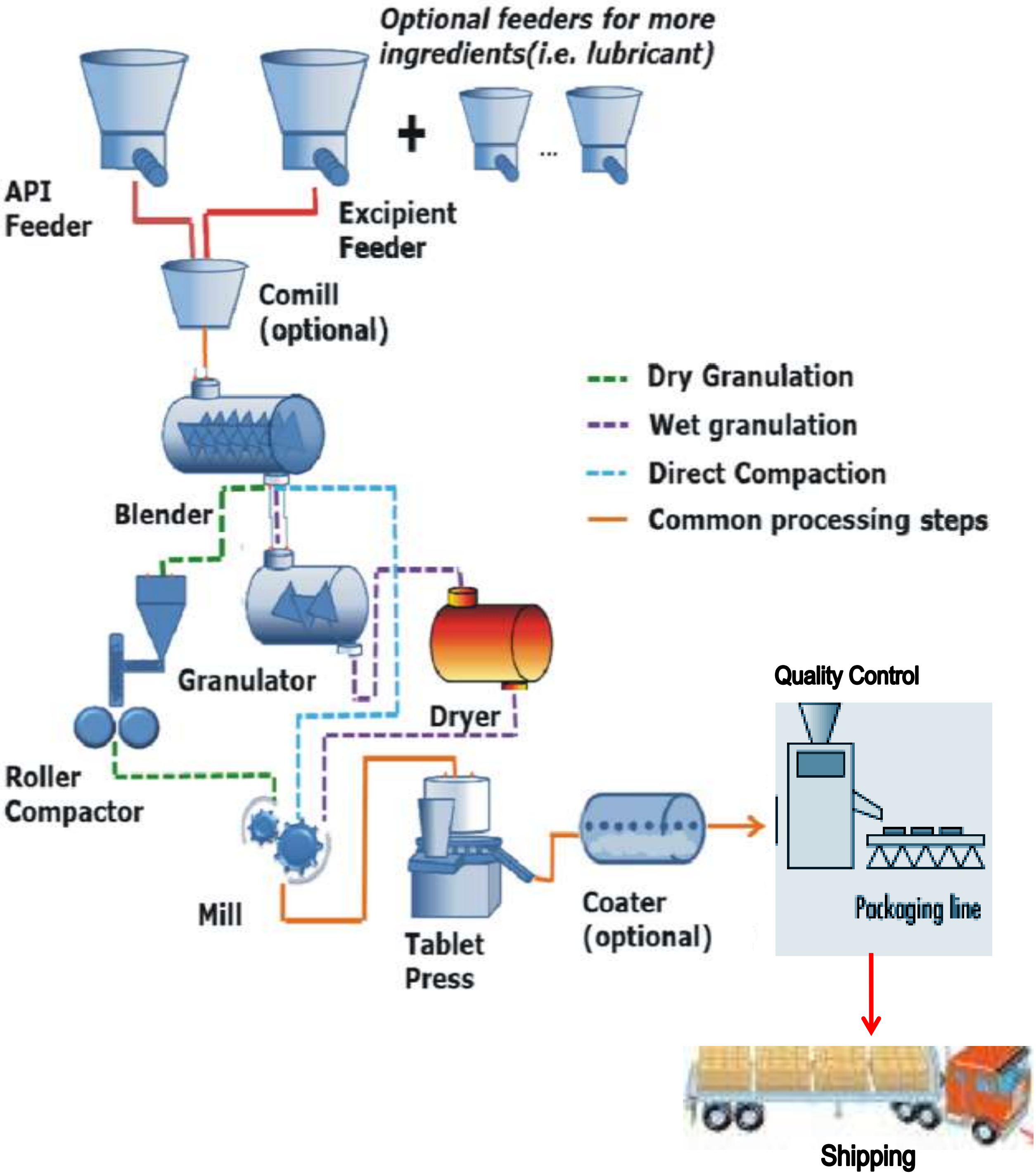


Figure 3.3: Overview of the Drug Process Line

The Active Pharmacological Ingredients (API) and Excipients move starting from work stage 1 through work stage 11 before it reaches customers in the form of finished items. During dispensing, the weight of each ingredient in the mixture is determined according to dose.

Dispensing is done by automated dispensaries with mechanical devices such as vacuum loading system and screw feed system working according to the computer files containing instructions for the production batch. Each item (dose) has different file names called Ericam number. By inserting the Ericam number, the machines automatically download the file containing codes or instructions to be executed. The powder/granules blending are done at the stage of pre granulation and/or post granulation stage of tablet manufacturing. Granulation provides homogeneity of drug distribution in blend. When the product is compacted properly, then it can be passed through a mill and final blend before tablet compression as shown in figure 3.3.

Drying is another important step in the formulation and development of a pharmaceutical product. It is important to keep the residual moisture low enough to prevent product deterioration and ensure free flowing properties. The machine used here is Fluidized – Bed Dryer (FBD) shown in figure 3.5.

Milling entails size reduction, crushing, grinding or pulverization to ensure greater uniformity of dose. Whereas, lubrication ensures that the tableting blend does not stick to the equipment during the tableting or compression process. Compression is done either by single punch machine (stamping press) or by multi station machine (rotary press) which 'squeezes' the ingredients into the required tablet shape with extreme precision. Automatic coaters are employed after cmpression for coatings; they are equipped with remote control panel, dehumidifier, dust collectors.

The function of in-process controls is monitoring and if necessary adaption of the manufacturing process in order to comply with the specifications. Quality control system seeks to achieve balance and to enable continuous improvement of inventory estimates. Drug items are packaged before they can be sent out for distribution. The type of packaging will depend on the formulation of the medicine but blister packs (primary package) are a common form of packaging. Blister packs are inserted into a carton or box (secondary package). The cartons of blister packs are in turn enclosed in barrels or pallets (tertiary package) and shipped in containers to distributors/consumers. Other auxiliary equipment in the manufacture of oral drugs at Juhel Process plat include granulation feeding device, tablet weight monitoring device, tablet deduster, fette machine, etc.

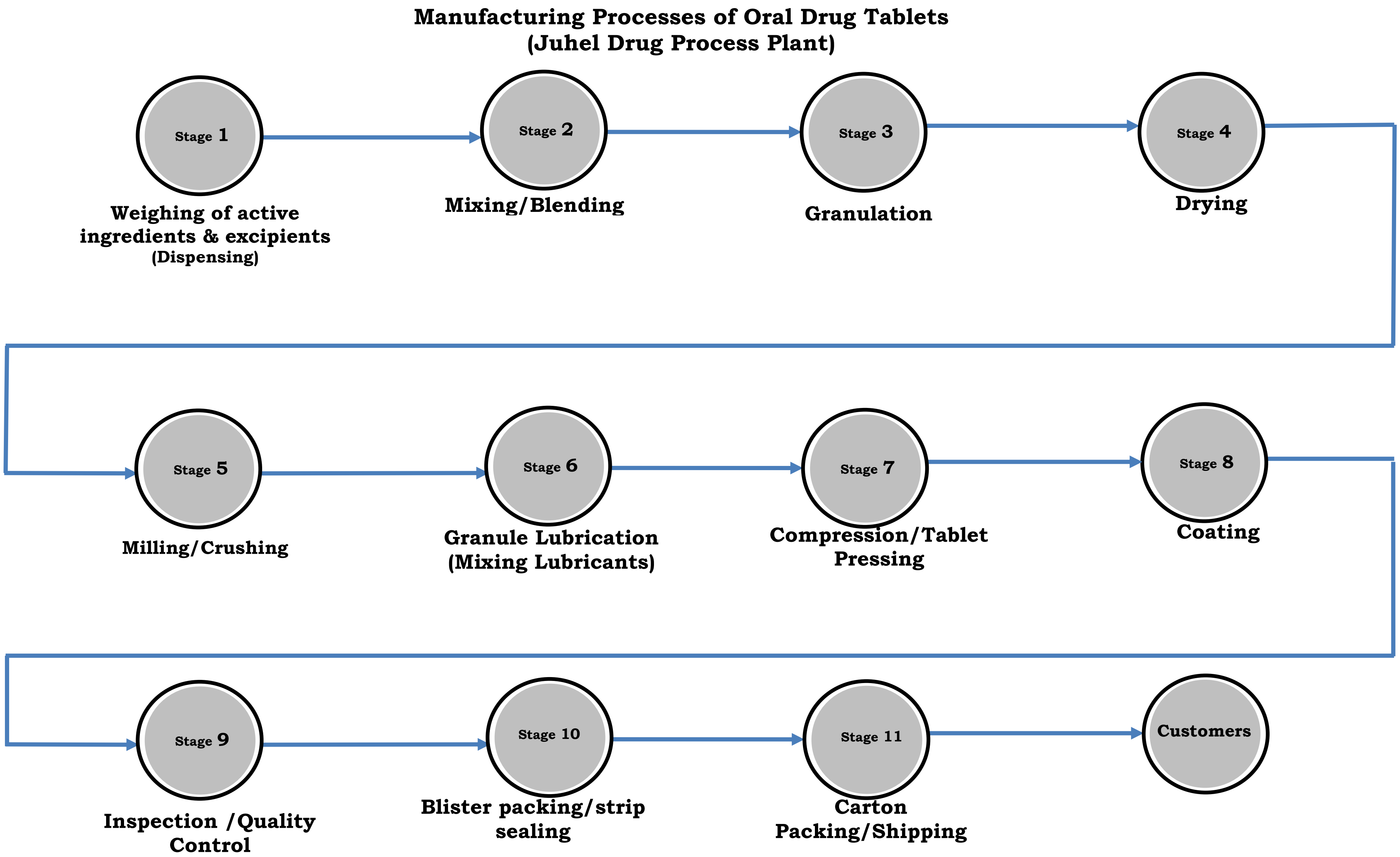


Figure 3.4: The Manufacturing Processes of Oral Drug Tablets at Juhel Drug Process Plant

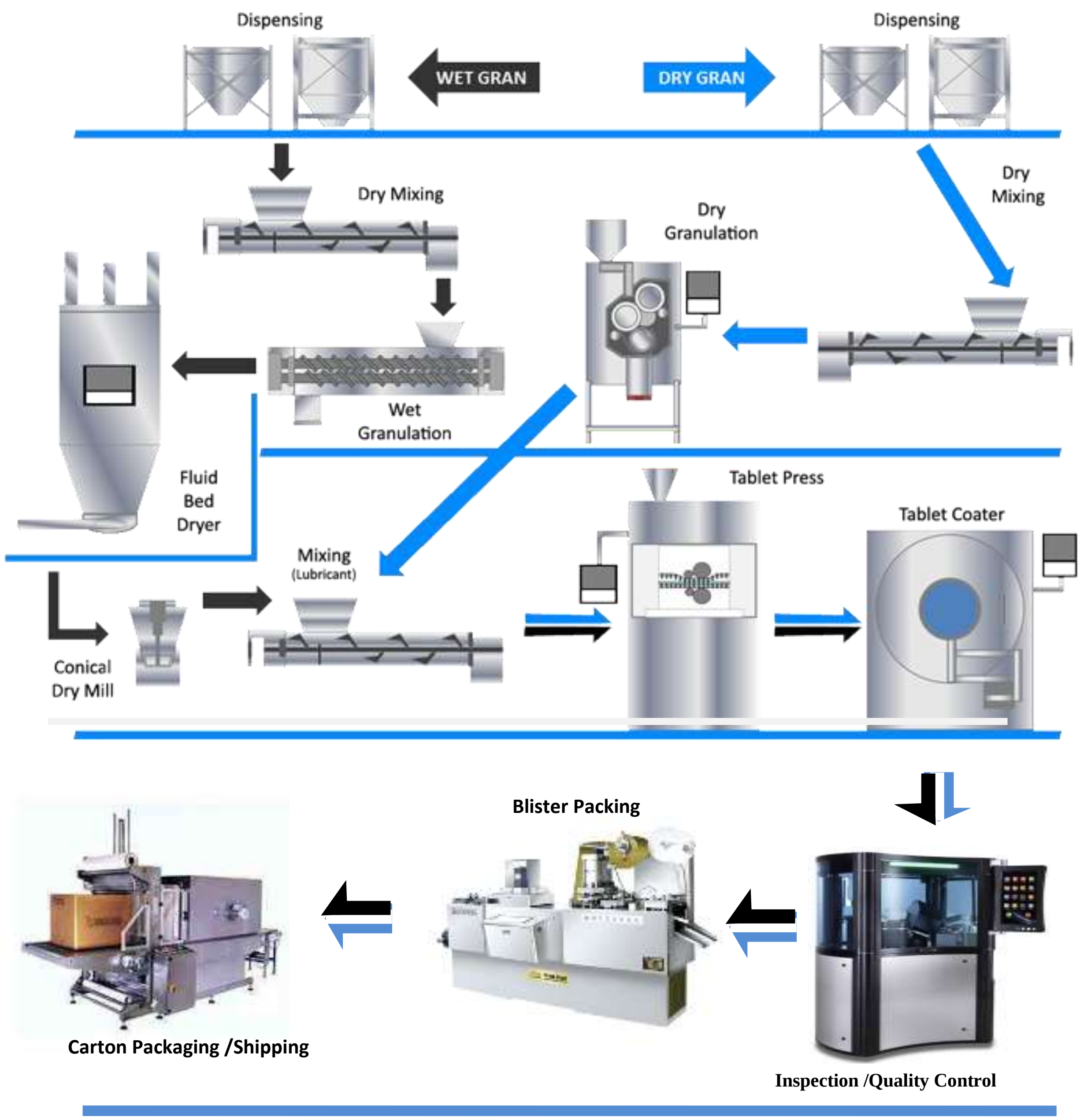


Figure 3.5: General Layout of the Drug Process Plant

3.2.3. Layout

Because of the type of manufacturing processes, the Drug Process Plant employs product flow layout as shown in the Figure 3.5. The benefit of this layout is that the process paths are clear so everyone understands what the next process is. Unfortunately, because of space limitation and the size of particular machines, most process paths are not straight lines so the processes require extra time for transport as a result of extra distances. Moreover, these problems also lead to other problems such as unfixed locations of buffers so WIP and inventory are not visible. Currently, the Drug Process Plant employs 297 workers to run the production processes for three shifts. All workers who do not work in the inspection /quality control are flexible operators who can handle various machines. They are normally rotated to handle other jobs weekly. To plan and manage the production processes, the Drug Process Plant is supported by other employees such as supervisors, technical staff and material planners as well as a manager.

3.2.4. The Ordering System

The ordering system at the Drug Process Plant is conducted using a MRPII system. Generally, this system works as follows (Figure 3.6). When a customer requires particular items, the customer's planning section firstly checks the inventory file at the computer screen that contains the list of the inventory status of the items.

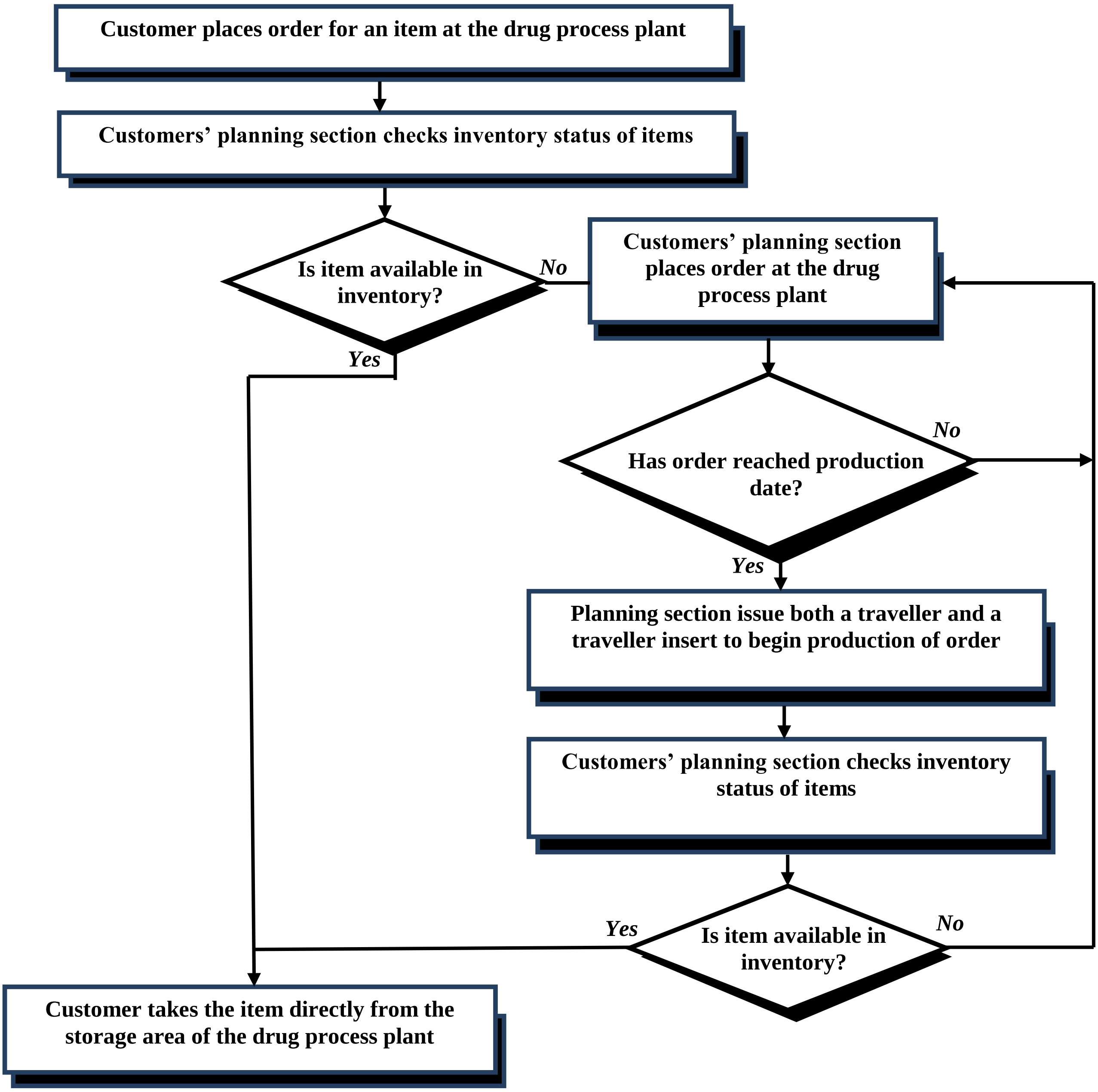


Figure 3.6: The Ordering System

If the items are available, the customer takes the items directly from the storage area of the Drug Process Plant. Otherwise, an order is placed to the Drug Process Plant. The order is then processed by the planning section at the Drug Process Plant to produce an updated Master Production Schedule (MPS). In this step, rough-cut capacity planning is used to optimise the utilisation of the resources by changing the date of production. This information and other MPS modifications are used as inputs to update the MPS. By incorporating the bill of material, the MRP system then generates a planned order schedule as a primary output, as well as inventory transaction and performance reports as secondary outputs. When the order reaches the production date according to the schedule, the planning section issues both a traveller and a traveller insert to the shop floor. Both of these documents give authority to the shop floor to begin production of the order.

Travellers and traveller inserts are issued for executing the production of an item. There is no production of the item until both documents are received at the shop floor. The traveller is a form containing information for executing the steps in production such as the process routing, the quantity, the Ericam number and material specifications. A traveller moves following the materials of the item. In relation to the traveller, a traveller insert is a form that must be filled out by operators. The traveller insert provides information, such as the production start and finish at each stage of operation, operator names, the quantity and the scrap produced at each stage of operation.

3.2.5 Order Quantity

The order quantity of most items at the shop floor is set based on the capacity of the tablet press (machines) since tableting/compression is the most critical process to determine batch sizes and order quantity. The machines are critical because they require significant setup time, which can cause bottle necks. The production capacity of the machine is 20 pallets or 120 sub-pallets (one pallet is later separated into six sub-pallets). The batch size of the item processed through the machines must be a multiple of 120. For example, if the average weekly order of the item is 370 units (sub pallets), 360 units is selected. The Drug Process Plant produces various items. This results in more time being required for waiting and queuing at the production facilities, as well as more efforts for scheduling and resource allocation. Based on the calculation of the total process, using the standard times as shown in Figure 3.7, around 76% of the throughput time for most items is spent on non-productive processes such as waiting and queuing.

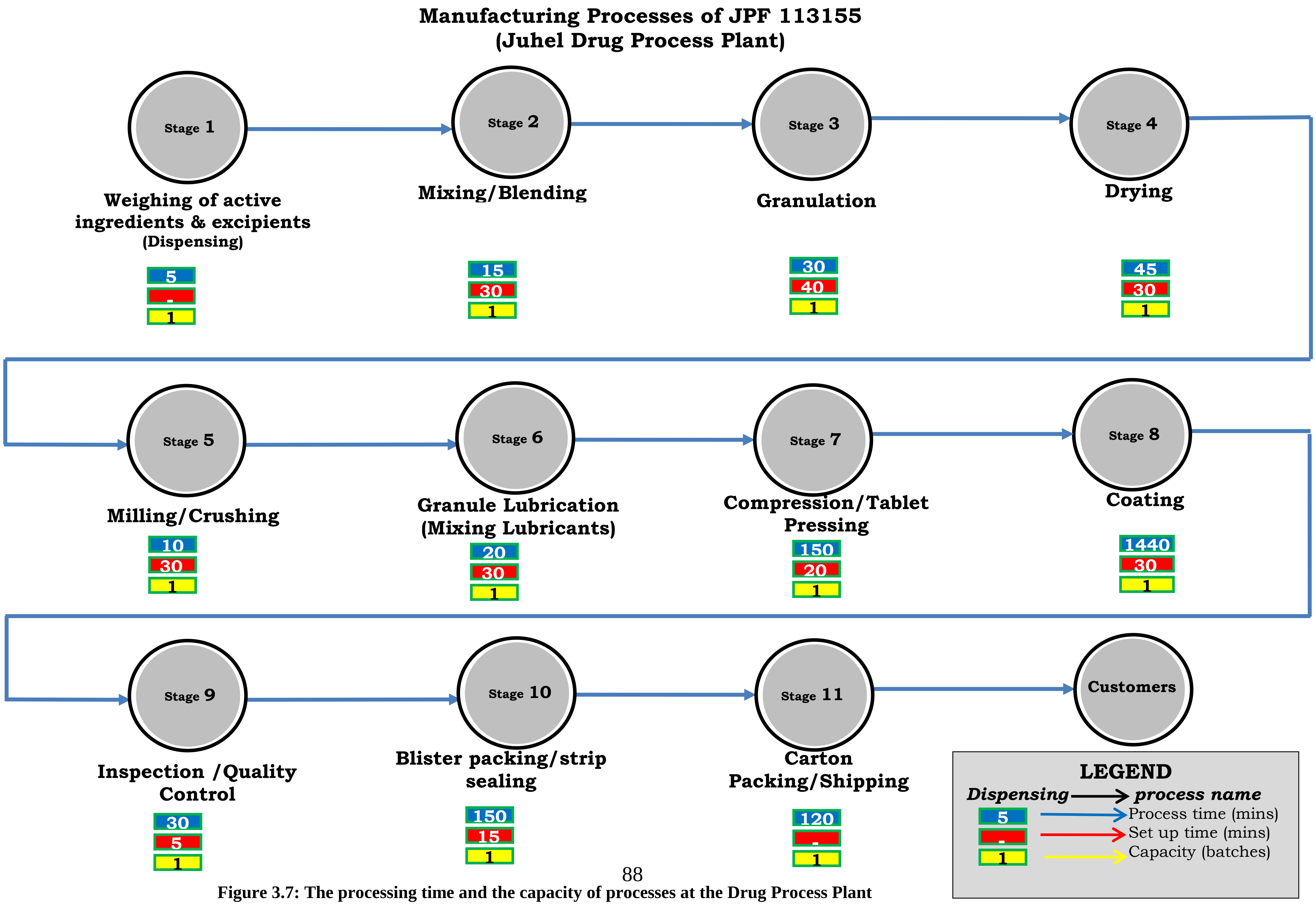


Figure 3.7: The processing time and the capacity of processes at the Drug Process Plant

As a result of space limitation, the WIP of items is located on conveyors. This makes it difficult to check the status and the amount of particular items. In addition, there is no fixed location for the conveyors so this also results in less consciousness of the importance of reducing inventory. Therefore, a more visual system should be established to enhance the ease with which the status and location of the inventory are observed. The production process in the Drug Process Plant was conducted by the MRP system. This led to extra inventory of finished items stored at the Drug Process Plant. Therefore, the introduction of the JIT system at the Drug Process Plant is crucial to eliminate this problem.

3.3 Proposing an alternative JIT system

Based on the study of the existing Drug Process Plant structure, an alternative JIT system is proposed in this section. A needs assessment and prototype design was set up for this research work. Initially, a tablet drug item (blend) was selected as a trial or a pilot project. The reason for this was that the pilot project could be easily monitored so the problems which appeared could be identified quickly. The successful implementation of the pilot project would motivate the development of similar systems for other items.

JPF 113155 which is Paracetamol 500mg was selected for prototype JIT design and implementation. The three reasons for selecting this item included:

1. Juhel Pharmaceutical Nigeria Ltd is a market leader in the production of this tablet so the successful improvement of the JIT system would help improve the performance of this plant.
2. Manufacturing processes of tablets are relatively simple, so this item was considered good for trial run.
3. This item has a weekly order that covers 20% of total order of the tablets, so the effects of introducing the new system would be more visible than lower volume items.

Considering the objectives of the system and problems encountered at the Drug Process Plant, five characteristics of the JIT system need to be determined i.e.:

1. The number of buffers - helps determine how many groups of JIT workstations would be required. In this work, a group of JIT workstations is called block.
2. The parameters of the pull system designed such as batch size, Kanban quantity and frequency of picking.
3. Mechanisms or operating procedures for running the system.
4. Visual control systems.

5. JIT devices for running the system – E.g., information boards and shelves.

These characteristics are discussed in the following sections.

3.3.1 JIT System Design Considerations

Main issues and problem in the manufacturing plant was identified by collecting relevant information and understanding the actual operating system. The range of information included manufacturing processes, operating procedures for executing orders, plant layout and items produced by the Plant. To implement the mechanisms of the alternative JIT system, the following factors were considered in the design: number and location of buffers, batch size and operating procedures or mechanisms for running the system/ information flow of the orders. The implementation involved activities to achieve model design specification. This step included training since training was considered the dominant factor for successful implementation of the system.

3.3.2. Determining the Number of Buffers

The manufacturing processes of JPF 113155 consist of 11 different processes with high variations in throughput times. Fixed buffers must be established between two selected processes to overcome shortages or over production in the JIT system environment. The other benefit of establishing buffers is that the amount of WIP in each buffer can be easily observed and controlled. There are many techniques that can be applied to find the best location of buffers with regard to the throughput time and the amount of WIP. In this work, a heuristic approach (Figure 3.8) was developed to determine the total number of buffers and to allocate the buffers to each stage in the JIT system. Heuristic buffer allocation algorithm uses simulation to determine the throughput for each buffer allocation. Queuing statistics was used to determine the rough-cut buffer capacity and its allocations to each buffer stage. Based on the confidence interval concept, a modified steepest descent search was applied to identify new buffer sizes.

Considering the production line with n stations and K units of buffer allocated to it, in this algorithm, first an initial buffer allocation was determined by allocating initial buffer value of K/(n-1) to each buffer slot and placing the remaining buffers in the center buffer slot. Then n-2 adjacent candidate solution for the initial buffer allocation was determined by subtracting one buffer value from the largest buffer value of the initial buffer allocation and adding it sequentially to each other buffer slot. These n-2 adjacent candidate solutions along with the initial buffer allocation formed n-1 simplex allocation. The throughput of each simplex was determined using aggregation method and sorted in the order of decreasing throughput. The best candidate had the highest throughput and the worst candidate had the lowest throughput.

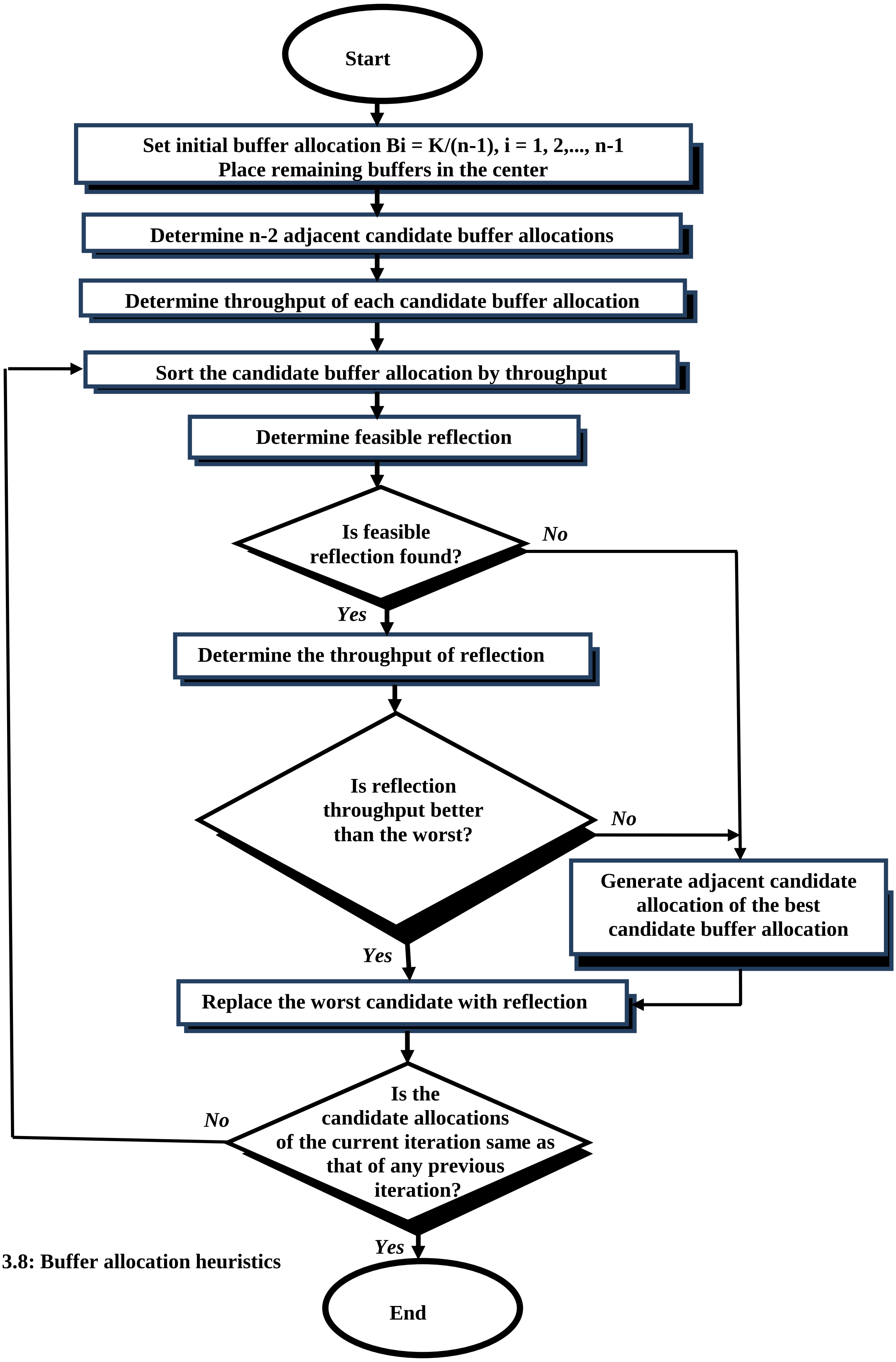


Figure 3.8: Buffer allocation heuristics

To determine the search direction to find a better allocation, a feasible reflection was identified. If the reflection throughput is better than the worst allocation, the worst allocation is replaced with the reflection and the stopping criterion is verified. If the stopping criterion is not reached then the procedure is repeated again by sorting all the candidate solutions by throughput and calculating the feasible reflection. If the reflection throughput is worse than the worst allocation throughput or if no feasible reflection is determined, the search is restarted by generating simplex around the best candidate solution in the current iteration.

The best candidate solution was chosen and its neighborhoods determined by moving one buffer unit from the largest buffer slot and allocating the same to subsequent buffer slots and their throughput was determined using aggregation method. When the stop criterion was not reached the candidate allocations was sorted by throughput and the procedure repeated. The buffer allocation algorithm was stopped when all the candidate allocations of the current iteration were the same as that of previous iteration. Since the situation again repeated the iterations that were previously tested, the procedure was stopped. The advantage of this algorithm is that the new reflection determined was farther away from current allocations. The locations of buffers have been decided according to practical reasons after conducting discussions with supervisors at the Drug Process Plant. Basically, there are four buffers required for the new JIT system as shown in Figure 3.9.

a. Storage/End Buffer

This buffer is a finished products buffer and it already exists in the MRP system. The purpose of this buffer is to store finished products until the customers take these products.

b. Buffer 2

This buffer is located between the inspection/ quality control and blister packing/strip sealing. The purpose of this buffer is to suspend the items until there is a signal or order from the customers. In this buffer, no JPF 113155 items will be processed further until they are needed by the customers. Buffer 2 improve the performance of the drug process plant by decoupling the effect of the differences in processing time and breakdown times of machines by ensuring continuous flow of parts through the production line.

c. Buffer 1

This buffer is located between the automated dispensaries and the mixer/blender. The purpose of this buffer is to control the quantity of active ingredients and excipients that must be processed. This increase production efficiency, eliminate waste, reduce overall costs and

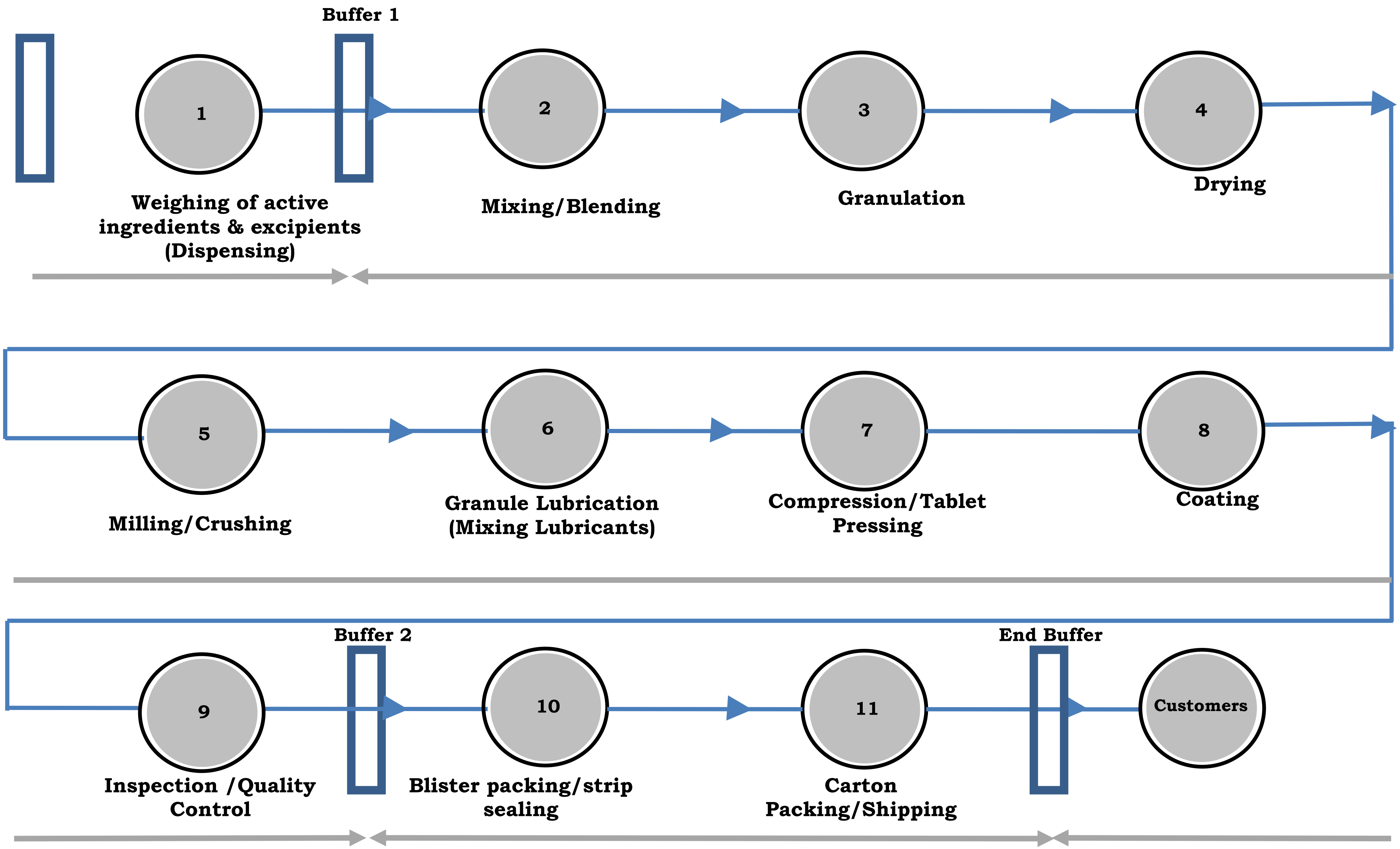


Figure 3.9: Location of Buffers

keep operations running smoothly.

d. Raw Materials Buffer

As with storage, this buffer already existed but the function was to store raw materials. The purpose of this buffer is to store and control the supply of raw materials from the vendors. By inserting these buffers between the two groups of processes, the total production process can be viewed as the combination of several blocks.

In the new system, the concept of trigger point is applied since the company wants to apply a single-card pull system that is considered to be simpler. However, this system can only be applied if there are no different parameters between two adjacent workstations or JIT blocks, particularly in terms of batch size and lead time. In the new system, the batch size and lead time are likely to be different from one block to another block, therefore, the concept of trigger point must be applied to deal with this problem. By using this concept, a Kanban operating at the particular block that requires a higher batch size is not executed directly but it waits until the total Kanban quantity received reaches the particular value that should be close enough to the batch size of the block. This value which is then called the trigger point, indicates that production must be started when the total requirements have reached the point. The other benefit of a trigger point is to dampen the variations of production and demand. Similar to a change in the number of required Kanbans conducted by supervisors, by using this concept the supervisor can also change the value of the trigger point in order to avoid shortage or overproduction as effects of the variations.

Although the use of trigger point has some advantages, there are some drawbacks as well. By applying the trigger point, the system tolerates a considerable amount of buffers that cannot be minimised unless the lead time or the setup time is reduced. In addition, if the demand is fluctuating, the shortage is likely to be unavoidable. To overcome this problem, the status of the trigger point must be updated continuously.

3.3.3. Determining the Parameters of the Pull System

One of most crucial steps in designing a pull system is determining the pull system parameters for running the system. The parameters of the system include the customer frequency of picking, the quantity taken by the customer, the number of sub-pallets (cartons) in the containers (referred to as Kanban quantity) and the capacity of each buffer. Before determining all of these parameters, discussions with the customer, the Drug Process Plant, were conducted. In this step, as a result of the previous approach, determining parameters was not based only on the theory but more on practical reasons as well. A practical formula such as the Kanban formula (Monden, 2011) cannot be applied since the lead time for each block is very different to others. For instance, block 3 and block 1 take 1 hour and 2 hours, but the block 2 requires a much longer time (around 6.5 days) as shown in figure 3.10.

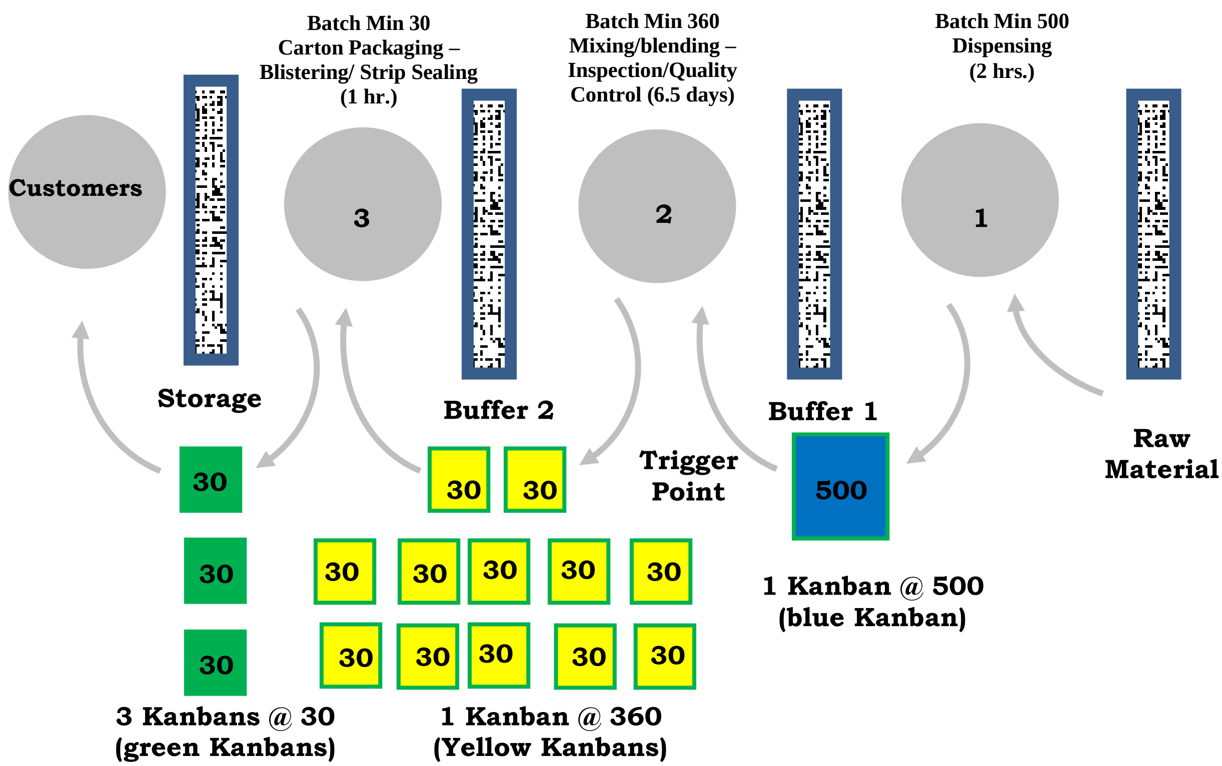


Figure 3.10: The design of pull system for JPF 113155

3.3.3.1. Block 3

There are three parameters that will be determined for this block i.e the batch size, Kanban quantity and the frequency of picking.

a. The Frequency of Picking

In the new system, the customers take the items within interval of three days instead of weekly as in the previous system. Therefore, the frequency of picking can be determined directly (daily).

b. The Batch Size and Kanban Quantity

The batch size is determined based on the following considerations. The average order of the trial item JPF 1131155 is 370 units weekly or 74 units daily. To stabilise the production, the batch size at the storage was determined to be 30 units so the Kanban quantity in the block 3 is also 30. The customer can take the finished items in multiple of 30 i.e 30, 60, 90 or even 120 daily depending on need. Since the average order is 74 units and the frequency of picking is daily, three Kanbans (or equal to 90 units) are sufficient to run the system at Block 3. Therefore, the customer is not allowed to take more than 90 units. However, the supervisors can add or reduce a Kanban when the system is considered to be tight or loose. To distinguish the Kanbans from another block, in this system, the colour of the Kanban is green.

c. Trigger Point

In block 3, a trigger point is not required since the processing time in the block is very short, that is around one hour. So a minimum quantity to indicate that the previous block must start production is not required and block 3 can replenish the empty container immediately.

3.3.3.2. Block 2

In this block, only two parameters will be determined i.e the batch size and Kanban quantity. Frequency of picking is not required because it depends on the requirement of the block 3.

a. The Batch Size and Kanban Quantity

The batch size is determined according to the following considerations. The throughput time in block 2 (from the mixing/blending process to the inspection/ quality control test) is around 6/5 days based on the most pessimistic estimate of supervisors. The batch size of block 2 should be 5 times 90 units (equal to three Kanbans at Block 3) or 450 units. Because of the capacity of the mixing/blending machines that only produces 120 sub-pallets (units) at once, the batch sizes for the trial item can be in multiples of 120 i.e 120, 240, 360, 480 or 600. However, the batch size of 360 units or 480 units is closer to 450 units. The last figure is not selected because it will increase the level of inventory in the buffer. In addition, a lead time of five days is the most pessimistic, which means the average can be lower than this figure, so 360 units is sufficient to run the system. Therefore, the batch size and the Kanban quantity at block 2 is 360 units. In this block only one Kanban is required. To distinguish the Kanbans from the other blocks, the colour of Kanban is yellow.

b. Trigger Point

As the supply of 360 units at block 2 will finish within four days so as to reduce the chance of shortages as well as to avoid the effect of the different batch sizes, the trigger point must be established in this block. Since the total average demand for five days is equal to 74 times 5 or 370 units, there is an average shortage of around 10 units (370 - 360) every five days. To overcome this problem, the trigger point is set at 300 units, which means there are 60 extra units (360 - 300) for five-day requirements. Therefore, in the new system, when the total Kanban quantity at buffer 2 achieves 300 units, the production in the previous block must be started or this means another Kanban must be issued to block 1. Another way to reduce the chance of shortages in block 2 is to decrease the throughput time from five days to four days. This can be carried out by improving the performance of each process such as by applying techniques including quality improvement, total preventive maintenance, or continuous improvement. However, if all efforts are not successful or there are undesired situations such as machine breakdown or increased production, a Kanban must be added.

3.3.3.3. Block 1

The last block, the automated dispensaries, has been set to run in batch sizes of 500 pallets (3000 sub-pallets) that will supply not only dispensed items but also other items based on average daily demands. The batch size of 500 units is determined according to the most reasonable production quantity of the operation with regard to the utilisation of the machines and the availability of the workers. In this block, the colour of the Kanban used is blue. Based on all of the above parameters, the design of the pull system for the trial item at the Drug Process Plant can be described as Figure 3.10.

Average Daily demand = 74 sub-pallets (standard deviation = 30 sub-pallets)
The number of sub-pallets in the standard container = 30 units

3.3.4. Designing Mechanisms or Operating Procedures for Running the System

Mechanisms and operating procedures are required to provide detailed step-by-step instructions for the implementation of a pull system. These management tools must be developed clearly so all people working with this system understand how to accomplish the task. Diagrammatically, the mechanisms of the pull system at the Drug Process Plant are based on the design of the system in Figure 3.10 as shown in Figure 3.11 (only for the block 3). The mechanisms of the new pull system can be described in the following procedures. Customers arrive to pick up full containers of sub-pallets from the storage area (end buffer). When taking the containers, they must place green Kanbans from the full containers on Board 2. Operators in the blister packing/strip sealing section must check whether Board 2 has cards or not. If there are cards, they take the cards and start production by taking raw materials from buffer 2 and putting them into the empty containers. The quantity of raw materials taken is equal to the total Kanban quantity detached from the Board 2. If buffer 2 reaches the trigger point, they place the yellow Kanban from buffer 2 onto Board 1. Operators in the mixing/blending section must check this board. If there is a yellow Kanban, they must take this card and start the production.

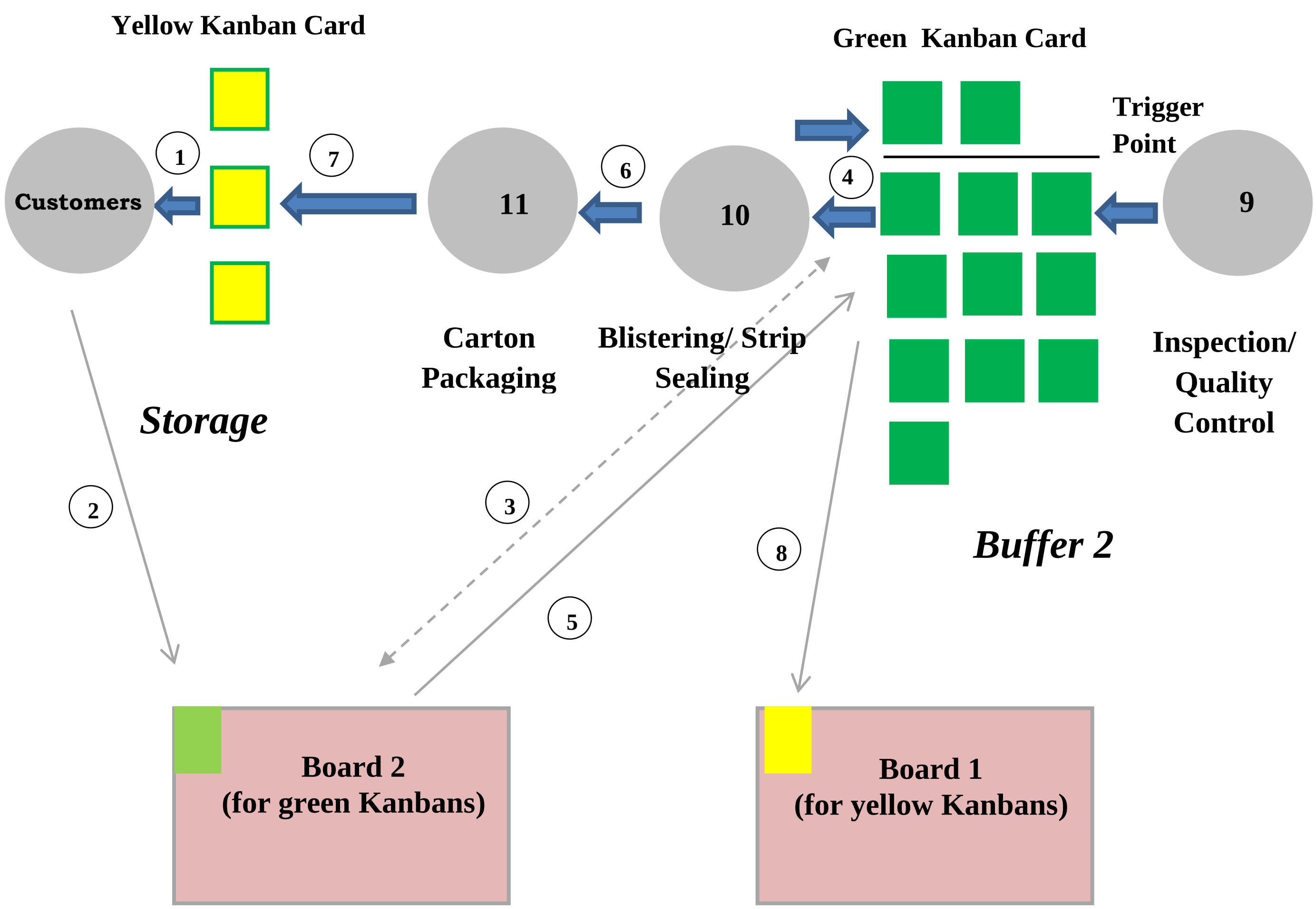


Figure 3.11: Mechanism of JIT System (Block 3)

In Block 3, the production quantity is 360 units as written on the yellow Kanban. The operating procedure for Block 3 can be described as in Figure 3.12. The numbers in the process flow chart refer to activities as shown in Figure 3.11. The process of customer picking up cartons of drug from the storage area is represented by the number 1 in the process flow chart while the process of taking the green card from container and placing it on Board 2 is represented by the number 2. The number 3 represent the process of checking Board 2 by operators at Blistering/ Strip Sealing section. Also, the process of taking the green card (by the operator at Blistering/ Strip Sealing section) from Board 2 and putting it into a container (raw material) from Buffer 2 is represented by the numbers 4 and 5 respectively.

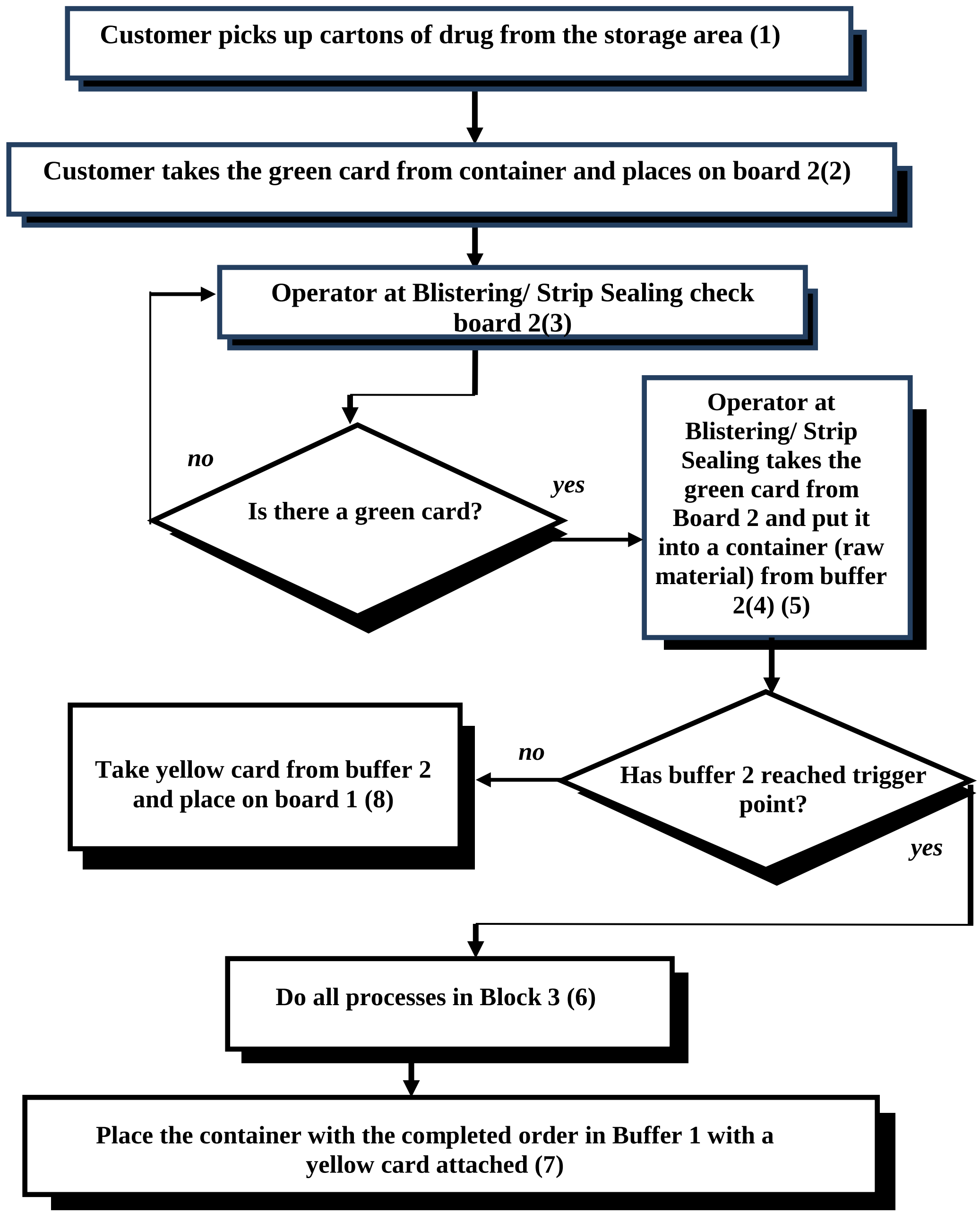


Figure 3.12: The operating procedure of the pull system (numbers referr to the mechanisms in Figure 3.11)

The process of doing all processes in Block 3 (i.e strip sealing and carton packing) is represented by the number 6. However, the number 7 represent the process of placing the container with the completed order in Buffer 1 with a yellow card attached. Furthermore, the process of taking yellow card from buffer 2 and placing it on Board 1 is represented with the number 8. Manufacturing processes such as inspection/quality control, blister packing/ strip sealing and carton packaging/shipping are represented with numbers 9, 10, 11 respectively in the process flow chart.

3.3.5. Designing the Means for Information Exchange

In this system, the Kanban is applied as a means of accelerating transfer of information between two adjacent workstations. Basically, the Kanban is not always in the form of cards, other forms of conveying information may be used - such as verbal, floor square, golf ball or electronic ordering signals. However, in this research, signal card/electronic ordering signal is used so as to exploit the multiple benefits of speed, accuracy, convenience, efficiency since there is a lot of information that must be included and conveyed i.e. the process routing, the quantity, the destination of the Kanban, the Ericam number and the material specification.

By considering the purpose of Kanbans, the role of travellers and the traveller insert must be evaluated. Since the role of travellers is almost similar to Kanbans, which is to authorise production, travellers can be replaced by Kanbans. Therefore, the Kanban card must contain the same information as written on the traveller. A sample of Kanbans used at the Drug Process Plant is shown in Figure 3.13. Although Kanbans can replace the role of travellers, the traveller insert cannot be replaced by a more visual system because the main purpose of this form is to provide information about the production activities that are required for the Drug Process Plant.

3.3.6. Designing JIT Devices for Running the System

Visual boards are used to attach Kanban cards so operators working in the first operation in each block can check whether there are cards or not on the boards. If there is a card, they must start processing the item with the quantity as written on the card. The location of the board should be close enough to the first operation of each block so operators working in this process can easily observe arrival of the cards.

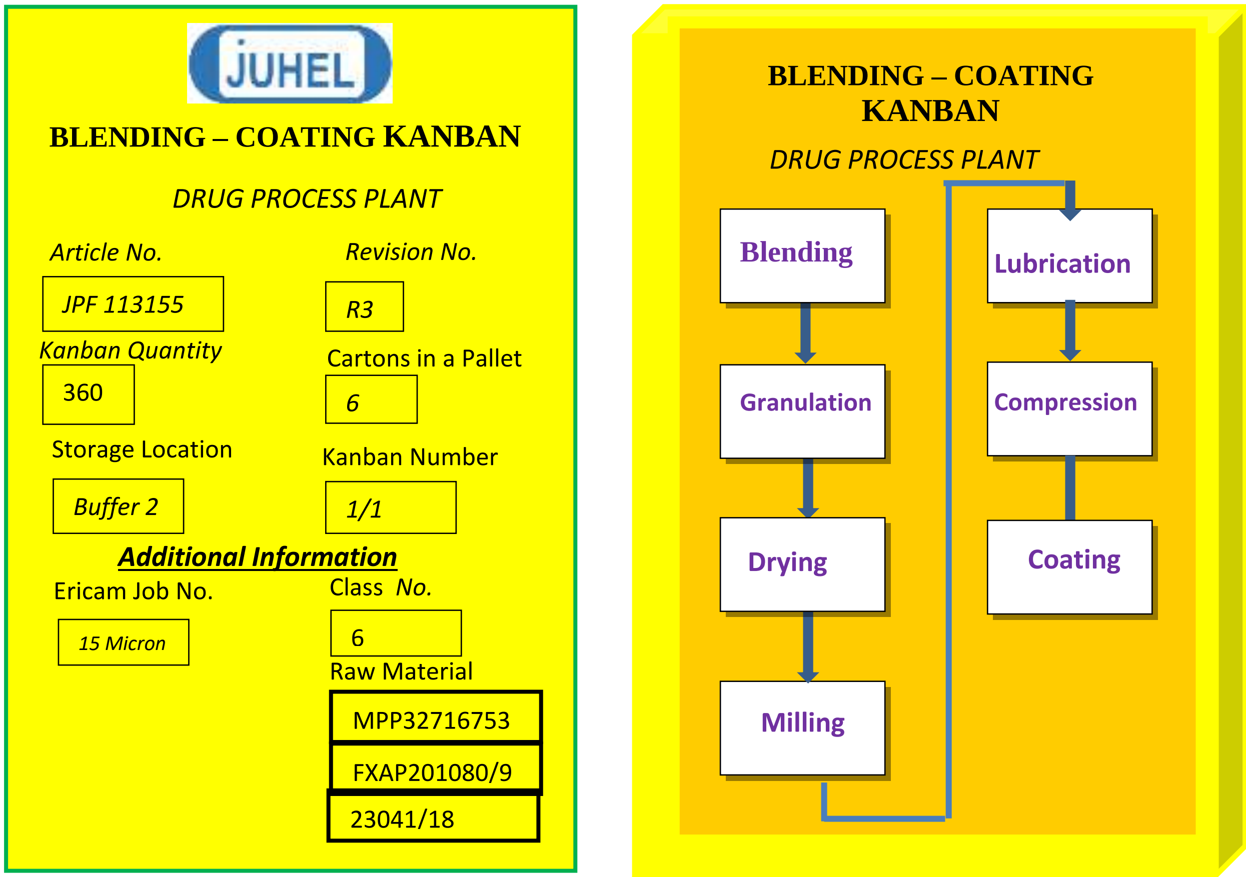


Figure 3.13: The design of a yellow Kanban (both sides) for block 2

In a pull system, the production runs in a fixed but smaller batch size for each item based on the Kanban quantity, therefore, the operators need to count the exact number of the items represented by the Kanban quantity before starting production. This job is very tedious, so to make this job easier, shelves and racks are specifically designed for holding a certain amount of items so operators will not be required to count the items. In the Drug Process Plant, both shelves and racks are designed to store product item JPF 113155. By using the racks and shelves that are designed to store the fixed quantity of product item JPF 113155, the operators only need to fill the empty shelves or racks without counting the product items.

3.3.7 Model Development Procedure and Code Generation

Code generation in this research work was done using ARENA /SIMAN software and TECNOMATIX simulation software. The final physical model of the JIT Manufacturing System

Model was developed alongside six sub-models namely: Supplier Sub Model, Route Sub-Model, Kanban Sub Model, Production Sub Model, Consumption Sub Model and Plant Sub Model. Animations were used to verify the logic of the simulation.

To achieve the objective of this study, first, the existing system was totally modeled and simulated. Secondly, the simulated model was tested and validated by analysis of variance. Thirdly, the optimum or most fitted JIT design is developed and tested to overcome existing system's limitations and its dynamic behavior. This solution is implemented and tested in a just-in-time production line.

This work developed an enhanced discrete event simulation JIT Manufacturing System Model described in Figure 3.14. The system consists of components, workers/machine operators and machines that make useful products. The system is managed across boundaries and interfaces. The boundaries define the scope of the system or subsystem, while the interfaces control the flows through transactions.

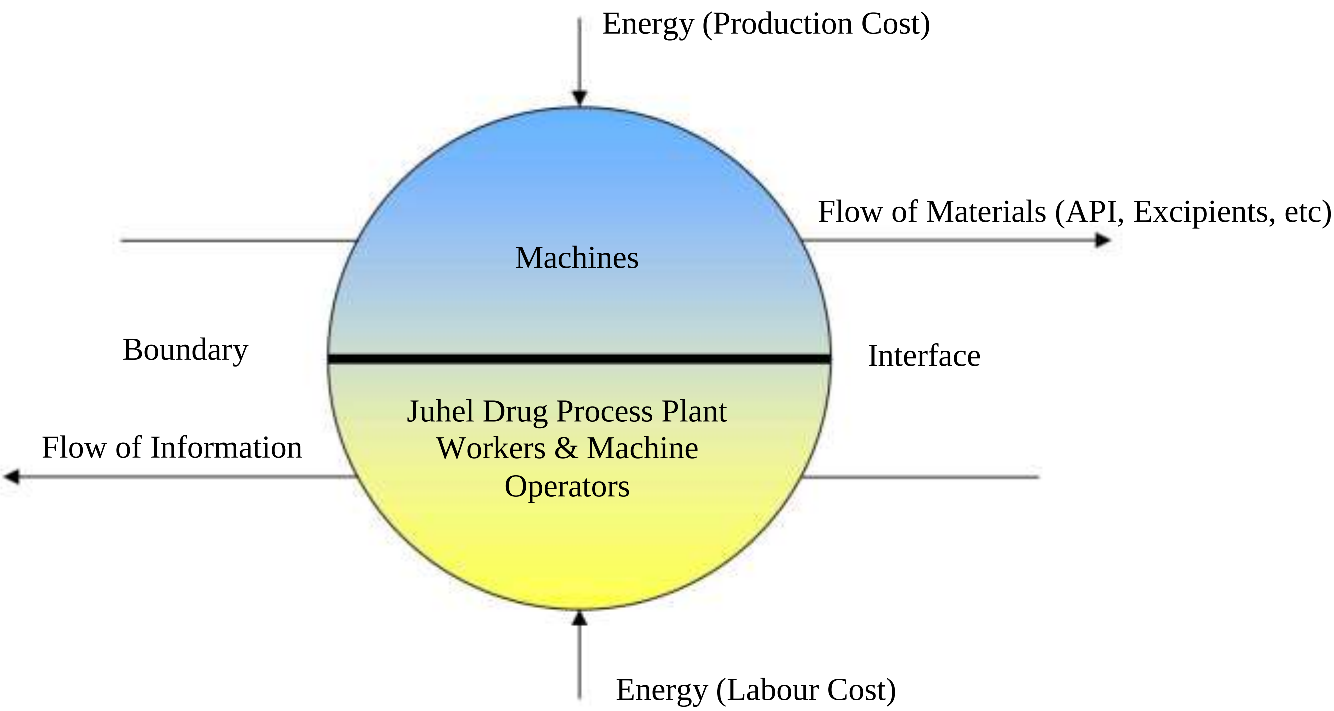


Figure 3.14: Enhanced Discrete Event JIT Manufacturing System

There are three flows in the enhanced discrete event simulation model: the flow of materials, the flow of information, and the flow of cost. These flows establish the value streams. Components of the value stream can be value-add or waste, depending on the operating conditions. For example, excess material flows become a stream of inventories, while excess information leads to confusion in process execution. By managing the flows, we can control the streams. An effective control of these streams is required for lean production.

As mentioned earlier, the interfaces control the flow. Conveyors regulate the flow of materials and a visual control regulates the flow of information between two stations. The interfaces arise from disconnected points in the system, e.g., the physical distances between two machines, the communication barriers between two people, or the control panels between a machine and an operator. It is often a good location for cost transactions. As the number of components and interfaces grows, the machines become factories and the plant workers /machine operators become organizations.

In the alternative JIT Manufacturing System Model, the parts represent the materials, while the kanban represent the information mechanism. In this way, we can analyze the efficiency of these flows. Associated with each device that handles the parts or kanban, a cost is applied to the operation of the device. Therefore a buildup of parts and kanban implies an increasing cost.

The experimental research design used to address the research problem in this work included three experimental factors; the various levels of manufacturing system alternatives (MAS), three levels of product mix complexity (MIX), and three levels of manufacturing overhead (MOH). Most simulation analysts apply an inferior design of experiments, changing one input at a time as opposed to factorial (2^{K-P}) designs, which controls estimated effects of input changes and shows the importance of interaction effects. For each performance measure used in this research work, the experimental design is a 3 X 3 full factorial with 60 replications, thus resulting in a total of 1620 (3x3x3x60) observations.

The experimental design is then:

$$Y_{aom} = \mu + MAS_a + MOH_o + MIX_m \quad \text{(Main Effect)}$$
$$+ MAS_a * MOH_o + MAS_a * MIX_m + MOH_o * MIX_m \quad \text{(Two-Way Interaction)}$$
$$+ MAS_a * MOH_o * MIX_m \quad \text{(Three-Way Interaction)}$$
$$+ eaom \quad (3.1)$$

Where: Y_{aom} = Performance Measurements

μ = Mean Effect

MAS_a = Manufacturing System Effect, a = 1, 2, 3

- MAS_1 = MPS
- MAS_2 = MRP
- MAS_3 = JIT

MOH_o = Manufacturing Overhead Level Effect, o = 1, 2, 3

- MOH_1 = Low
- MOH_2 = Medium
- MOH_3 = High

MIX_m = Product Mix Complexity Effect, m = 1, 2, 3

- MIX_1 = Narrow
- MIX_2 = Medium
- MIX_3 = Wide

eaom = Random Effect

3.3.7.1 Arena Simulation Software

In code generation phase, one of the simulation tool employed to construct this model is the ARENA /SIMAN software package. Arena which is a commercially available discrete-event simulation program provided a user-friendly, Windows-based interface while using SIMAN/Cinema simulation language to execute the simulations. The user did not directly interact with the SIMAN code, but Arena translated the user's actions into SIMAN code. Stochastic systems use random-number generators, so the output of the simulation is an estimate of the true system behavior. Multiple runs were made to determine a sample of system behavior, so a confidence interval was used to describe the output results. The ARENA /SIMAN software package was used in executing steps 3 and 4 of the JIT manufacturing system model (Figure 3.1). Model 1 consisted building the basic model and animation while model 2 entailed developing a more realistic model by containing other items or more complex factors. Using the following variables and equations, Arena calculates the confidence interval as follows (Devore and Farnum, 1999):

n = the number of samples

$\bar{X}$ (n) = the sample mean

S^2 *(n)* = the variance of the sample

$t_{n-1,1-\alpha/2}$ = the critical value from a t distribution with n-1 degrees of freedom

$$\bar{X}(\text{n}) = \frac{1}{\text{n}}\sum_{i=1}^{n} X_i \qquad (3.2)$$

$$S^2(n) = \frac{1}{\text{n}-1}\sum_{i=1}^{n}[X_i - \bar{X}(\text{n})]^2 \qquad (3.3)$$

Then the 100(1-α) % confidence interval is:

$$\bar{X}(\text{n}) \pm t_{n-1,1-\alpha/2}\sqrt{\frac{\text{S}^2(n)}{\text{n}}}$$

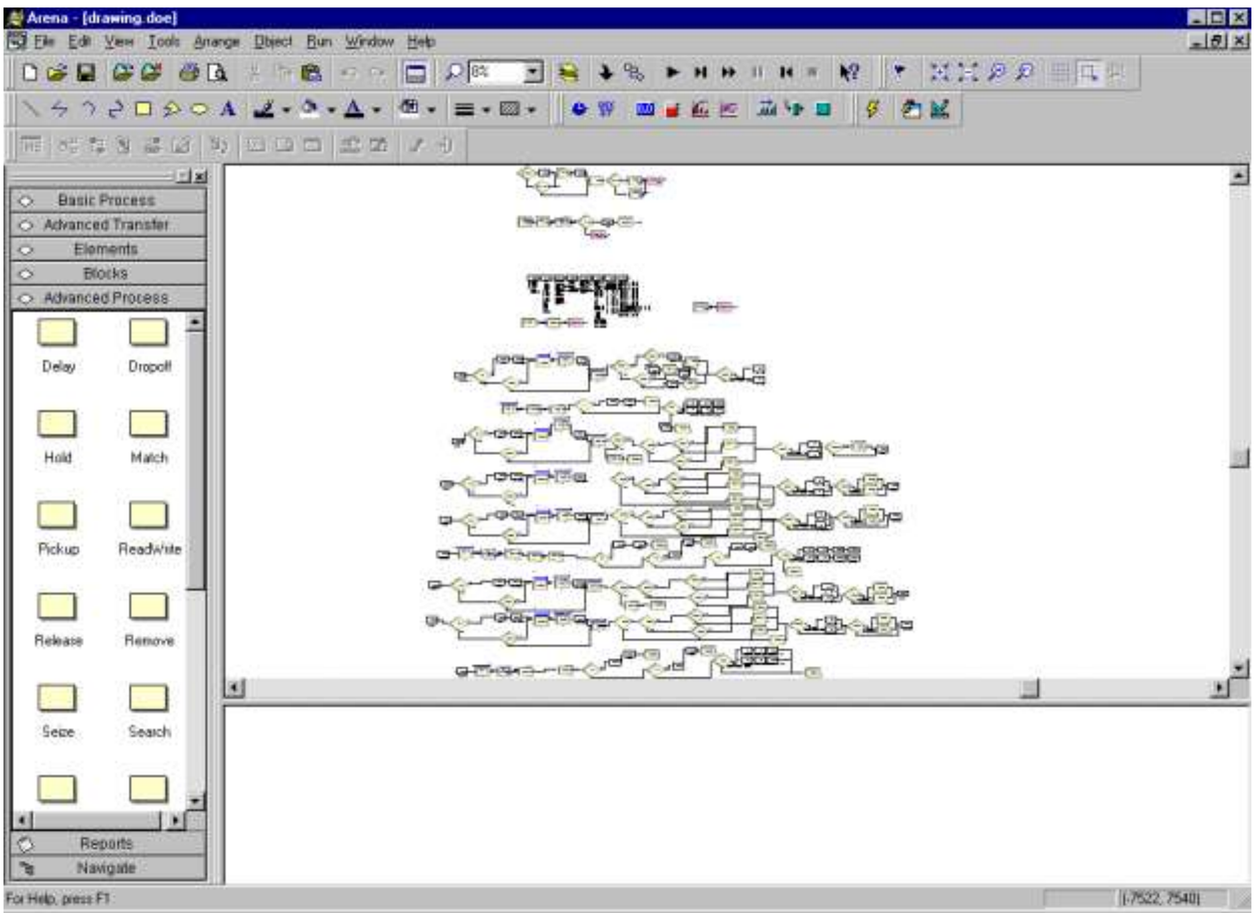


Figure 3.15: The Arena Interface

Figure 3.15 shows a typical Arena window. The user typically interacts with the interface shown in Figure 3.15 to both develop and run the model. To make or change a model in Arena, the user clicks on icons and drags them onto a larger screen. The user edited the behavior of each icon through a pop-up window. The user created a model, runs of the model was made and the program evaluated the model and produced an output report. Some of the preprogrammed Arena icons represent conveyors, machines, operators, etc. In instances where there is not a preprogrammed icon, the user created various system components using Arena logic blocks. Once a model was created, the user explored alternatives by modifying the resources, variables, properties, etc. and running the simulation.

Process Analyzer

The Process Analyzer (PAN) was used to evaluate the different scenarios after the Arena model has been finished, validated, and verified. The PAN was used to select a model, number of inputs and outputs of interest, enter values for the inputs, and ensure the model run with the new input values.

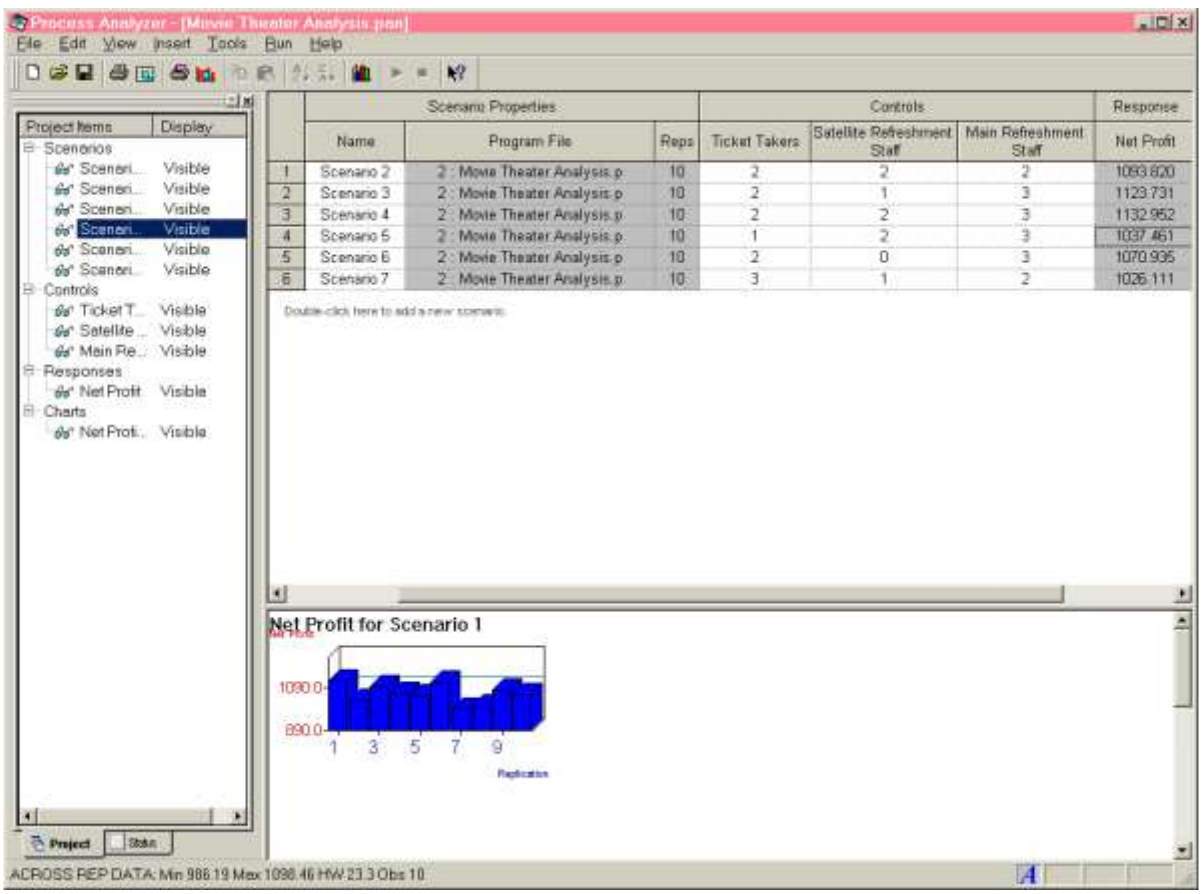


Figure 3.16: The Process Analyzer interface

The PAN usually displays the output values in a chart, as shown in Figure 3.16. The user modified inputs without losing previous results, and was even able to run multiple scenarios at once.

Output Analyzer

The Output Analyzer was used to create charts, moving average plots, graphs of user-specified confidence intervals, and correlograms from the results of an Arena model. Data manipulation and plots were done entirely in the Output Analyzer interface; the user did not interact with Arena in the analysis, only in the formulation of the model that created the data. To use the Output Analyzer, the user created a model in the Arena and created a statistics block that saves specified data results to a .dat file. Figure 3.17 shows some of the graphs that the Output Analyzer can create.

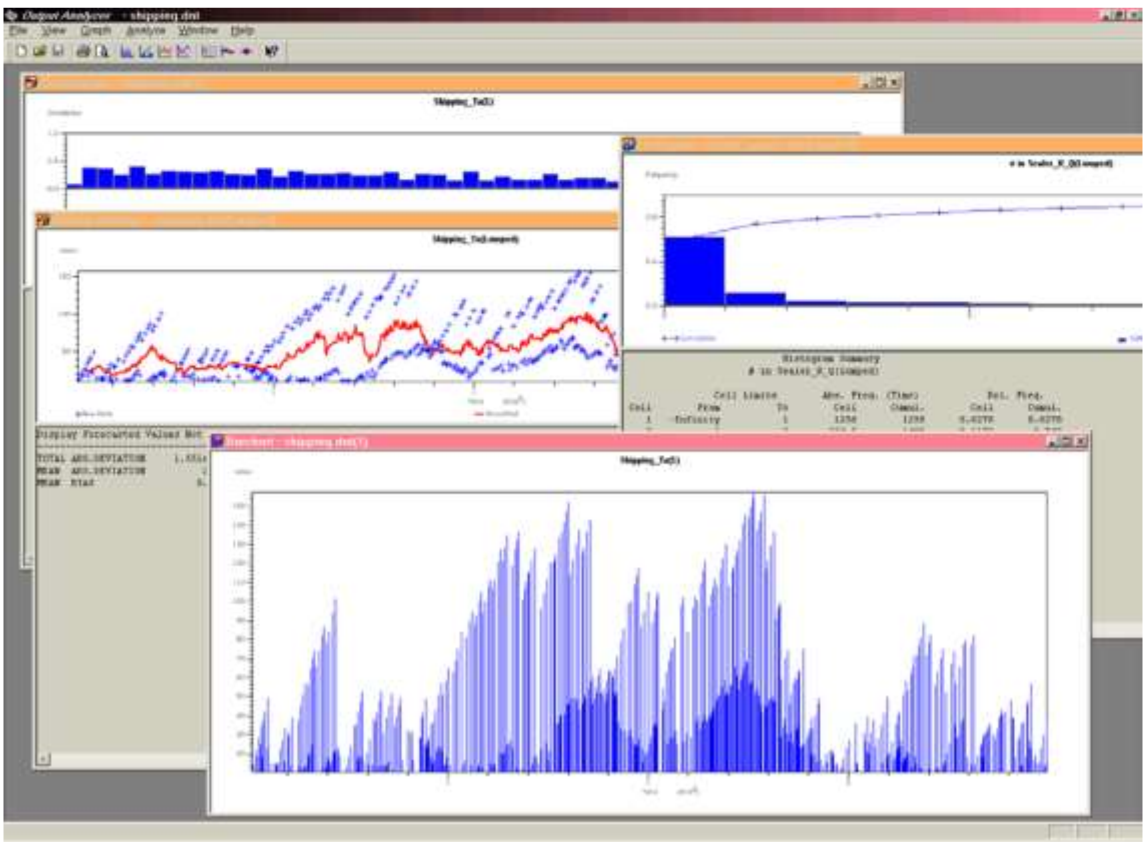


Figure 3.17: Graphs developed by the Output Analyzer

3.3.7.2 TECNOMATIX Simulation Software

A Visual Interactive Simulation system known as TECNOMATIX simulation software was used in executing and constructing the conceptual model of step 3 (Figure 3.1). This software was used to conduct simulation experiments, build and test the models on small incremental stage and to achieve the objectives of the study. The input parameters included setup time, machine alteration and shift alteration while the output parameter was throughput.

3.3.8 Alternative JIT System Evaluation

The alternative JIT system was evaluated using simulation to determine factors contributing to improved performance of the new system. The effects of factors such as number of buffers, location of buffers, kanban quantities and scheduling rule on inventory, visual control and flow time/ customer lead time were evaluated.

Also, the effects of trigger points on flow time, shortage of parts and WIP were evaluated based on the simulation results**.** The experiment further investigated the effects of the scheduling rules on performance measures such as utilisation and output of the trial items produced. Experiments were equally performed to find the optimal number of Kanbans that minimise the flow time as well as maximise the orders satisfied.

With the help of Design of Experiment (DOE), a total of 16 runs were taken to determine the Main Effect plot of Throughput for Signal - To - Noise Ratio. This also led to the determination of the optimum solution for Throughput. Behavior Analysis of the production control was evaluated by plotting production rate and total inventory level on the 'I_1 - I_2' plane. Sensitivity Analysis was also conducted to determine the effects of making changes in the model parameters (total demand of finished product, finished product demand changing rate, ordering cost, holding cost, etc) over a given optimum solution.

This research went further to determine the effect of the new JIT system on key manufacturing performance measures such as Demand Fulfillment Rate, Cycle-Time, and Net Operating Income by presenting the results and statistical analyses of the data collected from the ARENA simulation experiment. The initial data were downloaded into Excel and then uploaded into

SPSS for statistical analysis.

3.4 Modeling the Existing Drug Process Plant

The existing Drug Process Plant model was designed based on Unified Modeling Language (UML) Activity diagram in Figure 3.18. Figure 3.18 is the UML Activity diagram of the Drug Process Plant whereas Figure 3.19 shows the existing system modeled in ARENA software package. Appendix A1 presents the actual SIMAN language code for the existing drug process plant simulation model used in this experiment. This diagram model represents working processes of the plant in detail. The process begins with arrival of customers at the drug process plant. A visiting customer who has not placed an order in the drug process plant is channeled to the Customer planning section for preparing the bill of quantities and agreement document. At this point the customer makes a decision regarding further activities and transactions.

The customer can order for a drug item if he knows the exact item number (article number), scientific name and dosage or can perform drug items search. If the customer has decided to search for the drug items, he would go to the corridor. And again in the case when the terminal is busy, the customer uses requisite folder and search for a title in Kanban cards. After that, selection is placed in the order list, in such a manner that by using folders, the customer can select as many drug items as he needs. After the selection is completed, the customer could decide whether or not to purchase drug items and leave the drug process plant.

The process is similar when searching is provided through drug process plant terminal. If the terminal is available, the customer could log in, could select the search menu and enter search criteria. The result is a list of available drug items. The list can be revised or printed out. Searching process can be repeated until all the necessary drug items are worked out by the customer. And again, at this point customer could decide whether or not to purchase the drug items selected. When a list of drug items is not available, the customer is channeled to the storage area of the drug process plant, otherwise the process goes to finish. At the storage area of the drug process plant, the customer can ask for recommendations or annotations. And finally, the customer presents kaban card and list of items to be purchased which after confirmation the customer picks up the drug items from the storage area and leaves.

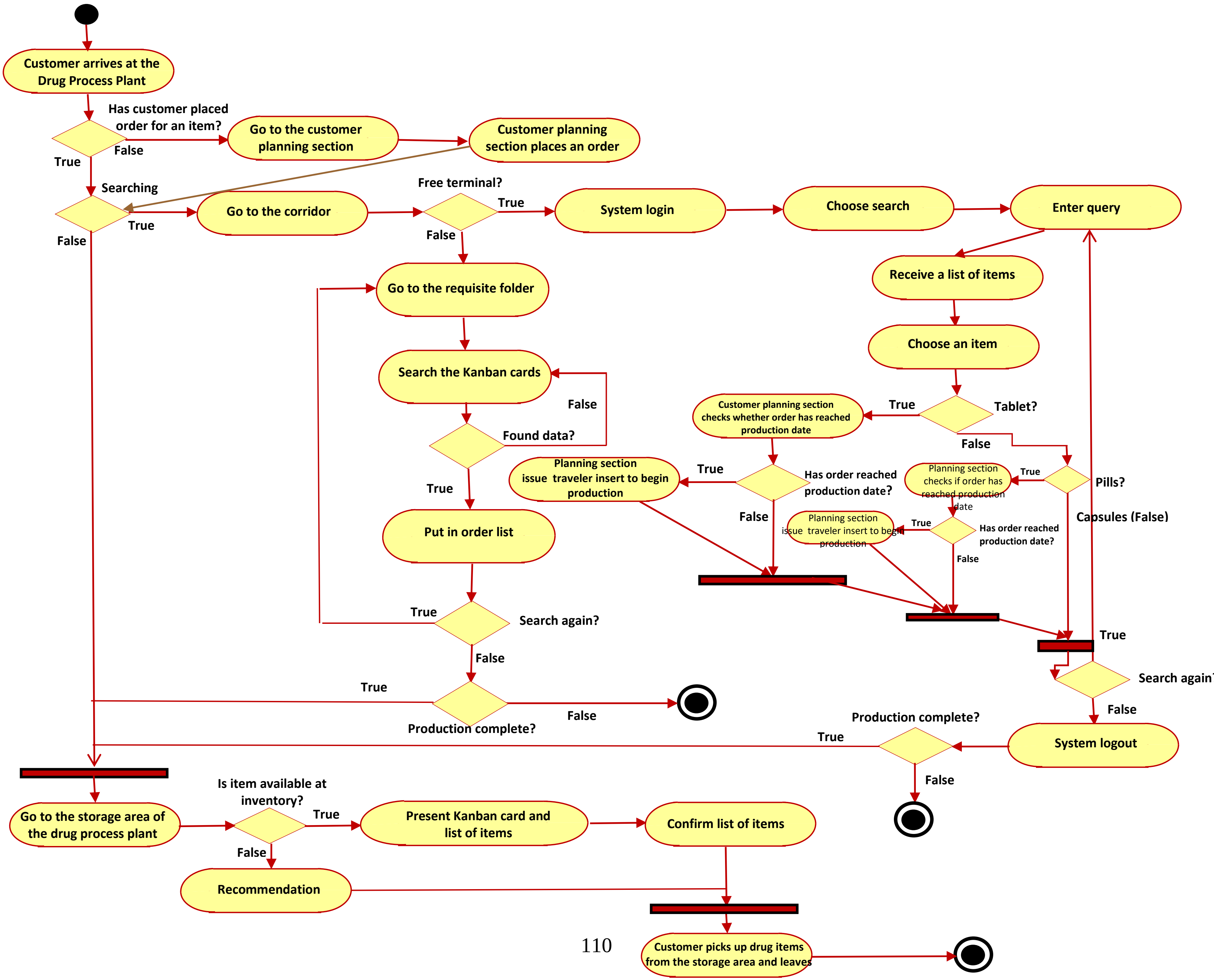


Figure 3.18: Unified Modeling Language (UML) Activity Diagram of the Drug Process

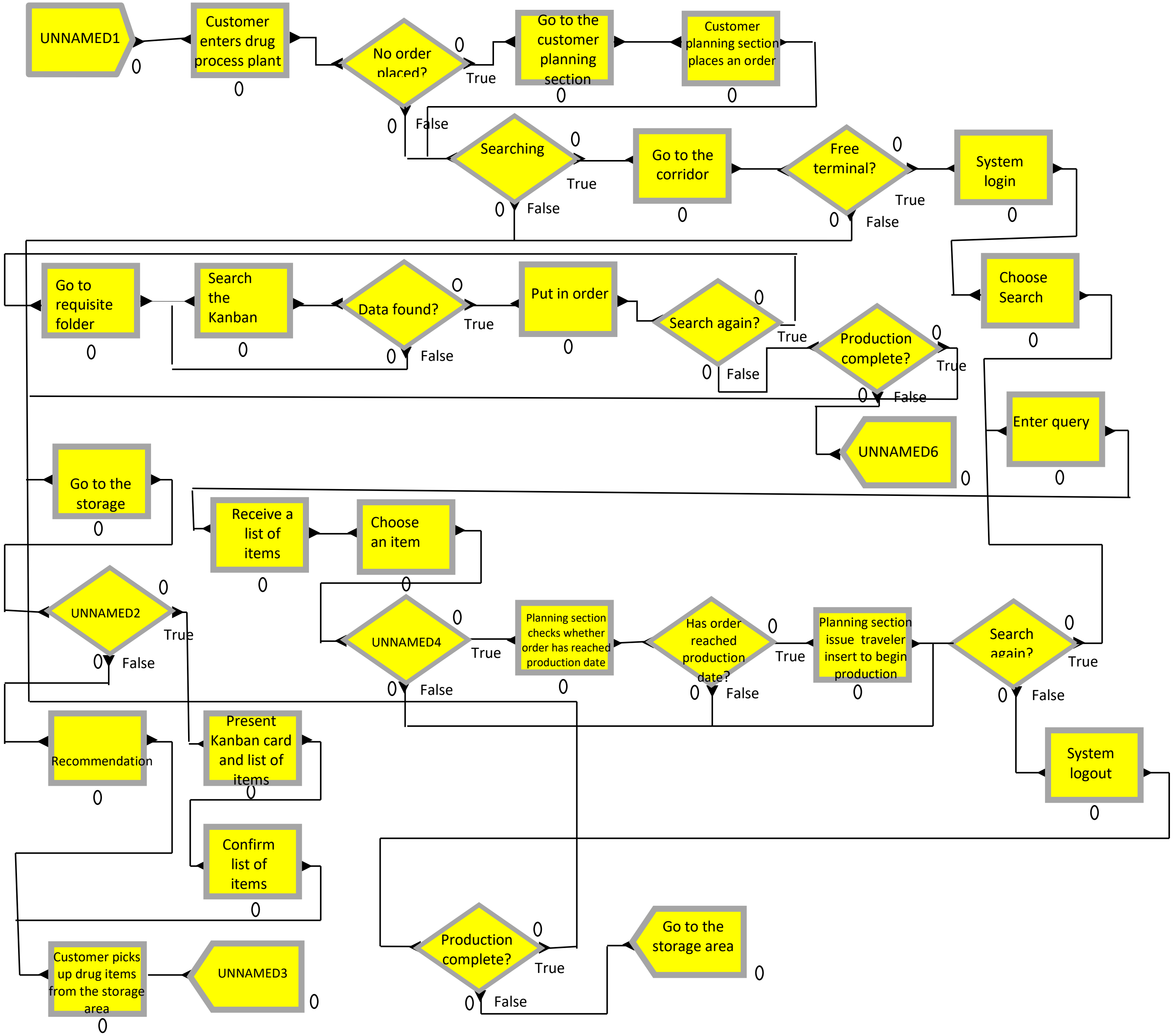


Figure 3.19: Existing Drug Process Plant

3.4.1 Description of Performance Parameters

The performance parameters that this system will work with include: Cycle Time (Lead Time), Flow Time, Demand Fulfillment Rate, Throughput Time, Inventory, Net Operating Income, Work in process Level, Product Mix and Manufacturing Overhead.

Cycle Time (CT) can be also called Lead Time or Delivery Cycle Time. It defines the amount of time from when an order is received from a customer to when the completed order is shipped. It consists of wait time and throughput time. Throughput Time or manufacturing cycle time defines the period required for a material, part, or subassembly to pass through the manufacturing process. It also defines the amount of time required to turn raw materials into completed product. Throughput time was extracted from Flow time / process time during the various stages manufacturing operation at the drug process plant.

Flow Time can be also called process time. Flow Time defines the period required for completing a specific job, or a defined amount of work. It is extracted during the various stages of the manufacturing processes at the drug process plant. Demand Fulfillment Rate (DFR) defines the percentage of customer or consumption orders satisfied from stock at hand. It is a measure of an inventory's ability to meet demand. It is extracted from the number of orders satisfied.

Inventory within the context of this research work, refers to all work that has occurred - raw materials, partially finished products, finished products prior to sale and departure from the manufacturing system. It is extracted during the various stages (stage 1 to 11) of manufacturing operation at the drug process plant considering indices such as raw materials procurement rate, buffer capacity, flow time, finished product demand rate and number of orders satisfied (output). Net Operating Income (NOI) defines the amount by which operating revenue exceeds operating expenses and was extracted from the financial statements of Juhel Drug Process Plant. Work in process *(*WIP*)* limits determine the minimum and maximum amount of work that lives in each status of a workflow and would be extracted by in-process inventory at manufacturing stage 1 to 11.

Product Mix (MIX) defines the total number of product lines that Juhel Nigeria Ltd offers to its customers. The four dimensions to Juhel's product mix include width, length, depth and consistency. Juhel Pharmaceutical Product Mix Complexity Effect used in this work includes:

MIX_1 = Narrow = Pills

MIX_2 = Medium = Capsules

MIX_3 = Wide = Tablets

Manufacturing Overhead (MOH) defines costs incurred through the manufacturing process even though they have nothing to do with the materials that are used or the wages paid to the manufacturing employees. They were extracted from the financial statements of Juhel Drug Process plant and are grouped into three Manufacturing Overhead Level effect:

MOH_1 = Low

MOH_2 = Medium

MOH_3 = High

3.4.2 Existing System Response after Simulation

Table 3.1: Existing System Response

(a) NOI(Millions)											
Observ.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**MEAN**
Simulated Old Physical System	79.13	65.87	66.48	66.92	65.27	65.25	66.34	68.19	65.04	69.00	67.75
(b) Cycle Time(Minutes)											
Observ.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**MEAN**
Simulated Old Physical System	761	823	737	806	818	746	735	743	854	791	781
(c) DFR (%)											
Observ.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**MEAN**
Simulated Old Physical System	66.10	69.00	61.00	73.00	65.00	68.00	67.00	73.00	72.00	65.00	67.91
(d) Inventory Turnover **(units on a scale of 20)**											
Observ.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**MEAN**
Simulated Old Physical System	9.00	12.00	15.00	1.00	13.00	12.60	8.00	13.50	10.2	12.8.00	10.48
(e) WIP(units)											
Observ.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**MEAN**
Simulated Old Physical System	680	720	690	710	710	723	654	740	630	775	703
(f) Throughput Time(Minutes)											
Observ.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**MEAN**
Simulated Old Physical System	339	445	306	354	311	306	330	335	335	363	342
(g) Flow Time(Minutes)											
Observ.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**MEAN**
Simulated Old Physical System	125	130	137	174	176	156	159	183	115	121	148

As shown in Table 3.1, the old physical system in terms of NOI gave a mean response of 67.75 in 10 observations after simulation. Also, the old physical system in terms of cycle time gave a mean response of 781 when simulated. The old physical system in terms of DFR gave a mean response of 67.91 when simulated whereas in terms of Inventory Turn-over a mean response of 10.48 was recorded when simulated. Table 3.1 further reveals that the old physical system in terms of WIP recorded a mean response of 703 when simulated but in terms of Throughput Time gave a mean response of 342 when simulated. Lastly, the mean response of the old physical system in terms of Flow Time was 148 after simulation.

3.5 Modeling and Simulation of JIT system

In the development of simulation models for the alternative JIT manufacturing system at the Drug Process Plant, the manufacturing processes are characterised as a discrete manufacturing system. This study will utilize a modified version of ARENA's existing "Electronic Assembly and Test System with Part Transfers" as a baseline model tool. The alternative JIT system model used for data generation is shown in Figure 3.20. The alternative JIT Manufacturing System Model in Figure 3.20 represents the final operations of the production of different sealed units (sub pallets). At the exit quality control testing the finished part either passes directly to finished goods to be shipped or is rejected and rerouted to the rework station. After rework, the part is again tested to ensure quality and is either passed, routed to finished goods inventory, and shipped or rejected for a second time and scraped.

In SIMAN, a discrete system is modelled by using a process orientation, a system which is simulated by describing the movement of entities according to the sequence of operations or activities in the system. The concept of entities is important for modelling a discrete manufacturing system. Basically, the movement of entities through the system results in changes to the status of the system. In this work, a Kanban is considered as an entity since the movement of a Kanban influences the status of the buffers, machines or materials. Each entity in a simulation model has its own specific and unique characteristics called attributes. The attributes of a Kanban entity are Kanban quantity and the type of items. The basic principle of JIT is that the material does not enter the next process until a Kanban arrives. The Kanban then pulls the material to the process.

The simulation tool employed to construct this model is the ARENA /SIMAN software package. ARENA is the interface to the SIMAN language. Even though a particular simulation tool is used, the generality of the concept and design remains intact. The advantage of using a simulation tool is that it allows us to build our simulation model concisely with reduced coding effort.

Mathematical Formulation of JIT System Model

Kanban Capacity:

The quantity of parts transported with each Kanban from one workstation to the next can be determined according to the known optimal Kanban numbers at each stage. The delivery of WIP to a workstation with one Kanban is termed as a shipment (part shipped).

Let Q^{j}_{s,k_j} (s=1,2,..., k_j, $s = k$ and j =1,2,...,N –1) be the quantity transported in *sth* shipment of total k_j shipments at *jth* stage, where k_j is the number of Kanbans employed in the *jth* Kanban stage.

In order to cope with the increasing time-dependent demand of the product, each subsequent (batch) of products at the *jth* Kanban stage ships $\frac{P_j T_{pj}}{k_j}$ more units than its previous shipment. Let Q^{0}_{s,k_j} be the amount of WIP shipped each time through k_j Kanbans at *jth* Kanban stage if there is constant demand (i.e. $p = 0$). If, for $p \geq 0$, the total increment of production volume during the production time T_{pj}, $P_j T_{pj}$ is distributed through k_j shipments during the cycle time CT, then, the total demand for products j, D_j (a one-to-one conversion assumed), at *jth* Kanban stage with k_j Kanbans can be expressed as

$$D_j = (Q^{0}_{s,k_j} + \frac{P_j T_{pj}}{k_j}) + (Q^{0}_{s,k_j} + 2\frac{P_j T_{pj}}{k_j}) + ... + (Q^{0}_{s,k_j} + k_j\frac{P_j T_{pj}}{k_j}) \quad (3.4)$$

$$= k_j Q^{0}_{s,k_j} + \frac{(k_j+1)}{2} P_j T_{pj}$$

From which, we obtain

$$Q^{0}_{s,k_j} = \frac{D_j}{k_j} - \frac{(k_j+1)}{2k_j} P_j T_{pj} \quad (3.5)$$

So for an increasing demand, the size of the first shipment (s = 1) after $\frac{T_{pj}}{k_j}$ time units from the beginning of production is given by

$$Q^{j}_{1,k_j} = Q^{0}_{s,k_j} + \frac{P_j T_{pj}}{k_j}$$

$$= (\frac{D_F}{k_j} - \frac{(k_j+1)}{2k_j} P_j T_{pj}) + \frac{P_j T_{pj}}{k_j} \quad (3.6)$$

Similarly, the size of second shipment (s = 2) is given by

$$Q^{j}_{2,k_j} = Q^{0}_{s,k_j} + 2\frac{P_j T_{pj}}{k_j}$$

$$= \left(\frac{D_j}{k_j} - \frac{(k_j+1)}{2k_j} P_j T_{pj}\right) + 2\frac{P_j T_{pj}}{k_j} \qquad (3.7)$$

In general, continuing in this way, the quantity shipped (total shipped) at the *sth* batch at *jth* Kanban stage, Q^j_{s,k_j}, is then given by incorporating the effect of time dependent linear demand and flexible production capacity at each stage, and expressed as:

$$\begin{aligned} Q^j_{s,k_j} &= Q^0_{s,k_j} + s\frac{P_j T_{pj}}{k_j} \\ &= \frac{D_j}{k_j} + \frac{P_j T_{pj}}{k_j}\left(\frac{2s-k_j-1}{2}\right) \qquad (s = 1,2,..., k) \qquad (3.8) \end{aligned}$$

Let q indicate the Kanban stage with $k = \max\{k\ ,\ j = 1,2,...,N-1\}$. Then, Q^j_{s,k_j} (1,2,..., k_j,1≤k_j ≤) can be represented in a matrix form **Q:**

$$Q = \left[Q^j_{s,k_j}\right] = \begin{bmatrix} Q^1_{1,k_1} & Q^2_{1,k_2} & \cdots & Q^q_{1,k_q} & \cdots & Q^{N-1}_{1,k_{N-1}} \\ Q^1_{2,k_1} & Q^2_{2,k_2} & \cdots & Q^q_{2,k_q} & \cdots & Q^{N-1}_{2,k_{N-1}} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ Q^1_{k_1,k_1} & Q^2_{k_2,k_2} & \cdots & \cdots & \cdots & Q^{N-1}_{k_{N-1},k_{N-1}} \\ 0 & 0 & \cdots & \cdots & \cdots & 0 \\ \cdots & \cdots & \cdots & Q^q_{k_a-1,k_q} & \cdots & \cdots \\ 0 & 0 & \cdots & Q^q_{k_q,k_q} & \cdots & 0 \end{bmatrix} \qquad (3.9)$$

Where the column of **Q** is determined by the number of Kanban stages and the row of **Q** is decided by the Kanban stage with maximum Kanbans.

Units Demand/Ordered:

Let y^p_j be the current inventory position of product *j*. At the end of each review interval, *R*, an order is placed in order to bring the inventory level up to S_j for each product. The inventory position is the current available inventory y_j plus any outstanding orders not received. At the end of the r^{th} review period, quantity demanded (market demand) D_j can be expressed as follows:

$$D_j = S_j - y^p_j \qquad (3.10)$$

Where

S_j = Order-up-to level of product j (units)

The cumulative amount of product *j* demanded (total demand for product j), Q_j, is the sum of the order quantities placed from *J* review periods which have occurred. Q_j is expressed as follows:

$$Q_j = \sum_{r=1}^{J} D_j \qquad (3.11)$$

Updating Inventory Level:

Let $\overleftarrow{y_{\iota a,t}} = (y_{j1,t}\, y_{j2,t}, \ldots, y_{jmj,t})$ represent the vector of current inventory held at the each age class during the j^{th}day. The quantity to be delivered at the beginning of day *t+l* is $D_{j(t-L)}$. As a transition is made from day *t* to *t+1*, $\overleftarrow{y_{t(t+1)}}$ can be expressed as follows:

$$\overleftarrow{y_{t(t+1)}} = (D_{j(t-L)}, y_{j1,t}\, y_{j2,t}, \ldots, y_{j(mj-1),t}) \qquad (3.12)$$

Let w_{jt} represent the number of units of product *j* that expire at the end of day *t*. Thus, at the end of day *t*, w_{jt} is

$$w_{jt} = y_{jmj,t} \qquad (3.13)$$

where $y_{jmj,t}$ is an element of the vector of $\overleftarrow{y_{\iota t}}$. The cumulative expired product after *D* days can be expressed as

$$w_j = \sum_{t=1}^{D} w_{jt} \qquad (3.14)$$

Income /Profit Function

Let π_j represent the Net Operating Income (NOI) for product *j*. π_j can be written as:

$$\pi_j = Z_j p_j - Q_j v_j - \bar{y}_j h_j \qquad (3.15)$$

Where Z_j = current cumulative sales of product j, p_j = selling price of product *j* (₦/unit), Q_j = total demand, v_j = marginal purchase cost for product j (₦/unit), $\bar{y}_j$ = average inventory of product *j* (units), h_j = marginal holding cost per item of product *j* applied to its average inventory for a specified length of time (₦/length of time)

Thus, the Net Operating Income (NOI) for all n product variants, π, is expressed as follows:

$$\pi = \sum_{j=1}^{n} \pi_j \qquad (3.16)$$

Let *l* be the length of a simulation run and *n* be the number of replications of a simulation run. The optimal system performance per simulation run of length *l* is estimated based on *n* replications and is expressed as follows:

$$\bar{\rho}_l = \frac{1}{n}\sum_{n=1}^{n} \pi_l \qquad (3.17)$$

The standard deviation of the performance per simulation run, S_l is expressed as

$$S_l = \sqrt{\frac{1}{n-1}\sum_{n=1}^{n}(\pi_n - \bar{\pi}_l)^2} \qquad (3.18)$$

Based on (3.9), (3.10), (3.11), (3.14), (3.16), (3.17), the dynamic mathematical programming formulation for the simulation-optimization model is stated below:

$$\text{Maximize } \rho = \sum_{j=1}^{n} c_j^{1,k} Q_{s,k_j}^{j} k_j Y_{aom} \qquad (3.19)$$

$$\rho = \sum_{j=1}^{n} \pi_{ij}\, Q_{s,k_j}^{j} k_j\, Y_{aom} \leq y_j^p \qquad (3.20)$$

i = 1, 2, 3, ….., m (Resource/ Capacity Constraint)

$Q_{s,k_j}^{j} \leq D_j$ For every j, j = 1, 2, 3, . . . , n (Market Demand Constraint)

$Q_{s,k_j}^{j} \geq 0$

Where:

ρ = System performance in terms of Net Operating Income (NOI), Inventory at the end Buffer, Work in Process Level (WIP=Q_{s,k_j}^{0}), Throughput Time, Demand Fulfillment Rate (DFR) and Cycle Time (CT)

Q_{s,k_j}^{j} - is the quantity transported in *sth* shipment of total k_j shipments at *jth* stage

k_j = α * T_{pj}/ σ

= α * [(μ / ζ) * (1 + λ)] / σ

k_j = is the number of Kanbans employed in the *jth* Kanban stage, μ = machine alteration, ζ = shift alteration, λ = conveyance interval, α = average production rate, σ = number of parts per kanban card, and T_{pj} = (μ / ζ) * (1 + λ) is the throughput time.

y_j^p - is the current inventory level of product *j*

D_j - is the market demand for product j

π_{ij} - represent the Net Operating Income (NOI) for product *j*

Y_{aom} = μ + MAS_a + MOH_o + MIX_m

Y_{aom} = Performance Measurements

μ = Mean Effect

MAS_a = Manufacturing System Effect, a = 1, 2, 3

MOH_o = Manufacturing Overhead Level Effect, o = 1, 2, 3

MIX_m = Product Mix Complexity Effect, m = 1, 2, 3

aom = Random Effect

$c_j^{l, k}$ - is the contribution margin of product j, with complexity k, under MAS $_l$

With m + n constraints for this model

Model Assumptions

Based on other simulation studies discussed in Chapter 2, and specifically on the Krajewski et al. (1996) study, the following assumptions are necessary:

1. No preemption of jobs once work has begun
2. No alternative routings
3. Zero setup times
4. Jobs are not split in the shop. All jobs are moved to the next work center or buffer area when the current work center operation is complete.
5. No backorders. Demand that cannot be filled is lost to the perfectly competitive market.
6. The first work center is never starved for work because raw material supply is not constrained.
7. Going from period *t* to period *t*+1, $\overleftarrow{y_{t(t+1)}}$ is determined according to (3.12) and outdated product, w_{jt}, is updated by using to (3.13) and (3.14).
8. The quantity demanded in r^{th} review period, D_j, is determined by (3.10) and the order arrives after the lead time elapses. The order-up-to S_j level is set prior to the simulation run.
9. Daily customer demand is generated for each product based on an adopted distribution *f(x)* with a mean and standard deviation of μ and σ. Each arrival is then scheduled to occur randomly throughout the day and each customer demands one unit of product. Demand is determined for each product variant based on K_j for all n product variants under consideration.
10. Based on inventory availability and the substitution dynamics, either a unit is sold or its demand is lost. Z_j and ζ_j are updated based on inventory availability and the customer's decision to substitute.

11. The Model is flexible and new elements can be easily added or removed.
12. The model works under ideal JIT conditions.

The flow charts in figures 3.20, 3.21, 3.22, 3.24, 3.28, 3.29, 3.30, 3.31, 3.32, 3.33, 3.34, illustrate the logic within each event routine in the model. SIMAN language codes for figure 3.20 is shown in Appendix A2, Appendix B, and Appendix C1. The decision logic sub model in ARENA will utilize the above maximization formulation, which includes all constraints for the resources and market demand, in order to determine optimal performance for the master production schedule.

From a modelling point of view, the Kanban triggers the change of status of the system. Another element regarded as an entity is material. Material is not necessarily represented as an entity and this depends on the approach used for modelling the system. However, by considering the materials as entities, the movement of the materials can be observed through animation. In this work, the purpose of the animation is to verify the logic of the simulation. The role of animations in JIT simulation is substantial particularly in reducing the time required to verify the model. Some common logical errors which include forgetting to initialise variables and failing to release resources after finishing an operation can be easily observed using animation. In addition, often a model that seems reasonable during the modelling phase may be too simplistic in animation, therefore, some modifications are required to improve the accuracy of the model.

3.5.1 Structure of the Alternative JIT Manufacturing System Model

There are three flows in the manufacturing model: the flow of materials, the flow of information, and the flow of cost. These flows establish the value streams. Components of the value stream can be value-add or waste, depending on the operating conditions. For example, excess material flows become a stream of inventories, while excess information leads to confusion in process execution. By managing the flows, we can control the streams. An effective control of these streams is required for lean production.

As mentioned earlier, the interfaces control the flow. For example a conveyor regulates the flow of materials and a visual control regulates the flow of information between two stations. The interfaces arise from disconnected points in the system, e.g., the physical distances between two machines, the communication barriers between two people, or the control panels between a machine and an operator. It is often a good location for cost transactions.

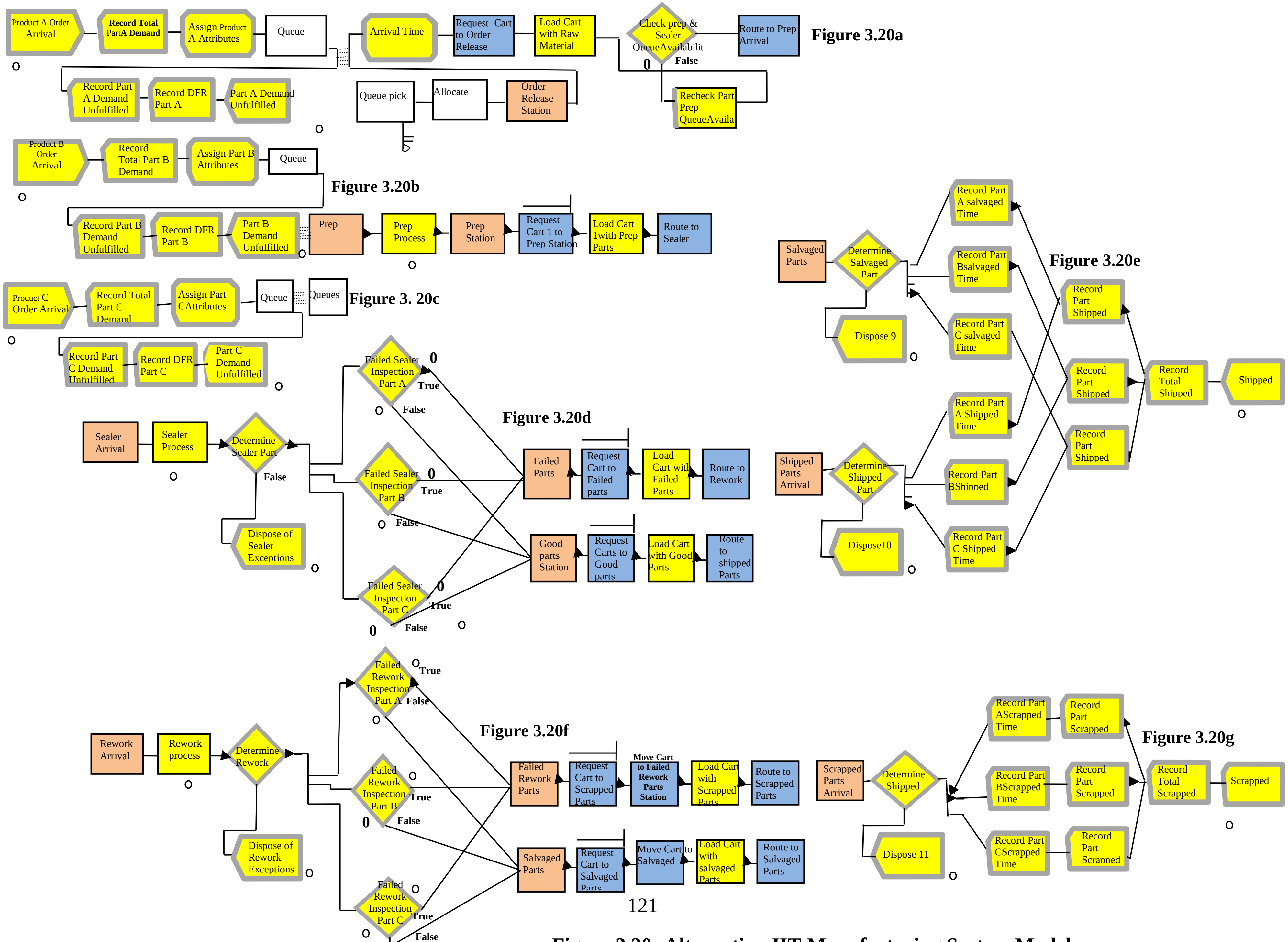


Figure 3.20: Alternative JIT Manufacturing System Model

In the JIT Manufacturing System model, the parts represent the materials, while the kanban represent the information mechanism. In this way, we can analyze the efficiency of these flows. Associated with each device that handles the parts or kanban, a cost is applied to the operation of the device. Therefore a buildup of parts and kanban implies an increasing cost.

As shown in Figure 3.20a, when order for product A is placed, total demand is recorded and the product attributes are assigned. This is recorded and the product attributes are assigned. This is placed on queue and request is then made to order release of raw materials which is then passed to sealer queue. As described in Figure 3.20b, on placing order for product B, total parts or quantity demanded is recorded and the assigned attributes to product B is then placed on queue. If the recorded part B demand is unfulfilled, prep process is initiated and the prep parts are routed to sealer. On arrival of product C order, total part demanded is recorded as shown in Figure 3.20c. Part attributes are assigned to product C and placed on queue. However, part C demand unfulfilled is recorded and routed to prep station.

Figure 3.20d describes the model operations that take place when the parts/products items arrive the strip sealing station for blister packing. The various products (A, B, C, etc) pass through sealer inspection. Failed parts are routed to rework while good parts are routed to shipped parts. Figure 3.20e illustrates the movement of both shipped and salvages parts on arrival. Time consumed and total quantity of products/parts shipped or salvaged is recorded in this model. Figure 3.20f is a model description of how parts arriving for rework are passed through inspection. Failed rework parts are routed to scrapped parts while salvaged parts are routed to salvaged parts and shipped. Figure 3.20g determines the quantity of scrapped parts on arrival. The total quantity of scrapped parts and time spent on scrapped parts are recorded in this model.

3.5.2 Simulation of Alternative JIT System Using "SIMAN" and "TECNOMATIX" Simulation Software

The simulation model developed in this work is based on the single-card pull system developed at the Drug Process Plant as described in Figure 3.10. This model consists of three blocks (workstations) where there is a buffer located between two workstations. In this model, the material moves according to the Kanban rule (Figure 3.21). If Kanbans arrive and the material is available, the workstation starts processing the material. Otherwise, if the material is not available, the Kanban waits until the buffer is replenished and the material is available. To run this model, in the beginning of the simulation, all buffers hold a particular number of materials as the initialisation. Without this step, the simulation never happens because the materials are never available.

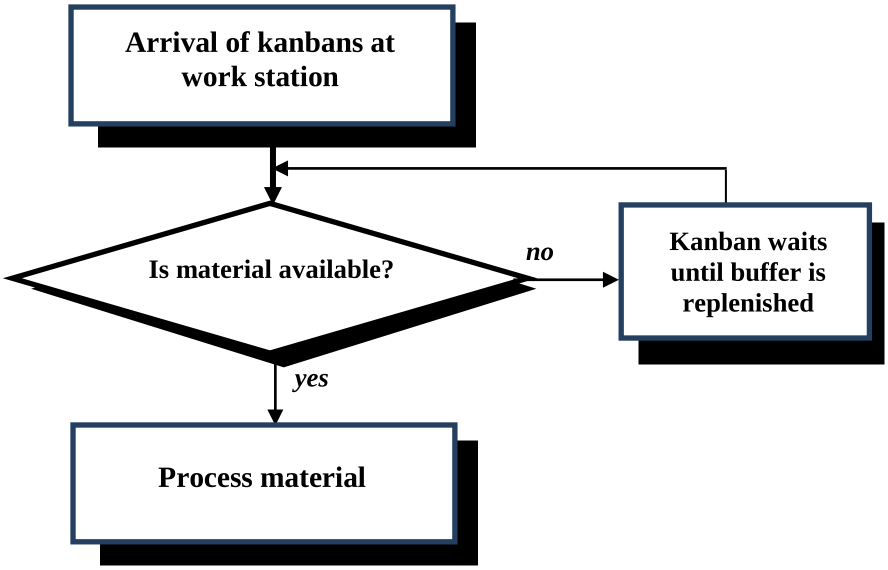


Figure 3.21: Movement of materials based on kanban rule

In this work, not all items produced by the Drug Process Plant will be simulated since there are around 79 periodical items of which the order quantities range from one sub-pallet to 700 sub-pallets. In the simulation model, several high-volume items are selected to represent the other Kanban items. The rest are represented by four hypothetical non-Kanban items that have total order volumes and total processing times the same as those represented. To model the JIT system at the Drug Process Plant, there are three stages:

a. Building the basic model and the animation.

b. Developing a more realistic model by extending the number of items represented and the parameters of the system.

c. Evaluating the actual system by increasing the number of buffers and Throughput.

3.5.2.1 Stage 1: Building the Basic Model and Animation

The objective of this stage is to develop the basic model and to verify the logic of the model. In stage 1, as described in the listing of files *model1.mod* and *model1.exp* in Appendix B, the item represented is only the trial item i.e. JPF 113155. The logic of this model can be verified early because of its simplicity. The flow diagram of this model is shown as Figure 3.22.

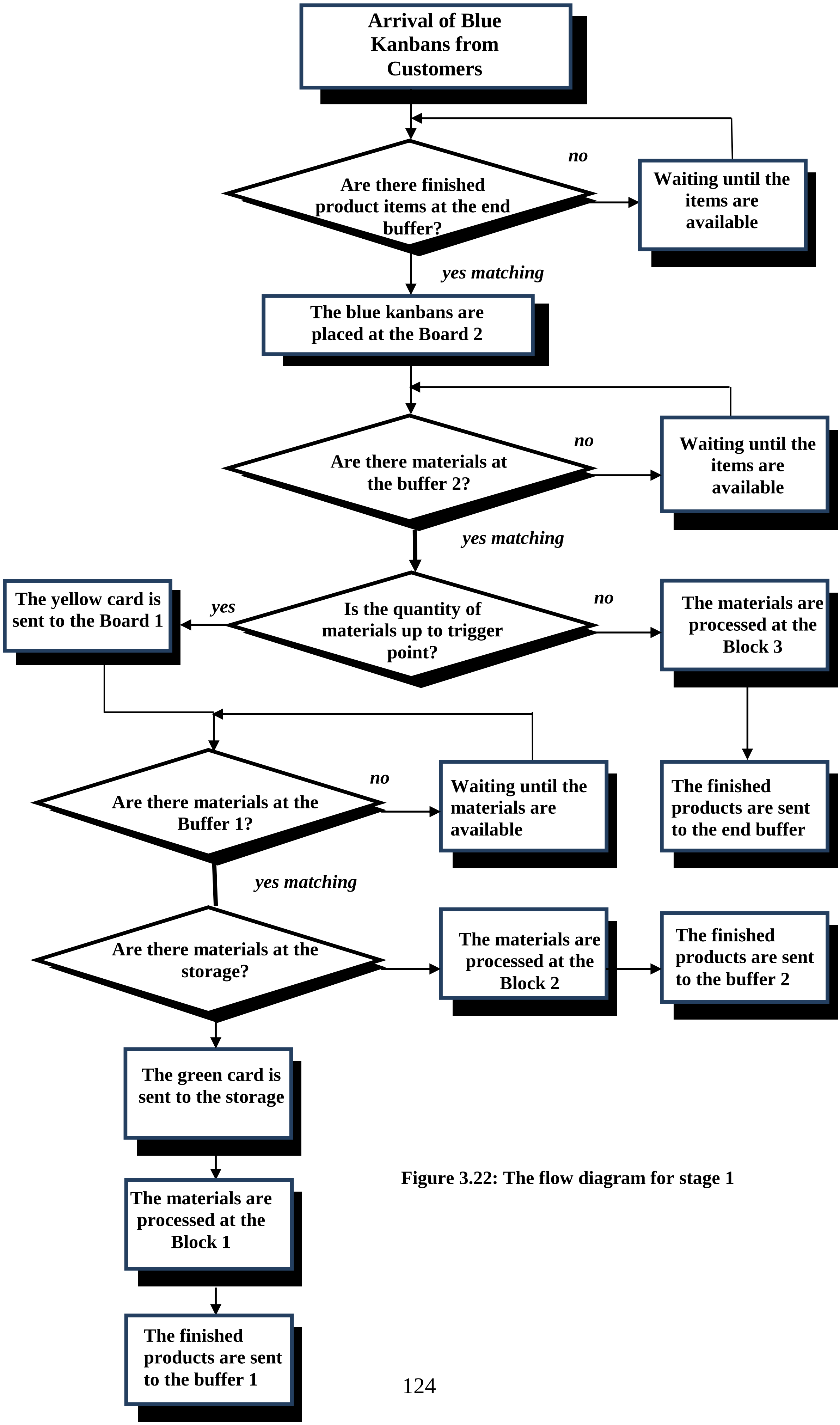


Figure 3.22: The flow diagram for stage 1

As the program is simple and the number of entities existing in the system is small, the verification of the logic of the model, particularly the movement of the entities can be conducted easily using animation. In the animation, it is difficult to observe the movement of too many entities on the same screen.

3.5.2.1.1 Pull Mechanisms

In this model, the pull mechanism is constructed by using MATCH, a SIMAN block, as recommended by Pegden *et al.* (2011). Basically, there are many approaches for simulating the pull mechanism, however, MATCH has the advantage that this mechanism can be easily animated using SIMAN. Basically the purpose of MATCH is to synchronise two or more randomly arriving entities. In the model file, two randomly arriving entities that will be matched are Kanbans and materials. By using MATCH, the materials will be sent to the next process only if there is an entity represented as a Kanban staying in the other queue. As written in the model file, an example of this mechanism is as follows:

```
Board2  QUEUE, Board2Q:
        DETACH;
Buff2   QUEUE, Buffer2Q:
        DETACH;
        MATCH, Buff2, Block3:
        Board2;
```

Based on above model listing, materials at the queue *buffer2Q* will be sent to the Block 3 if there is a Kanban at the queue *Board2Q*. If a match does not occur either a Kanban or material stays in the queue until both of them are available.

3.5.2.1.2 Trigger Point

In this stage, a trigger point is also represented since block 3 and block 2 have different batch sizes. Based on this concept, buffer 2 will be replenished if the cumulative number of parts has reached the batch size of block 2 (360 units). To simulate the trigger point, an entity represented by a green Kanban will pick up (match) the materials from buffer 2. When the number of materials picked up reaches 60 units (represented by two entities) at the first trial, an entity represented by a yellow Kanban will be sent to block 2 to start producing 360 units of the new parts. If in the next trial, another entity represented by a green Kanban arrives and the materials available at buffer 2 are more than 60 units, the yellow Kanban is not issued until the total requirement achieves 360 units or until the materials available are less than 60 units. This mechanism will ensure that there is a sufficient amount of materials consumed by block 3 and the pull system runs smoothly. In the model file, an example of this mechanism is shown as follows:

```
        X(5)=X(5)+1:
        X(6)=X(6)+Type;

        BRANCH, 1:
                IF,(X(6).ge.2).and.(X(5).eq.1),label1:
                IF,(X(6).ge.12).and.(X(5).eq.2),label1:
                ELSE,label2; ! send a green Kanban to the Board 2 (normal)
label1  ASSIGN X(6);
        DUPLICATE: 1, Board1; !send a yellow Kanban to the preceding block or block 2
```

Based on the above model listing, a yellow Kanban will be sent to the workstation (Block) 2 represented by the execution of *label1*, if the cumulative Kanban order (X(6)) achieves 60 units (or 2 entities, each entity representing 30 units) in the first trial (X(5)=1), or if the X(6) reaches 360 units (or 12 entities) in the next trial. Otherwise, if both conditions are not satisfied, *label2* is being executed. That means green Kanbans move as usual to Board 2.

3.5.2.1.3 Determining the Arrivals of the Trial Item

According to the order planning of the Plant, the arrival of the orders of JPF 113155 are daily. Therefore, if there are three shifts (24 hours), the arrival time is: 24 x 60 minutes = 1440 minutes. If the variation of arrival time is around 10%, this situation can be expressed in a statistical uniform distribution as UNIF (1440, 1584).

The simulation model will be employed to investigate the effect of the fluctuating orders. Although, the daily order in the trial period is constant, in the future it is likely to be fluctuating. The daily fluctuating order in the next six months can be described as in the following Table 3.2.

Table 3.2: Percentage of Order Quantities of JPF 113155.

ITEM	ORDER QUANTITY (UNITS)	PERCENTAGE
JPF 113155 (Trial)	30	10
	60	30
	90	50
	120	10

Based on table 3.2, the arrival and the proportion of the order quantities can be written in the model file as follows:

```
CREATE : UNIF(1440,1584,2):
         MARK(Arrtime1);
ASSIGN : Type=DISC(0.1,1,0.4,2,0.9,3,1.0,4); ! Arrivals of Green Kanbans
```

3.5.2.1.4 Entity Flows

SIMAN is designed for the conventional push system, therefore, to simulate a pull system, statement DUPLICATE will be used to send entities to the opposite direction in the push system. In each block, entities (materials) stay at each station according to the processing time. After being processed at the station, an entity must move to the buffer located at the subsequent block. Therefore, a DUPLICATE should be used to move the entity in the opposite direction. Similarly, this approach is used to send a signal or a Kanban to the preceding workstation. The original entities remain in the workstation for counting and after that they are disposed of.

3.5.2.1.5 Animation

The animation developed in this stage provides displays about the model such as the movement of entities, the amount of the buffers as well as the level of the orders queue. The movement of entities such as Kanbans and materials are animated. This display therefore gives a useful means to verify the logic of the model. To get insight into the performance of the system, the status of the parameters can also be observed such as the amount of each buffer as well as the number of items produced at each block. In addition, the animation also shows the histogram of the queuing orders so the level of unsatisfied orders can also be observed. The animation screen can be seen in Figure 3.23.

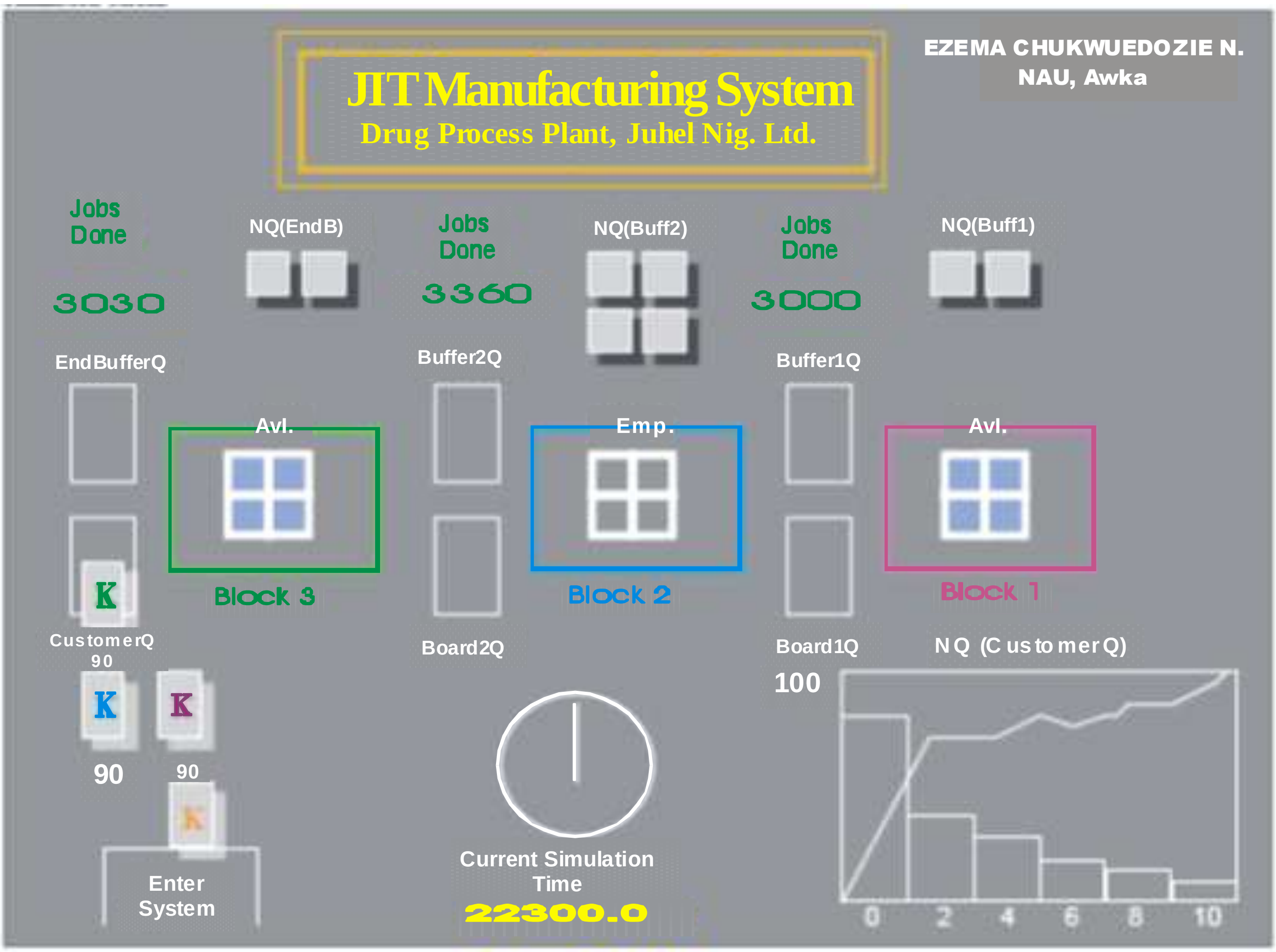


Figure 3.23: Animation Screen

3.5.2.2 Stage 2: Containing other Entities and Factors

Basically, the purpose of this stage is to develop a more realistic model by containing other items or more complex factors. Model developed here is the extension of previous, so it has similar logic. In this model, other Kanban items and non-Kanban items are included together with the trial item as well as factors that are significant to the operation of the system such as arrival time, batch sizes or waiting time. The complete listing of stage 2 i.e. *model2.mod* and *model2.exp* can be shown in Appendix C1.

3.5.2.2.1 Selecting Items to be Simulated

As previously explained, not all items produced by the Drug Process Plant will be simulated due to the limitation of the software and the scope of the study; therefore, selecting items in the simulation is essential. Based on the investigation, only 44 of items have periodical order quantities of more than 100 units or values less than ₦40000 as described in the list of Appendix D. By using the list, four major items covering 54% of the total order are selected for the simulation i.e. JPAP308002/R1, JPM 113277/R3, JPF 113666/R24 and JPM 1137627/R9. In the model, all these items are considered as Kanban items. Although these items have not yet been determined as Kanban items, the Drug Process Plant is highly likely to choose them as Kanban items due to the volume of these items. The rest (i.e. 40 items) are represented by four hypothetical items that will have the same characteristics in terms of production orders and processing time. These items are considered as non-Kanban items since the orders are low.

3.5.2.2.2 Determining the Arrivals of Orders

Besides the trial item as in stage 1, there are two types of items included in stage 1.

a. High-Volume Kanban Items

High volume Kanban items arrive at the customers' planning section weekly and each item is assumed to have the same chance to arrive. Therefore, arrival time of these items per week is calculated as:

7 (days) x 24 (hours) x 60 minutes = 10080 minutes

Since four items are created within a week, the uniform distribution of these items is: 10080/4 = 2520 minutes. If the variation of arrivals is assumed to be around 20%, then (2520 + (20% of 2520) = 3024). The uniform distribution of these items is UNIF(2520,3024).

Based on this information, in the model file, the arrivals and the proportions of the order quantities can be written in SIMAN as follows:

```
CREATE : UNIF(2520,3024):
         MARK(Arrtime2);
ASSIGN :  Type=DISC(.25,5,.5,6,.75,7,1.0,8); ! arrivals of high-volume Kanbans
```

b. Non-Kanban Items

Four non-Kanban items are included to represent 40 items. Although the order of each item represented has a different periodical arrival time, the items are assumed to be weekly items like the high-volume Kanban items. Since the total waiting time for 40 items cannot be represented in these items, this factor will be taken into account later in determining the processing time. The entity flow in stage 2 that includes the trial items, the high-volume Kanban items and the non-Kanban items can be described as Figure 3.24. The hollow small circles describe kanban entry, the shaded small circles describe material entry while the square shaped indigo boxes with dark shadows indicate buffer queue name.

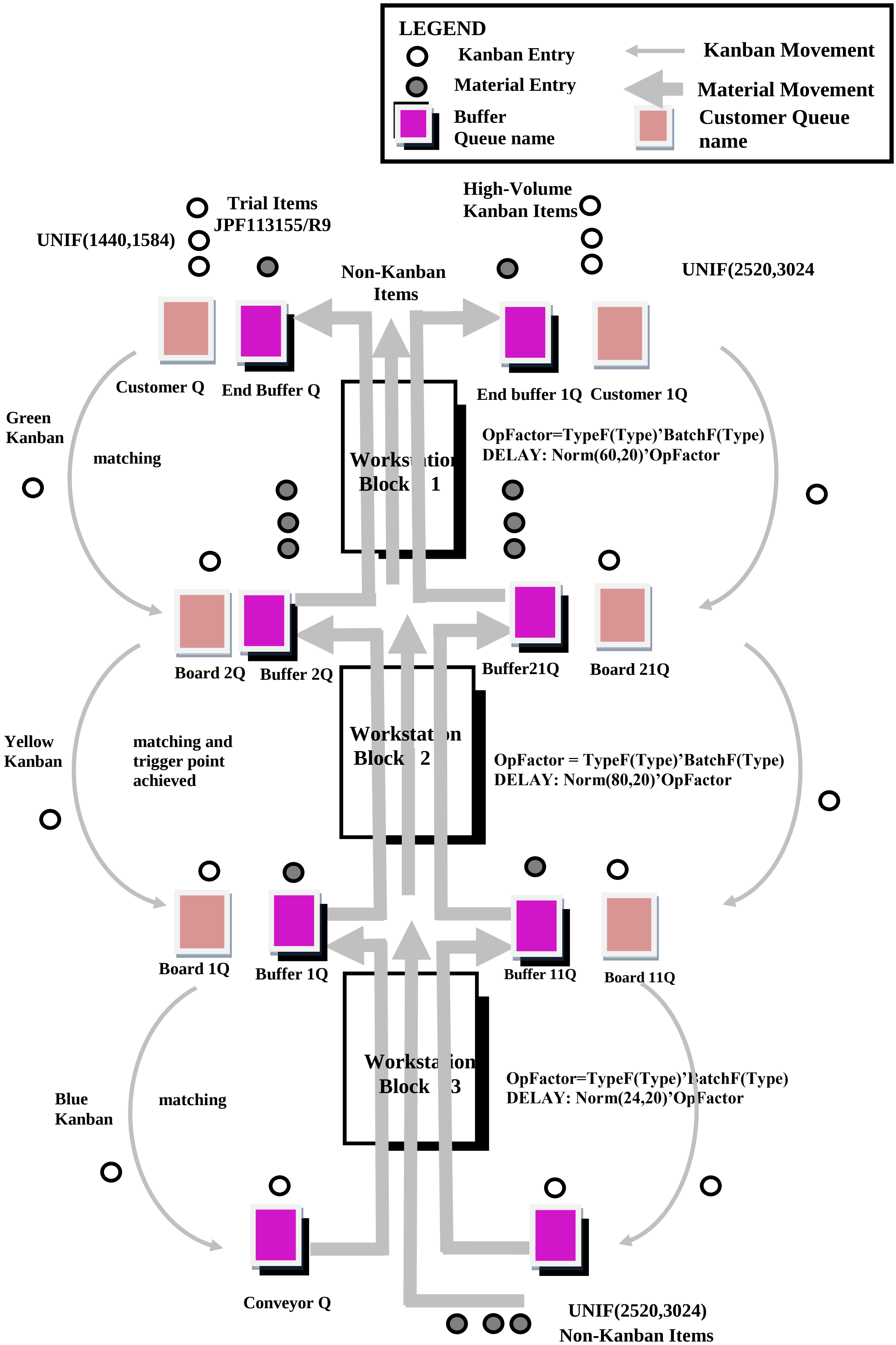


Figure 3.24: The flow of entities in stage 2

Also, as shown in Figure 3.24, tiny gray arrows describe kanban movement while the thicker gray arrows describe material movement. However, the square shaped light colored boxes indicate customer queue name.

Based on the above information, the arrivals and the proportion of the order quantities can be written as follows:

```
CREATE : UNIF(1440,1584,2):
         MARK(Arrtime3);
ASSIGN : Type=DISC(.25,5,.5,6,.75,7,1.0,8); ! arrivals of non-Kanban items
```

Non-Kanban items move directly from one workstation to another workstation according to the push system. In simulation, the entities representing the materials move directly in the opposite direction from block 1 to block 3 without waiting the arrival of Kanbans. The entities may wait at a workstation if the resource is busy.

3.5.2.2.3 Processing Time

The order quantity and the type of items are used to calculate the processing time for the high volume and non-Kanban items. In the model file, both factors are identified as multiplying factors called *BatchF* and *TypeF* respectively. Since the processing time and the order quantity of the trial item JPF 113155 are known, the standards for calculating the factors are based on this item.

In the model, the value of BatchF and TypeF for JPF 113155 are equal to 1. Basically, BatchF is determined based on the total production volume and the capacity of the mixing/blending machine. It is determined in the following steps. The original order quantity of the trial item in the push system is 360 units and the total production in the second semester is 4652 units. Since the order of the trial items is weekly, there are 4652/360 weeks or around 13 weeks to replenish the orders. Therefore, if the high-volume item JPAP308002/R1 is a weekly order item and the total production is 18000 units, the order size of this item is 18000/13 or around 1380 units. Because of the setup time of mixing/blending machines, the optimal batch size is 120 units so the weekly order for this item is rounded into 1320 units (a multiple of 120). Therefore, BatchF is 1320/360 or 3.7.

TypeF is determined directly according to the processing time of the items. For example, the tablets have a processing time of around 1.5 of the capsules, therefore, TypeF is 1.5. For the non-Kanban items which each represents 8 smaller items, TypeF is 5.0 to accommodate the effects of the waiting and queuing time required to process this item. Table 3.3 summarises factors of each item.

Table 3.3: The values of BatchF and TypeF

GROUP	ENTITY	BATCH SIZE FACTOR (Batch F)	FACTOR OF ITEM TYPE (Type F)
Trial Items JPF 113155	30- unit-order item	1.0	1.0
	60-unit-order item	1.0	1.0
	90-unit-order item	1.0	1.0
	120-unit-order item	1.0	1.0
High-Volume Kanban Items	JPAP308002/R1	3.8	1.5
	JPM 113277/R3	6.0	1.5
	JPF 113666/R24	5.0	1.0
	JPM 1137627/R9	2.0	1.5
Non-Kanban Item	Non-Kanban Item 1	3.3	5.0
	Non-Kanban Item 2	3.3	5.0
	Non-Kanban Item 3	3.3	5.0
	Non-Kanban Item 4	3.3	5.0

In SIMAN, the value of all multiplier factors is represented in the experimental file as the following list:

```
VARIABLES : TypeF(12),1.0,1.0,1.0,1.0,1.5,1.5,1.0,1.5
              5.0,5.0,5.0,5.0:
          BatchF(12),1.0,1.0,1.0,1.0,3.8,6.0,5.0,2.0
              3.3,3.3,3.3,3.3;
```

These variables are then used to calculate the processing time at each block as shown in the following list of the model file:

```
Block2    QUEUE,    Workstat2Q;
          SEIZE :   Workstat2;
          ASSIGN :  OpFactor=TypeF(Type)*BatchF(Type);
          DELAY :   Norm(240,10)*OpFactor;
          RELEASE : Workstat2;
```

3.5.2.3 Stage 3: Increasing the Number of Buffers and Throughput

With the help of "TECNOMATIX" Simulation Software, stage 3 was executed. This software was used to conduct simulation experiments to achieve the objectives of the study. The TECNOMATIX Plant Simulation is a VISM (Visual Interactive Simulation) system developed by Siemens Group. It gives beneficial approach to the users not only to work on reating and using TECNOMATIX models but also to build and test the models on small incremental stage. The model input parameters are Setup Time, Machine Alteration and Shift Alteration and output parameter is Throughput as shown in Figure 3.25.

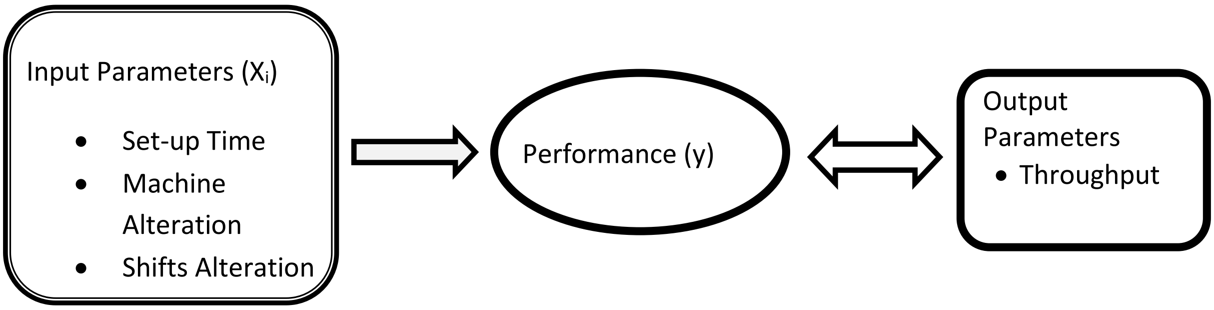


Figure 3.25: Conceptual Model of the Stage 3

The appropriate JIT practices (process variables) and the performance measures (response variables) are selected.

Assumptions

i. Parts are always available at the Store-Room.
ii. The Model is flexible and new elements can be easily add or removed.
iii. No stoppage occurs during the production in the model.
iv. For parts, First-In-First-Out (FIFO) rule is applied.
v. The model works under ideal JIT Conditions.

The screenshot of the model created using TECNOMATIX Simulation Software is shown in Figure 3.26. It contains different notifications which explain different entities. This model shows Juhel Drug Process Plant with pallet-based transport. The system contains manual and automatic workstations. One part per pallet runs through the system and is processed on the stations according to the processing times. Each station has processing times and a certain availability. The manual stations need a worker to start. These parameters determine how long a part stays on the station. The model was created using the basic objects of Plant Simulation. The objects were inserted and connected to reflect the layout of the real production line.

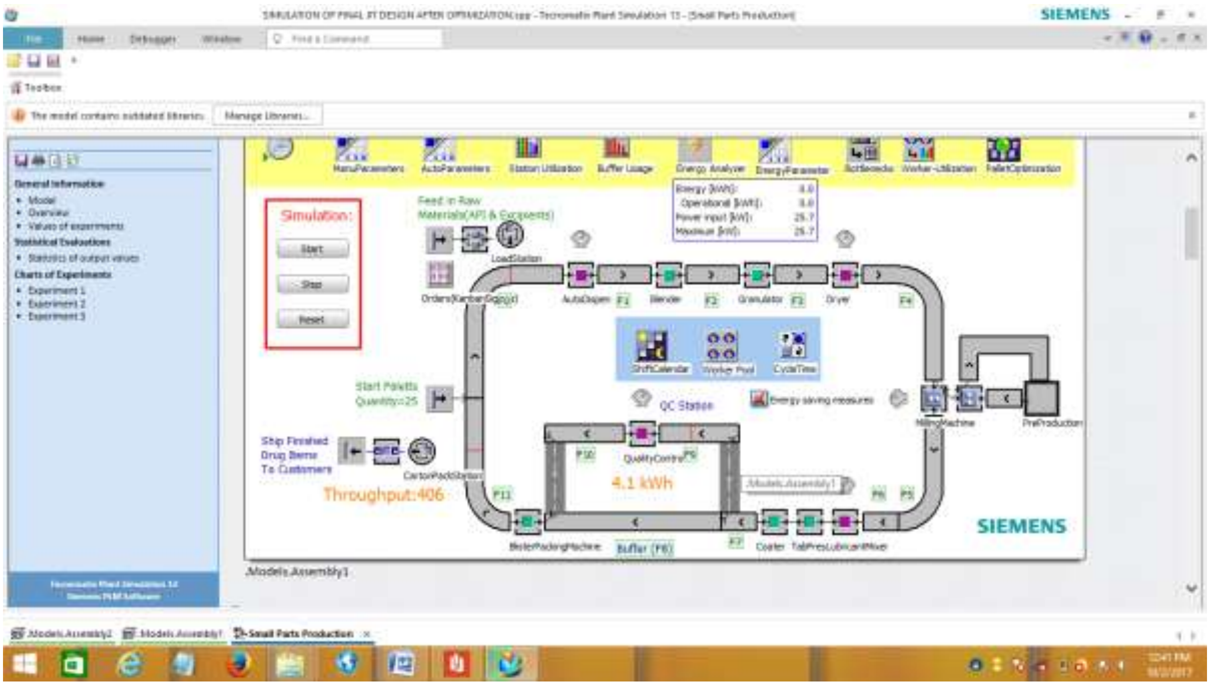


Figure 3.26: Development of Model using TECNOMATIX Plant Simulation Software

Pallets enter the system on the left hand side. The Load Station in the upper left corner of the production line loads one part onto a pallet. Then, the pallets move along passing several manual and automated workstations. The sub-parts arrive from the station PreProduction. At the Unload Station, the main part is unloaded from the pallet and leaves the system. The pallet moves on to the Load Station to be loaded with the next part.

3.6 Comparison of Performance Parameters

When the alternative JIT system was introduced for the first time, there were no significant problems in the implementation. Most operators did not have any difficulties when working with the new system. This may have happened because the system only employed one Kanban item so the process became simple and the operators could easily understand it. The use of process flow charts was also helpful to guide the operators. In the implementation, the role of the supervisors was important especially to guide operators as well as to observe how the system worked.

After the alternative JIT system had been operating for three weeks, that was regarded as a sufficient time to evaluate the system. There were several significant improvements compared to the previous system. The comparison between the previous and new alternative

JIT system was derived from three criteria i.e Lead Time, Inventory and visual control, Net Operating Income (NOI), Work in process level (WIP) and Demand Fulfillment Rate (DFR).

a. Lead Time

Customer lead time is considered as the first concern since the objective of the alternative JIT system is to satisfy the customer. Simply stated, customer lead time is the time required for customers from placing to receiving the orders. In the new system, customers can take the finished products away immediately because the products are already available at the end buffer. In the previous system, the customer must place an order first and it took around 10 days to get the items ordered. Unfortunately, although there was significant improvement in terms of the customer lead time, the manufacturing lead time in the new system did not really change much. Therefore, some improvements must be conducted to reduce this lead time including reduced setup time, reduced process variability, improved production scheduling and reduced machine break down.

b. Inventory

The amount of inventory is measured by using a practical approach as in the following step. To overcome the variability of orders and manufacturing lead time i.e around 360 units at each buffer, since block 2 and block 1 work in the batch sizes of 360 units, the average WIP at the shop floor can be estimated at around 360 units. Therefore, the total inventory for the previous system is (2 x 360 + 360) or 1080 units. In the new system, the Drug Process Plant holds the inventory of the finished items i.e. around 90 units reflected in the maximum amount of inventory available in the end buffer (three Kanbans). The average WIP remains the same as in the previous system i.e. 360 units. Therefore, the total inventory in the new system is (90 + 360) or 450 units.

c. Visual Control

Visual control is measured by comparing the degree of visibility and the availability of the visual devices in both systems. In the previous system, neither supervisors nor operators could check the amount of inventory in the buffer because there was no specified place for particular items and the WIP was not stored in fixed locations. On the other hand, in the new system, the inventory in each buffer is stored in an orderly way at the fixed location, thereby, it will motivate everyone to observe the amount of inventory properly. If the amount of inventory exceeds the normal quantity, the operators or supervisors can take immediate action or find solutions for example by reducing the number of Kanbans. In addition, the visual board, gives information about the status and number of Kanbans (normal, emergency and waiting), motivates the operators to solve the problem immediately. The more Kanbans at the emergency or waiting status, the more problems appear in the production. In conclusion, the new system provides better visual control than the previous system.

JIT can improve worker motivation since the implementation of the system requires more worker involvement and more worker authority. In addition, JIT system is also considered more flexible and less formal than previous systems since the order comes directly from customers, represented by Kanbans, not from the production planner as in the previous system so they can execute directly the orders without much instruction from other sections.

The other benefit of the JIT system is that problem solving becomes a first concern rather than just achieving production targets. In the previous system, both operators and supervisors were more encouraged to meet the due date rather than to improve the system that achieves less inventory and shorter lead times. Therefore, performance improvement, including inventory reduction at the end buffer tended to be ignored and it did not become the first concern because finding solutions was not a priority. In contrast, in the JIT system, workers are encouraged to make their own decisions on the production line; therefore, they have more responsibility and authority to solve the problems directly. Based on this evaluation, the differences between using the previous system and the new system are summarised in Table 3.4.

Table 3.4: The Results of the Implementation

RESULTS	BEFORE JIT	AFTER JIT	IMPROVEMENT
Lead Time	10 days	5 days	2 times
Inventory at the end Buffer	1080 units (2 x360 +360)	540 units (90 + 360)	50%
Visual Control	None	Self-Driven	Better
NOI	67.34	75.21	11.69%
WIP	Normal	Higher	Better
DFR	53.2%	99.7%	46.5%

d. Net Operating Income

Table 3.4 reveals that NOI in the old system was 67.34 but after JIT implementation in the pilot phase, NOI recorded 11.69% improvement. Lead Time before JIT implementation was

10 days but after JIT implementation it became 2 times better (5 days). Also, Inventory at the end buffer before was 1080 units but recorded 50% improvement after JIT implementation.

e. Work in process level and Demand Fulfillment Rate

Furthermore, the drug process plant originally had no visual system but the implementation of the JIT system brought in a visual control system that was self-driven and better than the existing old system. However, DFR recorded 46.5% improvement over the previous old system while WIP was higher and better in the new system unlike in the old system. There are many opportunities in various areas that can be conducted by the Drug Process Plant since the JIT system is not just related to material management but also to all activities for eliminating wastes, so the improvement can be related to other areas such as quality control, setup time reduction and maintaining relations with suppliers. If these areas can be improved, more benefits can be obtained by the Drug Process Plant.

Another problem is that Kanbans do not provide information about due date of production, so workers must put this order as a priority. Based on this problem, another rule for running the pull system at the Drug Process Plant must be included. Kanban items must become the first priority in the production to achieve planned lead time. The prime motive behind evaluation of the JIT system using simulation is to determine factors contributing to improving performance of the new system. As described in Chapter 3, the design of the new JIT system was conducted in a more practical rather than theoretical manner. Therefore, some JIT characteristics such as the number of buffers, Kanban quantities and the number of Kanban at each block are determined using practical reasons. In this work, there are four characteristics that were evaluated by using simulation to achieve lower inventory and shorter flow time. These include: a) Number of Buffers b) Location of Buffers c) Kanban Quantities d) Scheduling Rule

3.7 Alternative System Optimization

Design of Experiments (DOE) is used to determine best set of factors for the model optimization. For this purpose, the Taguchi design is done. The three factor two level Taguchi design is designed. For that, L16 orthogonal array is used. It is shown in the Table 3.5.

Table 3.5: Design of Experiment

RUN	SETUP TIME	MACHINE ALTERATION	SHIFT ALTERATION
1	5	Removing 1 m/c	8
2	5	Removing 1 m/c	8
3	5	Removing 1 m/c	12
4	5	Removing 1 m/c	12
5	5	Adding 1 m/c	8
6	5	Adding 1 m/c	8
7	5	Adding 1 m/c	12
8	5	Adding 1 m/c	12
9	10	Removing 1 m/c	8
10	10	Removing 1 m/c	8
11	10	Removing 1 m/c	12
12	10	Removing 1 m/c	12
13	10	Adding 1 m/c	8
14	10	Adding 1 m/c	8
15	10	Adding 1 m/c	12
16	10	Adding 1 m/c	12

This is the design of experiment drawn with the help of TECNOMATIX software. Here, in this design, the 1 indicates Low and 2 indicates high. The three input parameters Setup time, Machine Alteration and Shift Alteration. The low and high level for the DOE is explained in Table 3.6.

Table 3.6: Low and High levels of parameters

Sr. No.	Input Parameters	Units	Low	High
1	Setup Time	min.	5	10
2	Machine Alteration	-	Removing 1 m/c	Adding 1 m/c
3	Shift Alteration	Hrs.	8 (Current shift)	12 (current shift with overtime)

The Setup Time explains the time required for the machine to be ready for the any function or operation. So, the time 5 min is low level and 10 min is high level. The Machine Alteration means adding and removing the machine from the developed model. In this factor, at low level, the Machine M2 is not considered so the line has ten machines and ten conveyors; at high level, the Machine “Machine011” and Conveyor “Conveyor010” is connected to the main line of developed model. The third factor Shift Alteration explains the shift hours at the low level, the shift hrs are 8 hrs similar to current shift and at high level, extra 4 hrs are added to the current shift becomes 12 hrs.

The JIT system is not just related to Kanban implementation but it comprises a comprehensive approach for improving the performance of a system that covers batch size reduction, setup time reduction, quality improvement, production planning, and human resources management. Therefore, there will be more significant results if the improvement also covers those areas using an integrated approach.

Based on the analysis of the implementation of the new system, there are some factors that must be considered for further improvement including inventory reduction, improving visibility, batch size reduction and matching with other systems.

3.7.1. Batch Size Reduction

To achieve a true JIT system that reduces the inventory, batch sizes must be reduced to the minimum level. Since block 2 runs with a batch size of 360 units, which is the same as the previous system, this system actually does not provide significant improvement in terms of inventory reduction at the Drug Process Plant. The inventory moved only from the end storage to buffer 2. To achieve a true JIT system, block 2 must be divided into two or three new blocks so all the new blocks can run in smaller batch sizes. Most processes in block 2 require setup time (see Figure 3.11), the batch size of each new block can be calculated directly. For example, if two new blocks are inserted so block 2 consists of three new blocks, the batch size of each new block is 120 units (360/3) and each new block will require a lead time of around two days (6.5/3 days).

Diagrammatically, this can be shown in Figure 3.27. The batch size of 120 is more preferable since it is equal to the minimum batch size of mixing/blending machines, a group of facilities that determines the quantity batch size of each order. By running the production using this batch size, the Drug Process Plant will also become more responsive by anticipating the fluctuating orders.

3.7.2. Visibility Enhancement

The other benefit of dividing block 2 into the smaller blocks is that WIP becomes more visible than before. Block 2 is actually too long and hard to manage since it comprises 8 different processes that take around 6.5 days in all to finish. In addition, the accumulation of WIP within this block is difficult to detect. Therefore, more blocks in the system can provide a better visible indicator of WIP. This will motivate operators to detect the problems as they occur.

3.7.3. Setup Time Reduction

Basically, successful JIT implementation cannot be conducted without setup time reduction. Production of small batches, a characteristic of the JIT system, always requires reduction of setup time. Batch sizes can be reduced without reducing setup but the productivity of the machine becomes lower, so this is contrary to JIT principles. Setup time reduction is crucial especially when many items will be processed in the same production facilities. Since in the future, the Drug Process Plant will apply the pull system for most major items, setup time reduction must become the first priority. Two common approaches were employed in reducing setup times:

a. Physical Configuration

This approach was conducted by grouping products into families that are placed into dedicated cells. Reduced setup times were attained because not many tasks are required to load or unload similar parts. Unfortunately, this approach is hard to implement in the Drug Process Plant because of the type of manufacturing processes and the space limitation.

b. Engineering Methods

This approach is conducted by standardising tools, removing unnecessary adjustment, modifying fixtures and improving operators' skills. By considering the availability of resources in the Drug Process Plant, all of those techniques are suitable to apply.

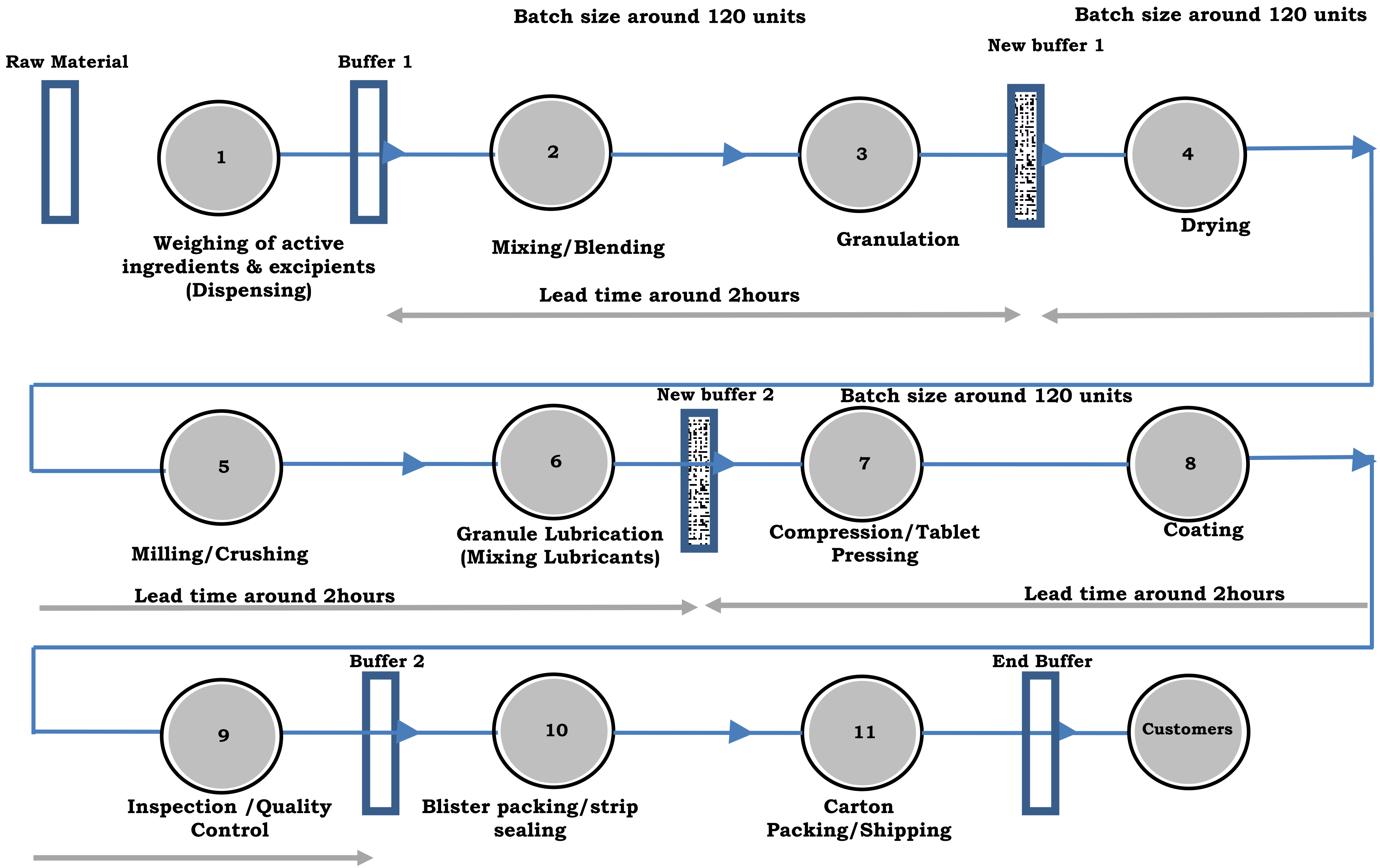


Figure 3.27: The effects of additional buffers on lead time and batch size

3.7.4. Product Variety Reduction

Almost 73% of the throughput time to process the items is spent for waiting and queuing, therefore, the Drug Process Plant, if necessary, must reduce the variety of the items. Various approaches were applied such as stabilised demands, standardizing products, avoiding special orders and machine variation reduction. To accomplish these approaches, application of new management methods or technologies were employed.

3.7.5. Matching With the Existing System

Continuing to use the MRP system in the JIT environment without any modification commonly results in an overwhelming increase of paperwork. Although, both MRP and JIT have benefits, both of them have different objectives and conflicting purposes (Chase, 2011). In the JIT environment, the MRP should be solely developed to manage demands and to create a Master Production Schedule (MPS), often also to order raw materials. As a result, MRP just deals with the report of finished products. Therefore, the rest of the operations at the shop floor are under the control of the JIT system. The traditional measurement system reported from MRP must be changed because it is not suitable for measuring the JIT performance. The use of a traditional measurement system such as labour efficiency and utilisation tends to emphasise a standard and encourage overproduction. The new measures must be focused on detecting improvements such as higher product quality, lower inventory levels, faster throughput time and flexibility.

In the trial, the MRP is still applied, not just to create MPS, but also for tracking and calculating capacity planning as well as reporting status/progress represented by the use of traveller inserts. In the future, this will not be required since the Kanbans can inform and estimate the requirement of the resources. This modification then requires a change of other systems such as performance measurement, incentive systems and quality control. In the Drug Process Plant, the pull system can result in an overwhelming increase in paperwork for the MRP. Since the pull system works in the smaller lot sizes from 360 units into 90 units, completion reports on the Kanban items required becomes fourfold. To avoid this problem in the future, the reporting period for Kanban items must be changed from daily to longer periods of time.

3.7.6. Quality Improvement

Although the overall defective rate in each item is around 5%, the Drug Process Plant is still expected to improve its quality performance because in the JIT system, reducing variability of the defects is also far more important rather than just reducing the percentage of defects. The lower the variability of the processes, the smaller the quantity of each buffer required between two stations. Therefore, this will improve production flow as well. To achieve better quality performance, responsibility for quality control must shift from inspectors to everyone involved in production. Currently, the responsibility for quality control in Juhel Nigeria ltd is carried out by inspectors because operators do not have sufficient skills to do this job. Therefore, in the future, training for operators is required to handle this.

3.8 Design of Final Physical Model Based on Simulation Results

The final physical model of the alternative JIT Manufacturing System was developed based on the simulation results and comprises six sub-models namely: Supplier Sub Model, Route Sub-Model, Kanban Sub Model, Production Sub Model, Consumption Sub Model and Plant Sub Model. The result of the six simulation sub-models (figures 3.28, 3.29, 3.30, 3.31, 3.32, 3.33) are shown in Appendix C2. The entities of the final physical JIT System model are parts, kanban, and cycles. The route and kanban sub models describes the flow of information while the supplier, production, consumption, and plant sub-models describe the flow of material. The kanban sub-model reorders parts; the route sub model schedules the shipping; the kanban sub-model reorders parts. Parts are produced in the production sub-model (Figure 3.31) and they are consumed in the consumption sub-model (Figure 3.32). Parts are shipped from the production sub-model to the consumption sub-model. In transit, they go through the supplier sub model (Figure 3.28), and the plant sub model (Figure 3.33). Kanban controls the reordering of parts.

All kanban cards start and end in the kanban sub-model (Figure 3.30). Parts and kanban cards from the supplier sub-model are transported to the plant sub-model. Cycle entities signal the transport cycles and they only exist in the route sub-model (Figure 3.29); they specify the time to dispatch.

3.8.1 Supplier Sub Model

The supplier sub-model models docking operations. Figure 3.28 shows the supplier sub-model. The model waits for kanban entities to arrive work station, when kanban cards are dropped off, the model sorts through the kanban cards for a particular supplier and send the cards to a kanban hold queue. The rest of the kanban cards go directly to an exit holding queue. The kanban hold queue waits for a docking complete signal to begin processing the kanban cards.

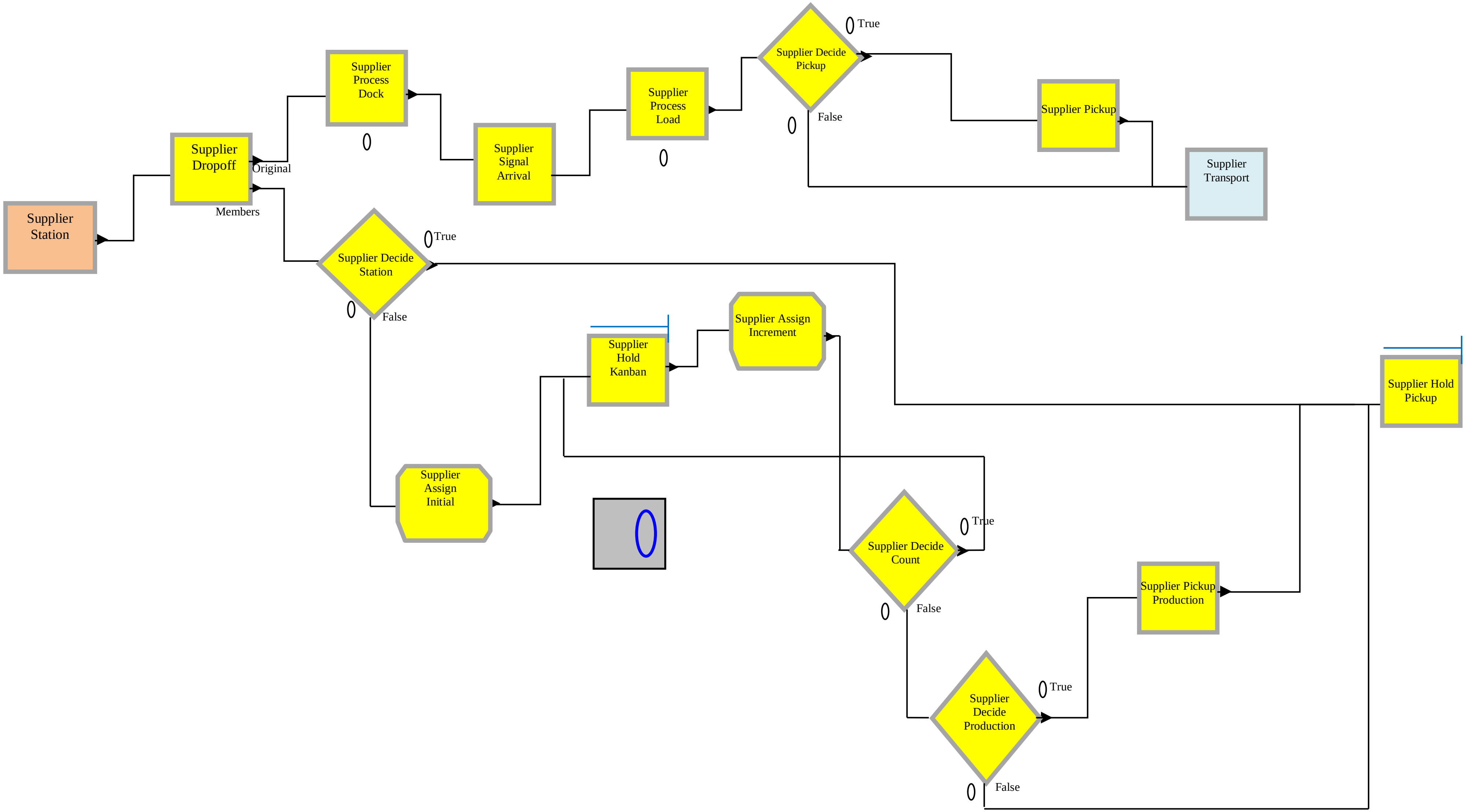


Figure 3.28: Supplier Sub Model

The due kanban cards are assigned a batch of parts from the production sub-model and sent to the exit holding queue. Sometimes, there is no part at the production sub-model, because the demand exceeds the level of production. If there is no part at the production sub-model, the kanban card proceeds directly to the exit holding queue. A kanban card with no part will be sent back to the plant, while a new kanban card is issued at the plant. Once the kanban cards are processed, the next event allows the the kanban cards and their parts to be picked up.

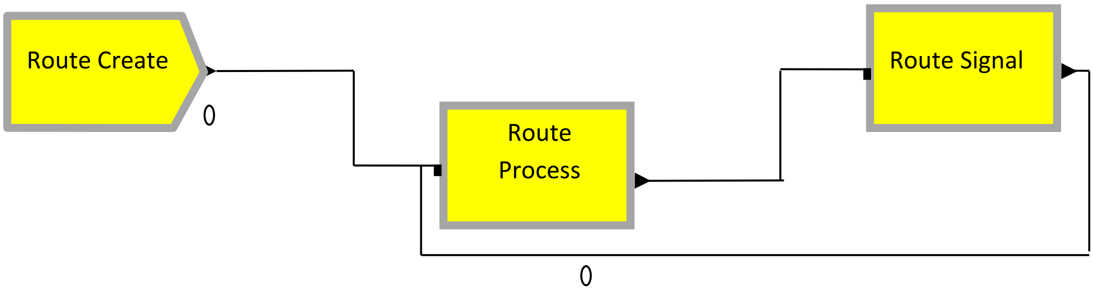


Figure 3.29: Route Sub Model

3.8.2 Route Sub Model

The route sub-model creates an entity, named cycle that signals the time to begin the transport cycle. The signal occurs periodically with its duration set by a delay block. Figure 3.29 shows the route sub-model.

3.8.3 Kanban Sub Model

The kanban sub-model describes the kanban system. Its function is to receive and send kanban cards as signals to authorize production and transfer parts from suppliers to the manufacturer. Figure 3.30 shows the kanban sub-model. Kanban cards are sent through signals from the consumption sub-model and the plant sub-model. The consumption sub-model put the kanban cards in a reordering queue; the plant sub-model signals the release of the reordering queue. In the Plant sub-model, the cards are released back to the kanban sub-model where they wait for consumption to occur before being released again.

3.8.4 Production Sub Model

The production sub-model models the production operations. Figure 3.31 shows the production sub-model. The model employs a number of prototype parts that waits in a queue for a signal from the kanban system. Once a signal is given, the parts duplicate themselves to the quantity required. The duplicates are delayed in a process block to simulate the production lead time. After that, they are batched and held in another queue for pickup.

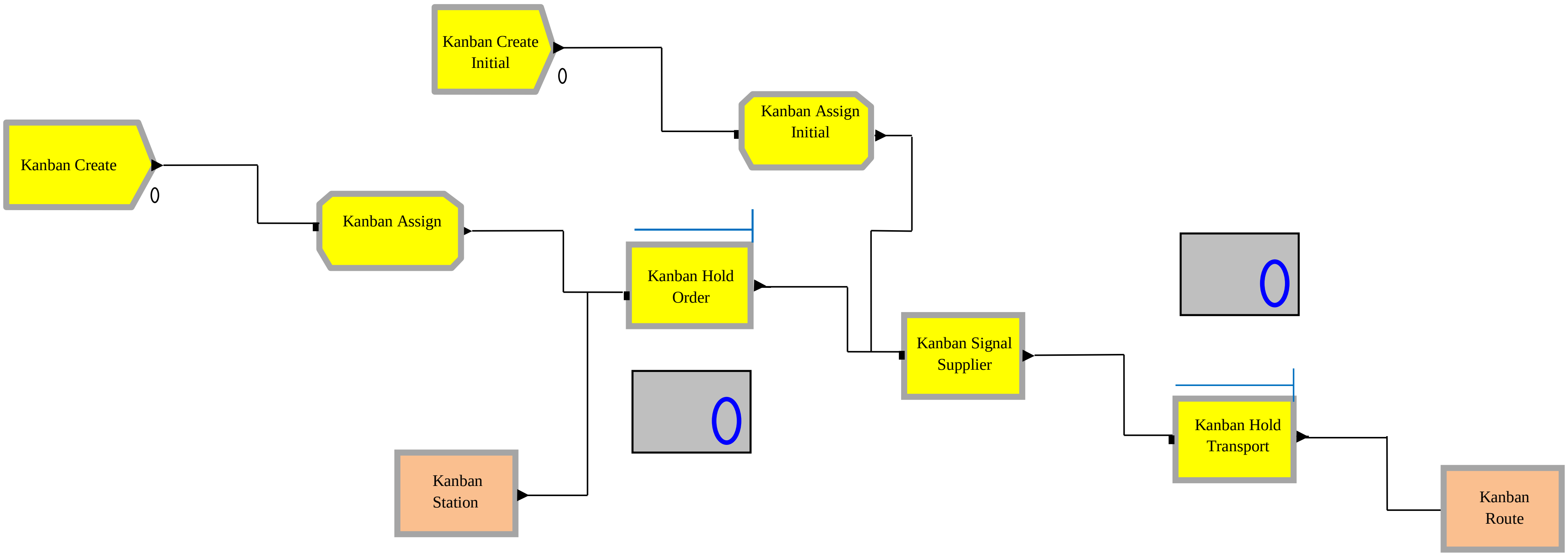


Figure 3.30: Kanban Sub Model

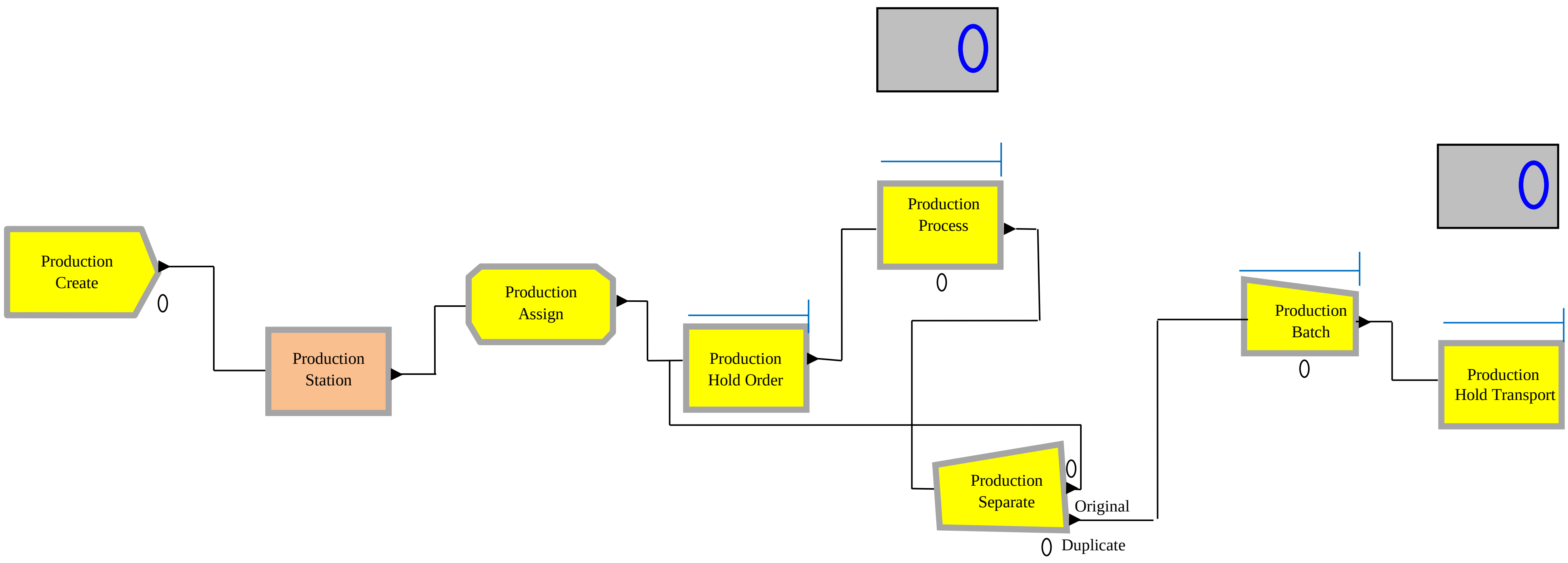


Figure 3.31: Production Sub Model

3.8.5 Consumption Sub Model

The consumption model simulates the consumption of parts inside the plant. Figure 3.32 shows the consumption sub-model. The sub-model consists of a consumption point process with two queues that represents the inventory level at the consumption point and the inventory level at the dock or staging area. The queue at the staging area regularly scans the inventory level (the other queue) at the consumption point. If the inventory level at the consumption point reaches a critical point, parts are released to the consumption point and a reordering signal is triggered to the kanban sub-model. The parts are consumed according to a predetermined demand distribution. The demand is generated by a create entity block that also simulates the production flow to the consumption point. A disposer destroys the parts after a delay process. The delay process simulates an application of a part at the consumption point.

3.8.6 Plant Sub Model

After a signal order for an item is received, it is first assigned a route based on the signal. Then, the signal is sent to all the relevant kanban queues for parts transported on that route, requesting release of the corresponding kanban cards. After that, the cards are picked up and taken to its first and subsequent destinations on the route. The plant sub model is shown in Figure 3.33.

3.8.7 System Flows

As mentioned earlier, kanban controls the reordering of parts. The flow of the kanban cards is as in Figure 3.34: A kanban card is issued in the kanban sub-model when inventory level hits a critical point. At a specific time, the card will be picked up and transported to its designated supplier. The supplier is where the card is dropped off. The card stays at supplier for a number of cycles to simulate the order-to-pickup lead time. After that, another card is picked up together with any available parts assigned to the card. The card is then returned to the plant and dropped off. The card is returned to a collection bin, i.e. a HOLD block that accumulates all the extra cards.

The parts are produced at the supplier. The flow of parts is as follows: A prototype part duplicates another part once a kanban signal is issued. This occurs at the same time that the kanban card is issued for the kanban flow. The part is delayed in a process block to simulate production or dispensing. It then goes to a batch block and becomes part of a pallet. The pallet is picked up at a specific time and travel together with its kanban card to the plant. At the plant the pallet is dropped off and moved to a holding block in the consumption sub-model.

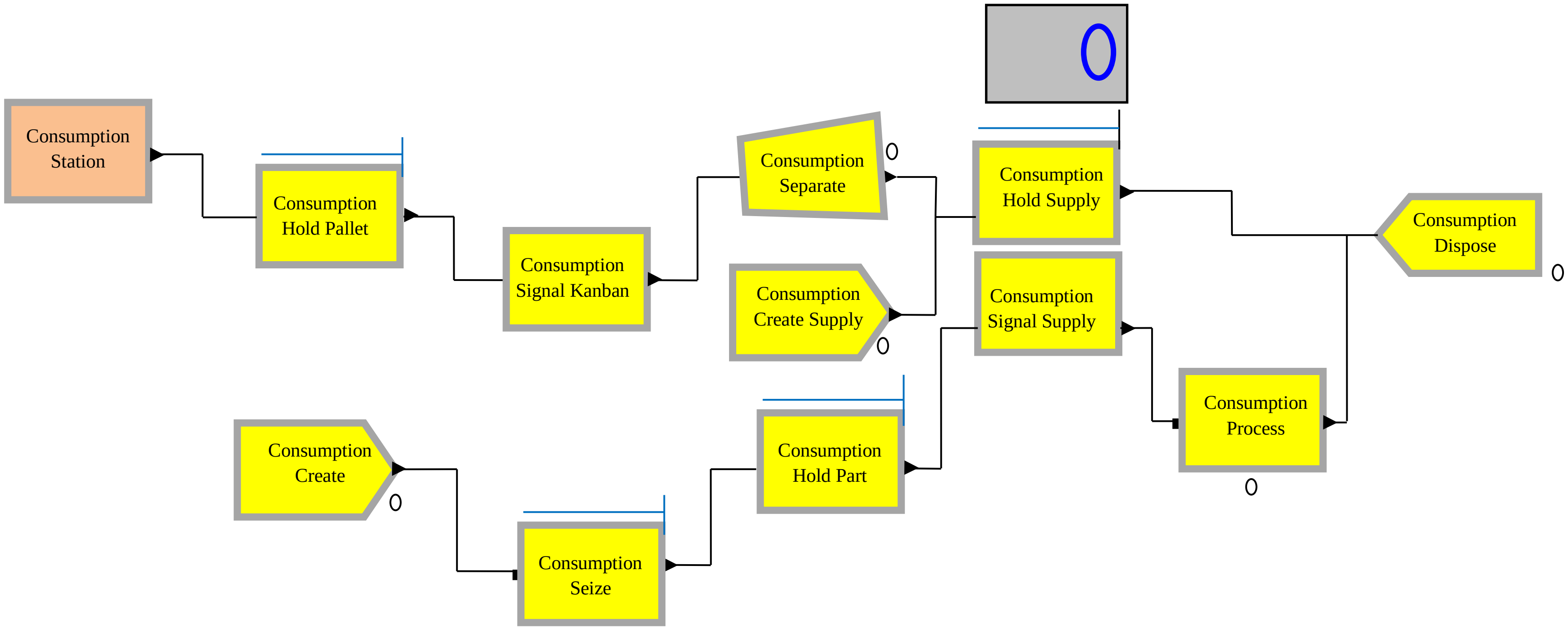


Figure 3.32: Consumption Sub Model

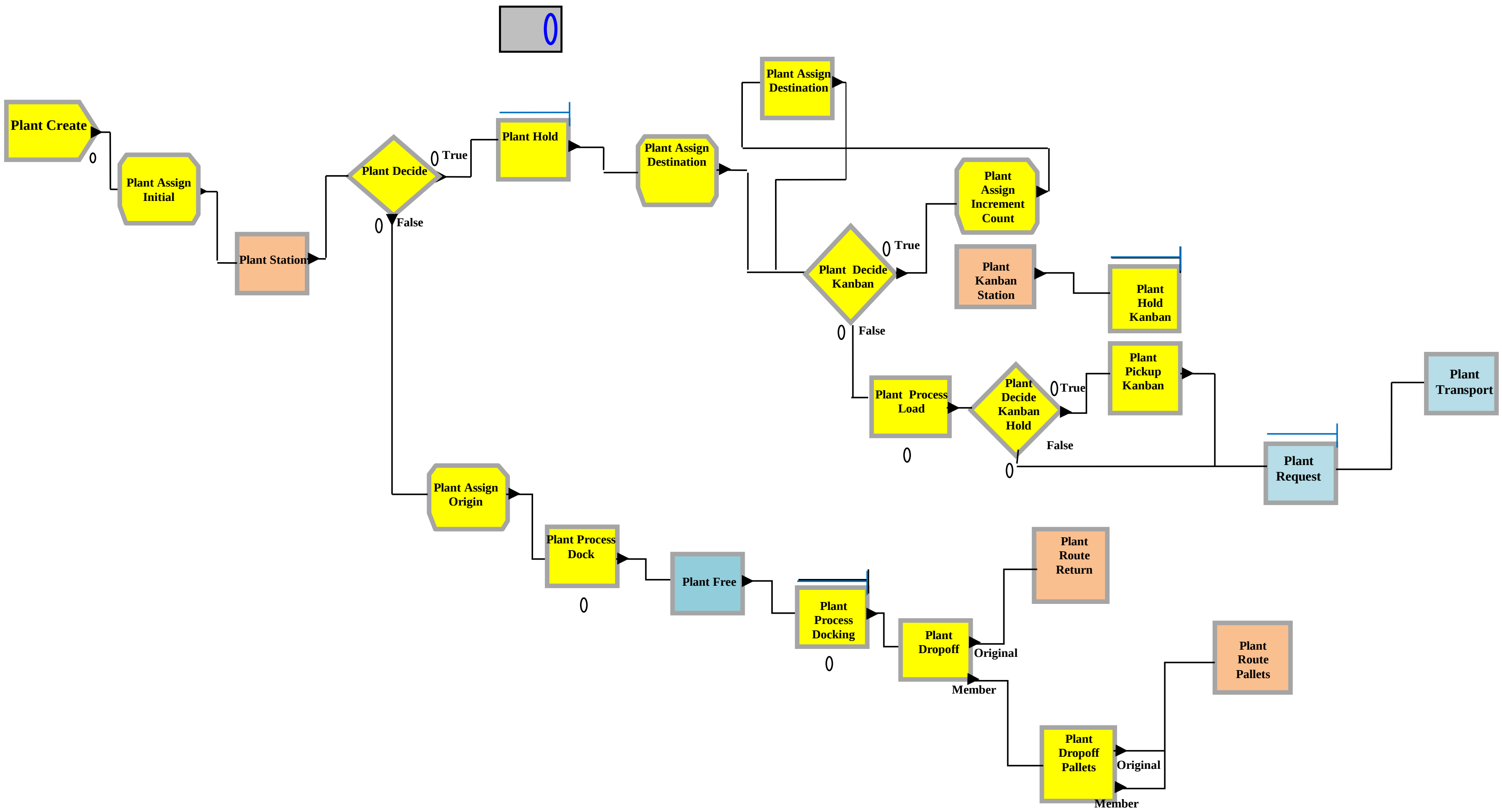


Figure 3.33: Plant Sub Model

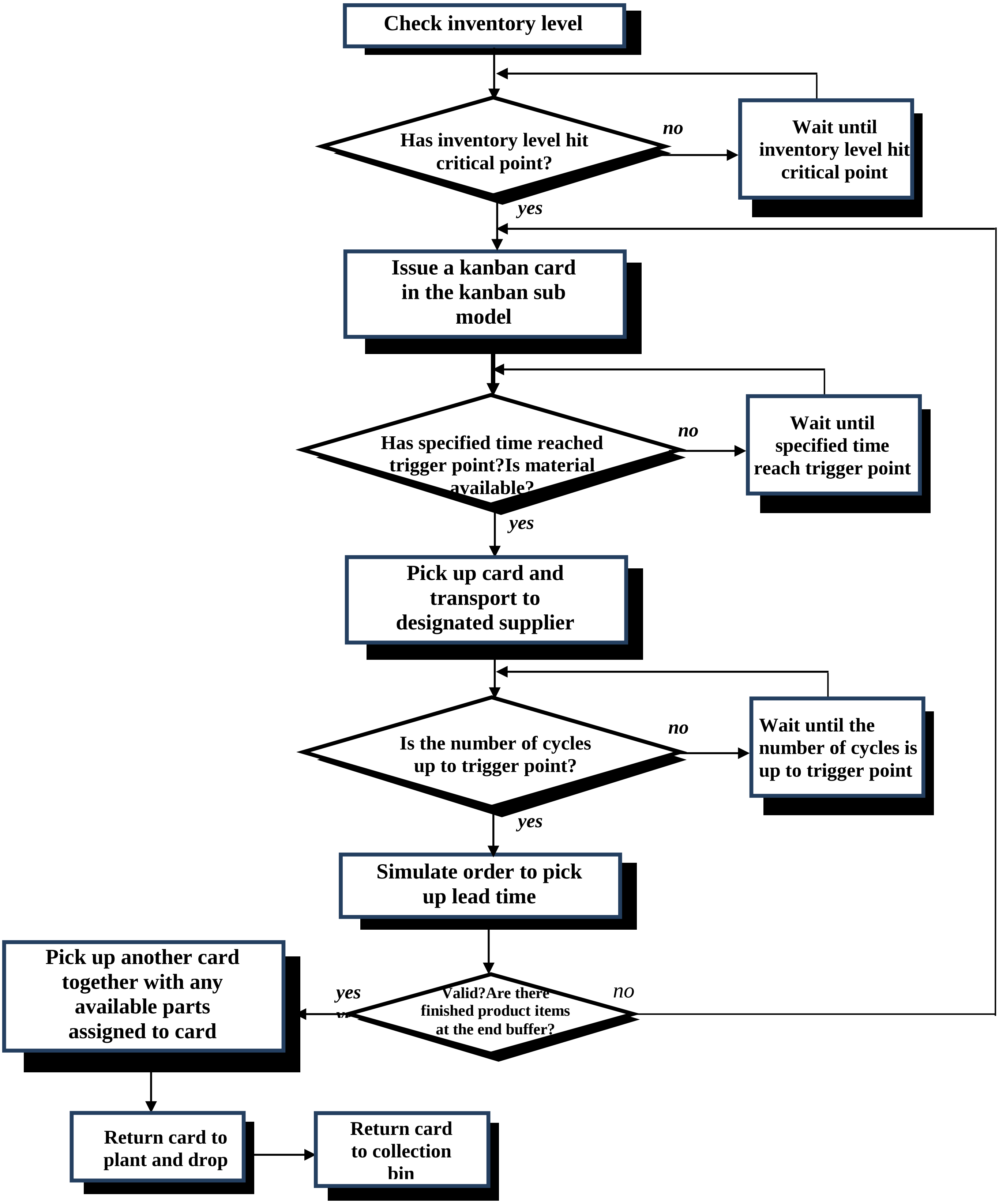


Figure 3.34: Flow of the kanban cards

3.9 Implementation of Final Physical Model on Shop Floor

Table 3.7: System Performance after Implementation on Shop Floor

(a) NOI(Millions)											
Observ.	1	2	3	4	5	6	7	8	9	10	MEAN
New Physical System after Implementation on Shop Floor	82.20	89.30	79.80	97.50	93.00	89.80	81.50	76.90	79.90	83.10	85.30
(b) Cycle Time(Minutes)											
Observ.	1	2	3	4	5	6	7	8	9	10	MEAN
New Physical System after Implementation on Shop Floor	616	627	654	643	623	635	639	644	617	637	634
(c) DFR (%)											
Observ.	1	2	3	4	5	6	7	8	9	10	MEAN
New Physical System after Implementation on Shop Floor	94.00	93.00	92.00	94.00	92.00	98.00	92.00	91.00	91.00	94.10	93.11
(d) Inventory Turnover (units on a scale of 20)											
Observ.	1	2	3	4	5	6	7	8	9	10	MEAN
New Physical System after Implementation on Shop Floor	10.40	13.90	14.00	11.00	15.20	11.90	17.40	14.20	13.53	17.00	13.85
(e) WIP(units)											
Observ.	1	2	3	4	5	6	7	8	9	10	MEAN
New Physical System after Implementation on Shop Floor	887	929	971	910	968	920	960	910	950	965	937
(f) Throughput Time(Minutes)											
Observ.	1	2	3	4	5	6	7	8	9	10	MEAN
New Physical System after Implementation on Shop Floor	220	212	260	204	274	212	240	253	281	212	237
(g) Flow Time(Minutes)											
Observ.	1	2	3	4	5	6	7	8	9	10	MEAN
New Physical System after Implementation on Shop Floor	113	111	103	130	142	113	135	132	113	120	121

As shown in Table 3.7, the mean response of the simulated new physical system in terms of NOI gave a mean response of 85.30 in 10 observations after implementation on the shop floor. Also, the mean response of the simulated new physical system in terms of cycle time was 634 when implemented on the shop floor. Whereas, the mean response of the simulated new physical system in terms of DFR was 93.11 after implementation on the shop floor.

However, the mean response of the simulated new physical system in terms of Inventory Turn-over gave a mean response of 13.85 when implemented on the shop floor. Furthermore, the mean response of the simulated new physical system in terms of WIP was 937 when implemented on the shop floor.

On the other hand, the mean response of the simulated new physical system in terms of Throughput Time was 237 when implemented on the shop floor. In addition, the mean response of the simulated new physical system in terms of Flow Time gave a mean response of 121 when implemented on the shop floor.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Comparison of Results based on System Performance

Models can give useful insights into the behaviour of systems. Models developed in the previous chapter were simulated to identify and compare the effects of JIT on Cycle Time/Lead Time), Flow Time, Demand Fulfillment Rate, Throughput Time, Inventory Level, Net Operating Income and Work in Process Level. Also, the effect of factors such as Trigger Point Levels, Scheduling Rules, the Number of Kanbans and Location of the Buffers were deduced. These factors were selected because they are under management control at the Drug Process Plant and they can be manipulated easily in the model. By analysing the simulation outputs, three major performance measures used to determine the effects of these factors were flow time (customer lead time), Work-in-Process (WIP) and shortage. Although the two last measures cannot be obtained directly from the simulation results, they can be calculated from variables available in the simulation results.

In the simulation, the analysis cannot rely on observations from a single replication since the simulation outputs are usually fluctuating due to the variation of variables in the model. Therefore, the use of statistical tools/functions is unavoidable to process the fluctuating data obtained from multiple replications. Since the use of the statistical tools is not a main concern in the work, a simple statistical procedure is used to investigate the results i.e. the procedure for comparing two or three systems. In the simulation, the replication length was set at four weeks (40320 minutes) which represents the maximum time that the model is able to run. The replication number was set into 10 and later 60 for the same reason. Basically, a sufficient number of replications were determined by using a statistical procedure that specifies a confidence level. However, the replications were assumed to be a sufficient figure for analysing the results.

4.1.1 System Performance

System performance in terms of Cycle Time (Lead Time), Flow Time, Demand Fulfillment Rate, Throughput Time, Inventory Level, Net Operating Income, Work in Process Level were extracted from the old physical system, simulated old physical system, simulated new physical system and the new physical system after implementation on shop floor as shown in tables 4.1.

Table 4.1: Analysis of System Performance

(a) NOI(Millions)											
Observ.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**MEAN**
Old Physical System	79.45	65.38	66.44	67.31	64.06	66.08	65.30	65.70	65.09	68.59	**67.34**
Simulated Old Physical System	79.13	65.87	66.48	66.92	65.27	65.25	66.34	68.19	65.04	69.00	67.75
Simulated New Physical System	84.33	89.64	81.40	94.63	91.210	88.70	81.50	76.10	82.10	83.82	85.54
New Physical System after Implementation on Shop Floor	82.20	89.30	79.80	97.50	93.00	89.80	81.50	76.90	79.90	83.10	85.30
(b) Cycle Time(Minutes)											
Observ.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**MEAN**
Old Physical System	783	722	781	872	781	746	731	789	851	789	785
Simulated Old Physical System	761	823	737	806	818	746	735	743	854	791	781
Simulated New Physical System	612	617	607	609	618	612	621	645	607	618	617
New Physical System after Implementation on Shop Floor	616	627	654	643	623	635	639	644	617	637	634
(c) DFR (%)											
Observ.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**MEAN**
Old Physical System	66.00	68.00	61.00	71.00	63.00	66.00	64.00	72.00	73.00	64.00	66.80
Simulated Old Physical System	66.10	69.00	61.00	73.00	65.00	68.00	67.00	73.00	72.00	65.00	67.91
Simulated New Physical System	94.60	93.00	92.50	95.60	93.00	98.10	94.00	91.20	91.00	94.10	93.71
New Physical System after Implementation on Shop Floor	94.00	93.00	92.00	94.00	92.00	98.00	92.00	91.00	91.00	94.10	93.11
(d) Inventory Turnover **(units on a scale of 20)**											
Observ.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**MEAN**
Old Physical System	8.00	11.00	14.90	-1.00	13.00	12.00	7.00	12.00	10.4	12.00	9.93
Simulated Old Physical System	9.00	12.00	15.00	1.00	13.00	12.60	8.00	13.50	10.2	12.8.00	10.48
Simulated New Physical System	11.00	13.00	15.00	13.00	15.50	12.00	17.00	14.70	16.43	17.00	14.46
New Physical System after Implementation on Shop Floor	10.40	13.90	14.00	11.00	15.20	11.90	17.40	14.20	13.53	17.00	13.85
(e) WIP(units)											
Observ.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**MEAN**
Old Physical System	680	730	670	610	670	720	650	720	630	770	685
Simulated Old Physical System	680	720	690	710	710	723	654	740	630	775	703
Simulated New Physical System	890	930	970	910	970	920	966	920	950	977	940
New Physical System after Implementation on Shop Floor	887	929	971	910	968	920	960	910	950	965	937
(f) Throughput Time(Minutes)											
Observ.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**MEAN**
Old Physical System	345	456	314	354	312	306	332	355	375	374	352
Simulated Old Physical System	339	445	306	354	311	306	330	335	335	363	342
Simulated New Physical System	213	210	248	200	369	209	239	250	280	209	243
New Physical System after Implementation on Shop Floor	220	212	260	204	274	212	240	253	281	212	237
(g) Flow Time(Minutes)											
Observ.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**MEAN**
Old Physical System	126	136	139	194	191	155	166	185	115	125	153
Simulated Old Physical System	125	130	137	174	176	156	159	183	115	121	148
Simulated New Physical System	112	109	103	117	143	112	134	126	112	115	118
New Physical System after Implementation on Shop Floor	113	111	103	130	142	113	135	132	113	120	121

Table 4.1 is a description of the system response in terms of Cycle Time /Lead Time, Flow Time, Demand Fulfillment Rate, Throughput Time, Inventory Level, Net Operating Income and Work in Process Level in ten observations.

As shown in Table 4.1a, the mean response of the old physical system in terms of NOI was 67.34 while a mean response of 67.75 was recorded when simulated. Also, the mean response of the simulated new physical system in terms of NOI was 85.54 but gave a mean response of 85.30 when implemented on the shop floor. This indicates that the new JIT system outperformed the old physical system in terms of NOI.

Table 4.1b show that the mean response of the old physical system in terms of cycle time was 785 while a mean response of 781 was recorded when simulated. Also, the mean response of the simulated new physical system in terms of cycle time was 617 but gave a mean response of 634 when implemented on the shop floor. This indicates that the new JIT system outperformed the old physical system in terms of cycle time.

As revealed in Table 4.1c, the mean response of the old physical system in terms of DFR was 66.80 while a mean response of 67.91 was recorded when simulated. Also, the mean response of the simulated new physical system in terms of DFR was 93.71 but gave a mean response of 93.11 when implemented on the shop floor. This indicates that the new JIT system outperformed the old physical system in terms of DFR.

Table 4.1d indicated that the mean response of the old physical system in terms of Inventory Turn-over was 9.93 while a mean response of 10.48 was recorded when simulated. Also, the mean response of the simulated new physical system in terms of Inventory Turn-over was 14.46 but gave a mean response of 13.85 when implemented on the shop floor. This indicates that the new JIT system outperformed the old physical system in terms of Inventory.

As shown in Table 4.1e, the mean response of the old physical system in terms of WIP was 685 while a mean response of 703 was recorded when simulated. Also, the mean response of the simulated new physical system in terms of WIP was 940 but gave a mean response of 937 when implemented on the shop floor. This indicates that the new JIT system outperformed the old physical system in terms of WIP.

Table 4.1f reveal that the mean response of the old physical system in terms of Throughput Time was 352 while a mean response of 342 was recorded when simulated. Also, the mean response of the simulated new physical system in terms of Throughput Time was 243 but gave a mean response of 237 when implemented on the shop floor. This indicates that the new JIT system outperformed the old physical system in terms of Throughput Time.

Table 4.1g indicate that the mean response of the old physical system in terms of Flow Time was 153 while a mean response of 148 was recorded when simulated. Also, the mean response of the simulated new physical system in terms of Flow Time was 118 but gave a mean response of 121 when implemented on the shop floor. This indicates that the new JIT system outperformed the old physical system in terms of Flow Time.

Table 4.2: Summary of System Performance

Performance Parameter	Old Physical System	Simulated Old Physical System	Simulated New Physical System	New Physical System after Implementation on Shop Floor	Percentage difference between Old Physical System & New Physical System after Implementation on Shop Floor
NOI	67.34	67.75	85.54	85.30	26.7
Cycle Time	785	781	617	634	-19.2
DFR	66.80	67.91	93.71	93.11	39.4
Inventory Turnover	9.93	10.48	14.46	13.85	39.5
WIP	685	703	940	937	36.8
Throughput Time	352	342	243	237	-32.7
Flow Time	153	148	118	121	-20.9

Table 4.2 is a summarized comparative analysis of system performance based on the developed models. It shows that the simulated new physical system outperformed the old physical system in terms of NOI, Cycle Time, DFR, Inventory, WIP, Throughput Time and Flow Time. Results of the physical implementation of both the old and the new system on the shop floor slightly varied with the results of the simulated physical systems.

However, the new system after physical implementation on the shop floor recorded 26.7% increase in NOI, 39.4% increase in DFR, 39.5% increase in inventory turn-over (work that has occurred) and 36.8% increase in WIP. On the other hand, the new physical system after implementation on the shop floor recorded 19.2% decreases in cycle time, 32.7% drop in Throughput Time and 20.9% cut in Flow Time. This shows that the new system (JIT manufacturing system) was very effective in reducing Cycle Time, Throughput Time and Flow Time. The new system was equally very effective in achieving higher NOI, DFR, Inventory and WIP.

4.1.2 The Effects of Trigger Point

The purpose of this experiment was to determine the optimal level of the trigger point that can reduce the WIP as well as the customer lead time and the lower the WIP, the higher the risk of the shortage. In this experiment, the effects of the trigger point on shortage were also investigated.

4.1.2.1 The Effects of Trigger Points on Flow Time and WIP

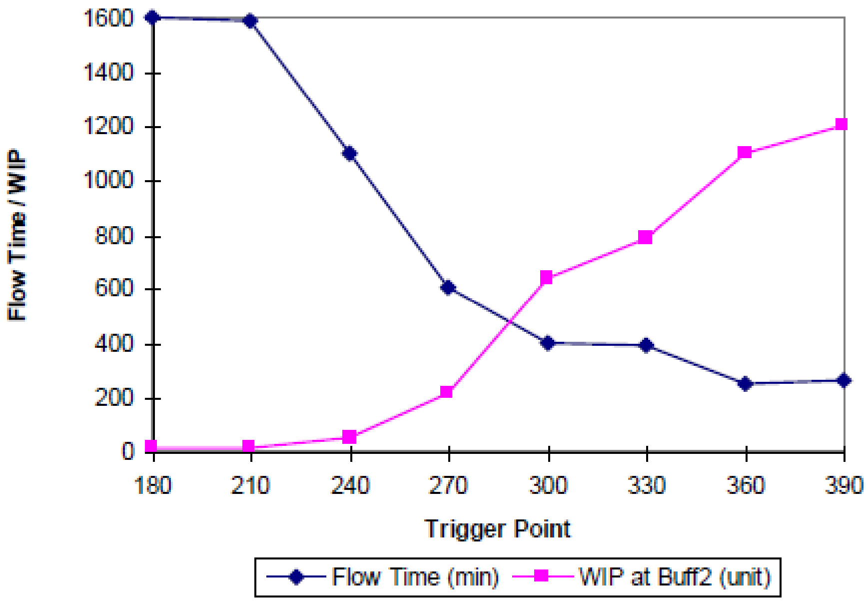


Figure 4.1: The effects of trigger points on Flow Time and WIP

By changing the values of the trigger points, the results of the simulation can be shown in Figure 4.1. From this chart, by running the four-week simulations as the trigger point increases, the average flow time representing the customer lead time decreases and the average WIP at buffer 2 increases. This is not surprising because an increase of the trigger point is the same as an increase of the safety buffer at buffer 2. The high buffer level is highly likely to reduce the waiting time since the orders can be accomplished immediately.

The number of satisfied orders also increases as a result of decreasing the customer lead time. Unfortunately, this also means creating extra WIP. Therefore, the trade-off between the WIP and the lead time should be attained. Another interesting result from Figure 4.1 is that an increase of the trigger point after the point of 360 does not give significant reduction of flow time while the increase of the WIP remains high. Therefore, the trigger point is effective for reducing the customer lead time up until a certain level, after that, there is no benefit in increasing the trigger point. Since the Drug Process Plant wishes to reduce the customer lead time and inventory simultaneously, based on Figure 4.1 a trigger point of 270 or 300 (the existing trigger point) is the best compromise between both objectives.

Another factor affected by trigger point is shortage. The shortage is obtained by subtracting the total Kanban quantity arriving by the order satisfied. Ideally, in the JIT system, there is no shortage since the Kanban arrival is always accomplished. However, if the arrival of orders is probabilistic and the Kanban quantity is fluctuating, shortages are unavoidable. Therefore, shortage must be minimised since it can affect the customer lead time. As an increase in the trigger point is the same as an increase in the safety buffer at buffer 2, the high buffer level is highly likely to reduce the risk of shortage experienced by the customer. However, this results in an increase of the WIP as shown in Figure 4.2.

4.1.2.2 The Effects of Trigger Points on WIP and Shortage of parts

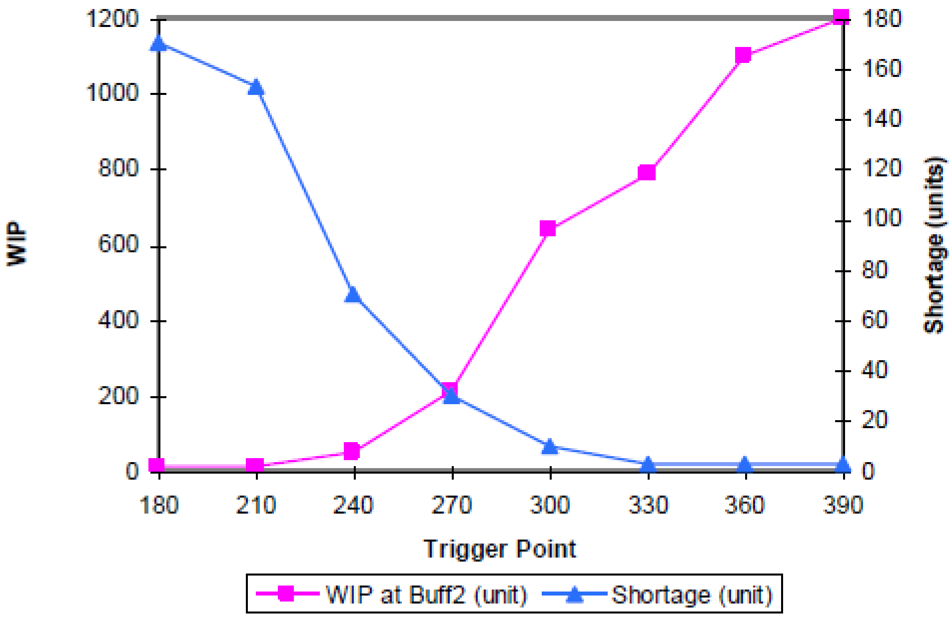


Figure 4.2: The effects of trigger points on WIP and Shortage of parts

As the Drug Process Plant also wishes to reduce WIP as well as shortages, the trigger point must be set to satisfy both objectives. Based on the simulation results as shown in Figure 4.2, a trigger point of 270 provides the best trade-off between both objectives.

4.1.3 Effect of Scheduling Rules on System Performance

The purpose of this experiment is to investigate the effects of the scheduling rules on the performance of the system. There are two performance measures selected i.e. utilisation and the trial items produced. Utilisation was selected since in practice JIT implementation is usually accomplished with other push items, therefore, it is essential to optimise the production facilities where two different methods perform together. Since block 2 is the longest process, the utilisation of this block is used in the experiment as an indicator of the overall system. Another measure, the trial item produced, is also used to investigate which scheduling rules are more favourable for the production output of trial items.

In the simulation, there are four rules used i.e Lowest Value First (LVF), First Come First Serve (FCFS), Highest Value First (HVF) and Last in First Out (LIFO). The value is determined by setting JPF 113155 as the highest priority, high-volume Kanban items as the second priority and the non-Kanban items as the last priority.

By changing the scheduling rules, the results of the simulation can be shown in Figure 4.3. From this chart, by running four-week simulations, FCFS provide the highest utilisation of the facilities. However, basically, there are no significant differences amongst the results (all figures around 85%). These results may be affected by the type of production flow employed at the Drug Process Plant. As the manufacturing process forms a single flow, the scheduling rules may not affect the utilisation of facilities very much because all items move to the same production route.

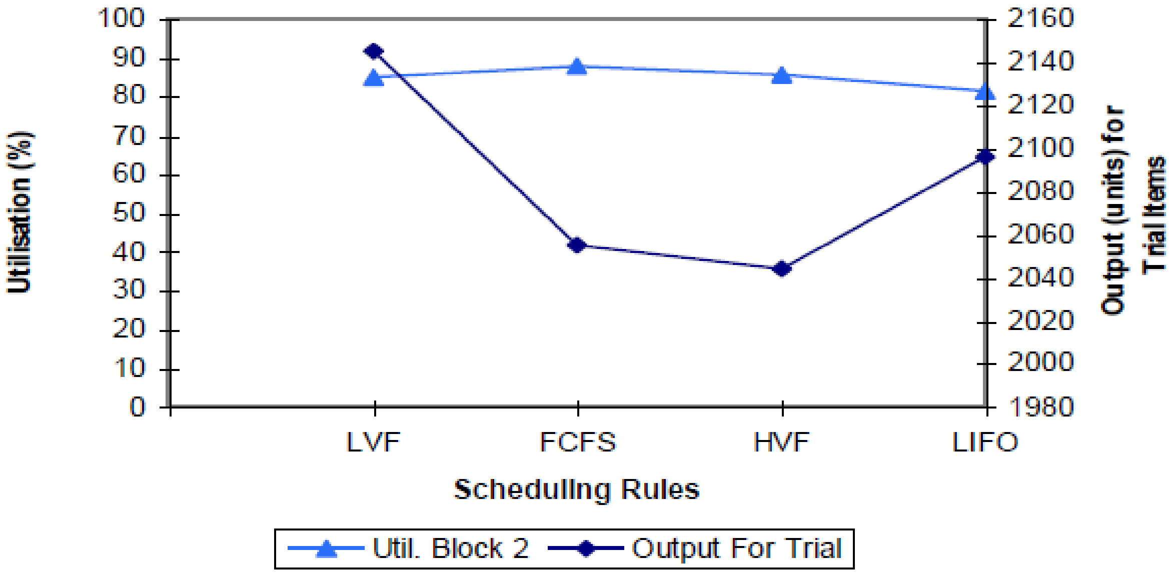


Figure 4.3: The effects of the scheduling rules on the utilisation and the output of the Trial Item

In terms of the output of the trial, LVF provides the highest output. This is not surprising since this rule places the trial item as a priority. Therefore, the flow time required to replenish the orders will be shorter than other rules so the items produced will be higher.

Other interesting results include the fact that that the difference of an increase in output is basically not much different compared to other rules. For example, in a four-week simulation, LVF produces 2150 items or only 100 units (or 25 a week)higher than HVF. This result may not be quite significant compared to the unexpected effects that may occur such as increasing bottle necks due to a change of the scheduling rule. This may happen because the number of items representing high-volume and non-Kanban items is not sufficient to show the differences i.e. only four items each. The use of a small number of items as a representation of a high number of items may not be able to show the effect of waiting or queuing dramatically. For further research, by using the new version of the software, it may be possible to construct a model that involves more representative items for identifying the effects more clearly.

4.1.4. The Effects of Number of Kanbans on Flow Times and Orders Satisfied

The purpose of this experiment was to find the optimal number of Kanbans that minimise the flow time as well as maximise the orders satisfied. By changing the number of Kanbans available in the model file, the effects can be observed as shown in Figure 4.4. Based on this figure the effects of increasing the number of Kanbans for JPF 113155 on both the customer lead time and orders satisfied are minor especially after the number of Kanbans reaches four. However, a decrease of the number of Kanbans drastically affects the customer lead time and the number of satisfied orders. This may happen since the main proportion of arrival orders is 90-unit Kanbans so three Kanbans with the quantity of 30 units are the most reasonable figures to satisfy the orders in terms of both flow time and orders satisfied.

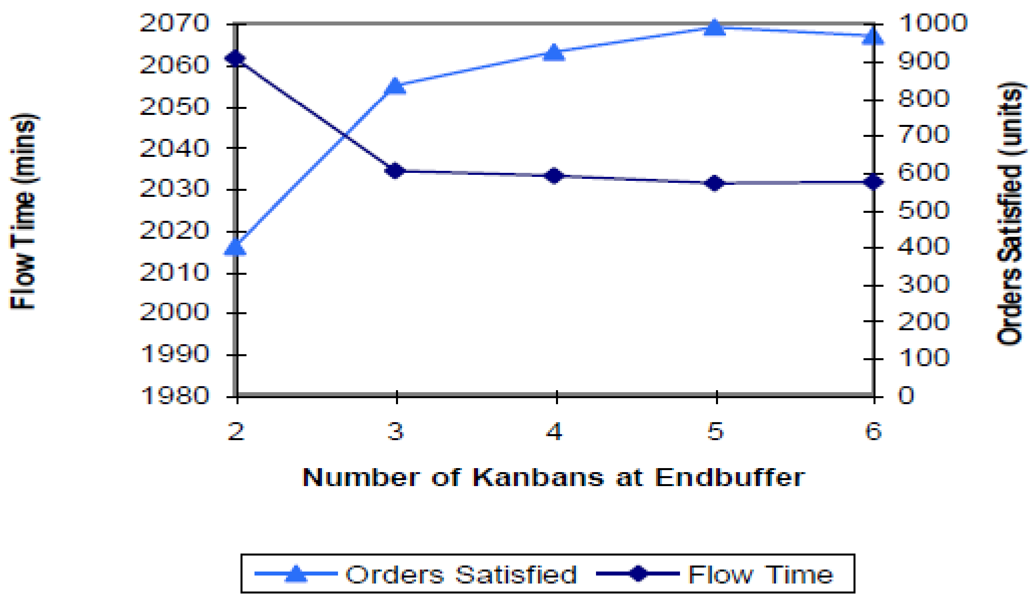


Figure 4.4: The Effects of Number of Kanbans on Flow Times and Orders Satisfied

In addition, since the proportion of Kanban arrivals remains the same during the simulation, an increase of the number of Kanbans does not produce drastic effects on the number of parts satisfied. In conclusion, the number of Kanbans must be determined on the basis of the average periodical orders.

The orders should be stabilised especially for avoiding shortage since shortage can drastically affect the performance of the JIT system as shown in the chart. The role of supervisors is therefore crucial especially for observing the incoming orders. If the orders are fluctuating, they must add or reduce the number of Kanbans so this keeps the system running smoothly.

4.1.5 The New Locations of Buffers

In this experiment, the new buffer locations were investigated since the existing locations were determined based on practical reasons and it is essential to understand the effects to the overall performance of the system. By considering the type of processes and the balance of the processing time at each block, buffer 1 was moved from the existing location (between the automated dispensaries and mixing/blending area) to a new place between the granulation and drying area.

Similarly, buffer 2 was moved from the existing place between the inspection/quality control and blister packing/strip sealing area to a new process between compression/tablet pressing and coating. The new locations of the buffers can be shown as in Figure 4.5.

In the simulation, there are six criteria that were investigated i.e. flow time Kanban items, the flow time of high-volume Kanban items, the flow time of non-Kanban items, WIP, orders satisfied and shortage. Since the processing time at block 2 becomes shorter than the existing design, the batch size can be reduced into 240 units. Consequently, the processing time at block 3 becomes longer so in the experiment the number of Kanbans was increased to six to avoid regular shortage.

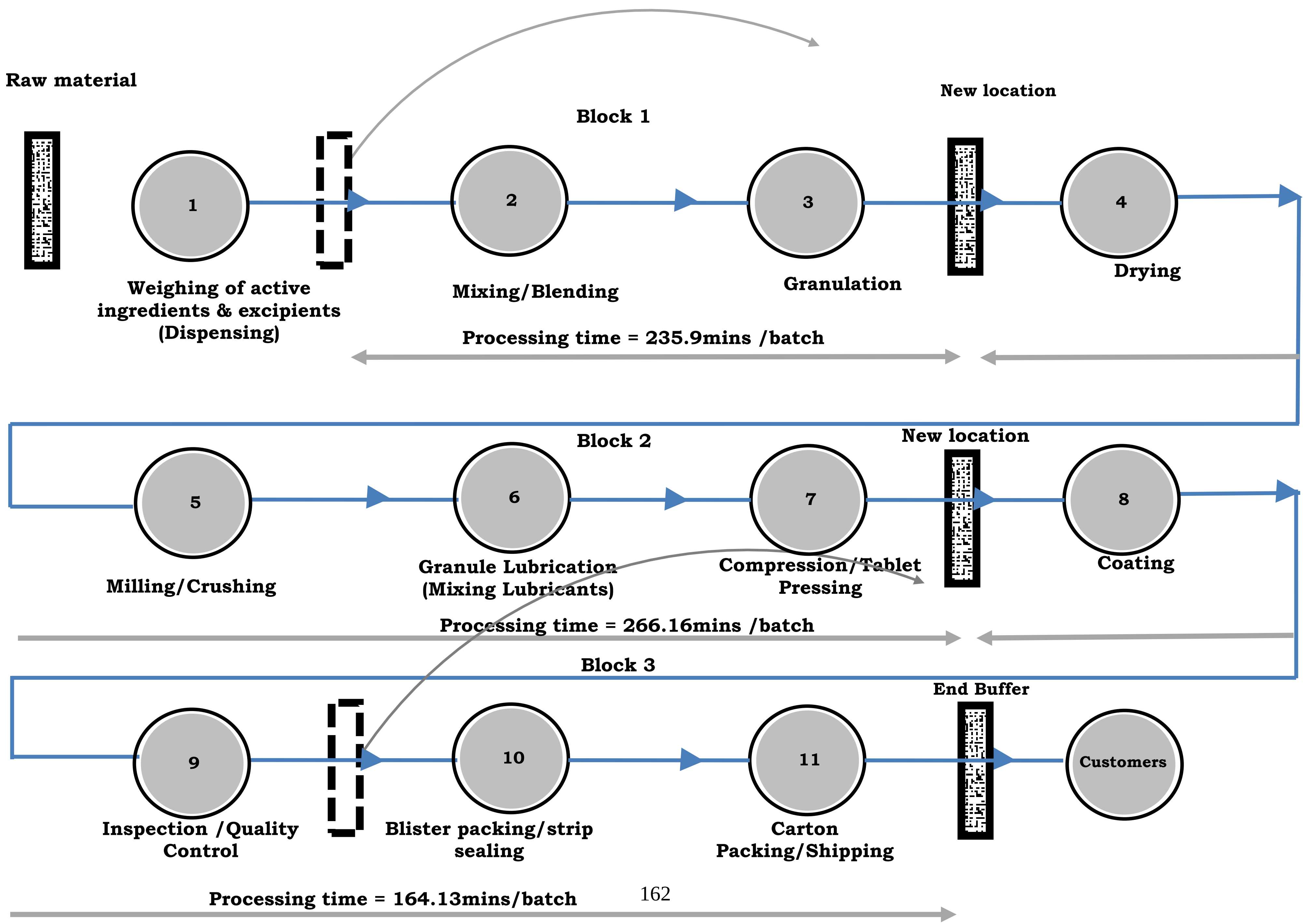


Figure 4.5: The new locations of the buffers

In this experiment, the comparison between the new and the existing design was conducted by using a statistical procedure for comparing two systems shown in Table 4.3 and Table 4.4.

Table 4.3: Statistical Analysis for Comparing the Old and the New System

The existing location of buffers

		Observ.	1	2	3	4	5	6	7	8	9	10	MEANS	STD
TP=	*10*	**Flowtime1**	345.61	456.27	314.90	2354.70	400.72	606.75	432.13	355.66	375.12	374.30	**604.65**	**620.04**
FCFS		**Flowtime2**	620.40	612.92	660.60	1204.30	574.84	1012.50	640.95	1053.50	681.84	542.60	761.15	235.28
K=	*3*	**Flowtime3**	2025.00	2301.00	2447.10	2740.00	2260.20	2866.60	1899.10	3019.80	1759.90	3021.80	2445.10	452.88
T=	*40320*													
Block 1=	*123.00*	**NQ(CustQ)**	0.02	0.12	0.01	1.59	0.03	0.07	0.01	0.01	0.02	0.01	0.19	0.49
Block 2=	*210.17*	**NQ(EndB)**	2.38	2.08	2.48	0.84	2.37	1.99	2.32	2.37	2.30	2.42	2.15	0.49
Block 3=	*20.00*	**NQ(Buff2)**	6.02	5.84	6.74	0.94	5.02	6.22	6.85	6.68	8.32	6.36	5.90	1.94
		NQ(Buff1)	0.89	0.73	0.75	0.71	0.72	0.72	0.85	0.85	0.82	0.73	0.78	0.07
		30	4.00	0.00	4.00	4.00	2.00	1.00	3.00	2.00	2.00	6.00		
		60	7.00	7.00	8.00	9.00	13.00	9.00	11.00	7.00	4.00	8.00		
The trial item		**90**	14.00	15.00	13.00	13.00	9.00	15.00	12.00	16.00	17.00	11.00		
		120	2.00	5.00	2.00	1.00	3.00	2.00	1.00	2.00	4.00	2.00		
		OUTPUT	68.00	73.00	67.00	61.00	67.00	72.00	65.00	72.00	77.00	63.00	68.50	4.95
		OUT 2	6.00	7.00	6.00	5.00	6.00	7.00	6.00	7.00	7.00	6.00		
		OUT 1	6.00	6.00	6.00	5.00	6.00	7.00	6.00	7.00	7.00	6.00		
		SHORTAGE	**0.00**	**-6.00**	**0.00**	**-4.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**-1.00**	**2.16**
		INVENT	4.00	11.00	5.00	-1.00	5.00	12.00	7.00	12.00	7.00	9.00	7.10	4.09

The new location of buffers

		Observ.	1	2	3	4	5	6	7	8	9	10	MEANS	STD
TP=	*6*	**Flowtime1**	389.45	445.38	306.44	374.61	540.06	466.98	2501.30	3235.70	315.09	483.59	**905.86**	**1051.33**
FCFS		**Flowtime2**	626.13	636.87	509.11	694.92	691.27	855.25	566.34	685.19	515.04	1105.00	688.51	177.98
K=	*9*	**Flowtime3**	2122.20	2289.30	1913.80	3270.50	2243.00	1892.80	2334.50	1566.90	1912.90	3255.10	2280.10	566.52
T=	*40320*													
Block 1=	*235.90*	**NQ(CustQ)**	0.12	0.17	0.07	0.09	0.18	0.12	2.21	3.45	0.07	0.18	0.67	1.18
Block 2=	*266.16*	**NQ(EndB)**	1.46	1.37	1.54	1.43	1.23	1.35	0.49	0.00	1.57	1.37	1.18	0.52
Block 3=	*164.13*	**NQ(Buff2)**	6.11	6.23	7.37	7.06	5.18	7.06	2.05	1.43	9.54	6.91	5.89	2.46
Batch Siz	*240*	**NQ(Buff1)**	0.83	0.72	0.81	0.72	0.81	0.86	0.81	0.89	0.81	0.65	0.79	0.07
		30	4.00	0.00	0.00	1.00	1.00	3.00	6.00	4.00	2.00	3.00		
		60	7.00	11.00	13.00	11.00	10.00	10.00	11.00	9.00	13.00	10.00		
		90	14.00	14.00	13.00	12.00	14.00	12.00	8.00	12.00	11.00	11.00		
The trial item		**120**	2.00	2.00	1.00	3.00	2.00	2.00	2.00	2.00	1.00	3.00		
		OUTPUT	68.00	72.00	69.00	71.00	71.00	67.00	60.00	61.00	65.00	68.00	67.20	4.10
		OUT 2	6.00	7.00	7.00	6.00	7.00	6.00	5.00	5.00	6.00	7.00		
		OUT 1	6.00	7.00	7.00	6.00	7.00	6.00	5.00	5.00	6.00	7.00		
		SHORTAGE	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**-5.00**	**0.00**	**0.00**	**-0.50**	**1.58**
		INVENT	4.00	12.00	15.00	1.00	13.00	5.00	0.00	-1.00	7.00	16.00	7.20	6.39

Table 4.3 Contd.

1. Comparison of flow time 1

Observ.	1	2	3	4	5	6	7	8	9	10	MEANS	STD
OLD	345.61	456.27	314.90	2354.70	400.72	606.75	432.13	355.66	375.12	374.30	**604.65**	**620.04**
NEW	389.45	445.38	306.44	374.61	540.06	466.98	2501.30	3235.70	315.09	483.59	**905.86**	**1051.33**
difference	-13.54	10.89	8.46	1980.09	-139.34	139.77	-2069.17	-2880.04	60.03	-109.29	**-301.21**	**1318.43**

t9,.975=	2.26216	sd-bar=	416.92559
H= t9,.975*sd-bar=	943.151	Interv1=	-1244.37
Interval=difference-bar	+/- H	Interv2=	641.94

2. Comparison of flow time 2

Observ.	1	2	3	4	5	6	7	8	9	10	MEANS	STD
OLD	620.40	612.92	660.60	1204.30	574.84	1012.50	640.95	1053.50	681.84	542.60	**761.15**	**235.28**
NEW	626.13	636.87	509.11	694.92	691.27	855.25	566.34	685.19	515.04	1105.00	**688.51**	**177.98**
difference	1.33	-23.95	151.49	509.38	-116.43	157.25	74.61	368.31	166.80	-562.40	**72.64**	**289.41**

t9,.975=	2.26216	sd-bar=	91.520899
H= t9,.975*sd-bar=	207.035	Interv1=	-134.40
Interval=difference-bar	+/- H	Interv2=	279.67

3. Comparison of flow time 3

Observ.	1	2	3	4	5	6	7	8	9	10	MEANS	STD
OLD	2025.00	2301.00	2447.10	2740.00	2260.20	2866.60	1899.10	3019.80	1759.90	3021.80	**2445.10**	**452.88**
NEW	2122.20	2289.30	1913.80	3270.50	2243.00	1892.80	2334.50	1566.90	1912.90	3255.10	**2280.10**	**566.52**
difference	13.30	11.70	533.30	-530.50	17.20	973.80	-435.40	1452.90	-153.00	-233.30	**165.00**	**634.28**

t9,.975=	2.26216	sd-bar=	200.57735
H= t9,.975*sd-bar=	453.737	Interv1=	-288.74
Interval=difference-bar	+/- H	Interv2=	618.74

Table 4.3 Contd.

4. Comparison of Inventory

Observ.	1	2	3	4	5	6	7	8	9	10	MEANS	VAR
OLD	4.00	11.00	5.00	-1.00	5.00	12.00	7.00	12.00	7.00	9.00	**7.10**	**4.09**
NEW	4.00	12.00	15.00	1.00	13.00	5.00	0.00	-1.00	7.00	16.00	**7.20**	**6.39**
difference	0.00	-1.00	-10.00	-2.00	-8.00	7.00	7.00	13.00	0.00	-7.00	**-0.10**	**7.34**

t9,.975=	2.26216	sd-bar=	2.3211587
H= t9,.975*sd-bar=	5.25083	Interv1=	-5.35
Interval=difference-bar +/- H		Interv2=	5.15

5. Comparison of Output

Observ.	1	2	3	4	5	6	7	8	9	10	MEANS	VAR
OLD	68.00	73.00	67.00	61.00	67.00	72.00	65.00	72.00	77.00	63.00	**68.50**	**4.95**
NEW	68.00	72.00	69.00	71.00	71.00	67.00	60.00	61.00	65.00	68.00	**67.20**	**4.10**
difference	0.00	1.00	-2.00	-10.00	-4.00	5.00	5.00	11.00	12.00	-5.00	**1.30**	**7.02**

t9,.975=	2.26216	sd-bar=	2.2213609
H= t9,.975*sd-bar=	5.02507	Interv1=	-3.73
Interval=difference-bar +/- H		Interv2=	6.33

6. Comparison of Shortage

Observ.	1	2	3	4	5	6	7	8	9	10	MEANS	VAR
OLD	0.00	-6.00	0.00	-4.00	0.00	0.00	0.00	0.00	0.00	0.00	**-1.00**	**2.16**
NEW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-5.00	0.00	0.00	**-0.50**	**1.58**
difference	0.00	-6.00	0.00	-4.00	0.00	0.00	0.00	5.00	0.00	0.00	**-0.50**	**2.88**

t9,.975=	2.26216	sd-bar=	0.9098229
H= t9,.975*sd-bar=	2.05816	Interv1=	-2.56
Interval=difference-bar	+/- H	Interv2=	1.56

20/11/16

By using a confidence level of 95%, the summary results of the comparison for each criterion is shown as in Table 4.4

Table 4.4: The Summary results of the simulation for comparing the old and the new system

CRITERIA	STATISTICAL DIFFERENCE	MEANS DIFFERENCE
1. Customer lead time for the trial item (flow time 1)	no	50% longer than the existing system
2. Customer lead time for the high volume items (flow time 2)	no	10% longer
3. Customer lead time for non-Kanban items (flow time 3)	no	10% shorter
4. Work-In-Progress (WIP)	no	4% more
5. The number of satisfied order (output)	no	3% more
6. Shortage	no	50% more

Based on Table 4.4, some conclusions can be drawn. With some criteria, there are significant differences between the means from both systems such as customer lead time for the trial item and shortage. However, statistically we cannot state that the two systems are different since none of the criteria has the statistical difference for the confidence level of 95%.

This experiment can be continued by investigating other locations for buffers. Unfortunately, because of the capability of the software, most of the investigation for other locations cannot be conducted because the number of entities exceeds the limit and the simulation stops automatically.

4.1.6 Throughput for Signal - To - Noise Ratio

With the help of DOE table (Table 3.5) in chapter 3, total 16 runs are taken. The Screenshot for some of the Runs are shown in Figure 4.6:

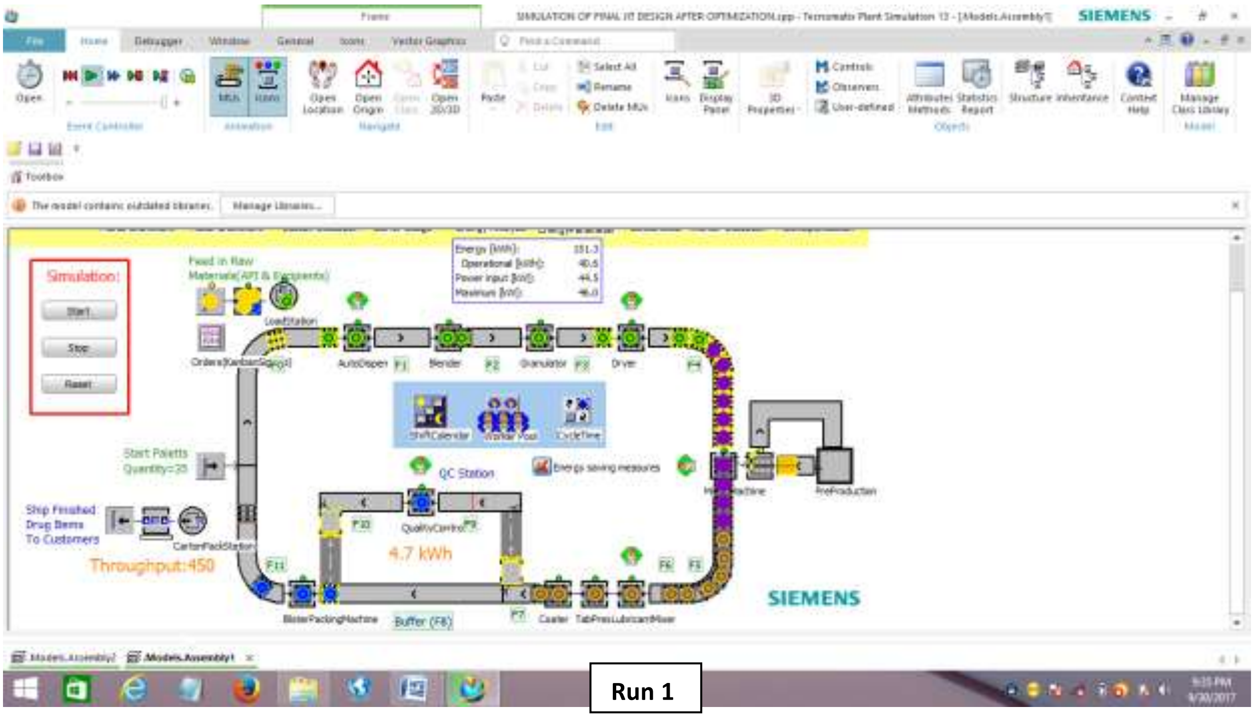


Figure 4.6a: Screen Shot of Run 1

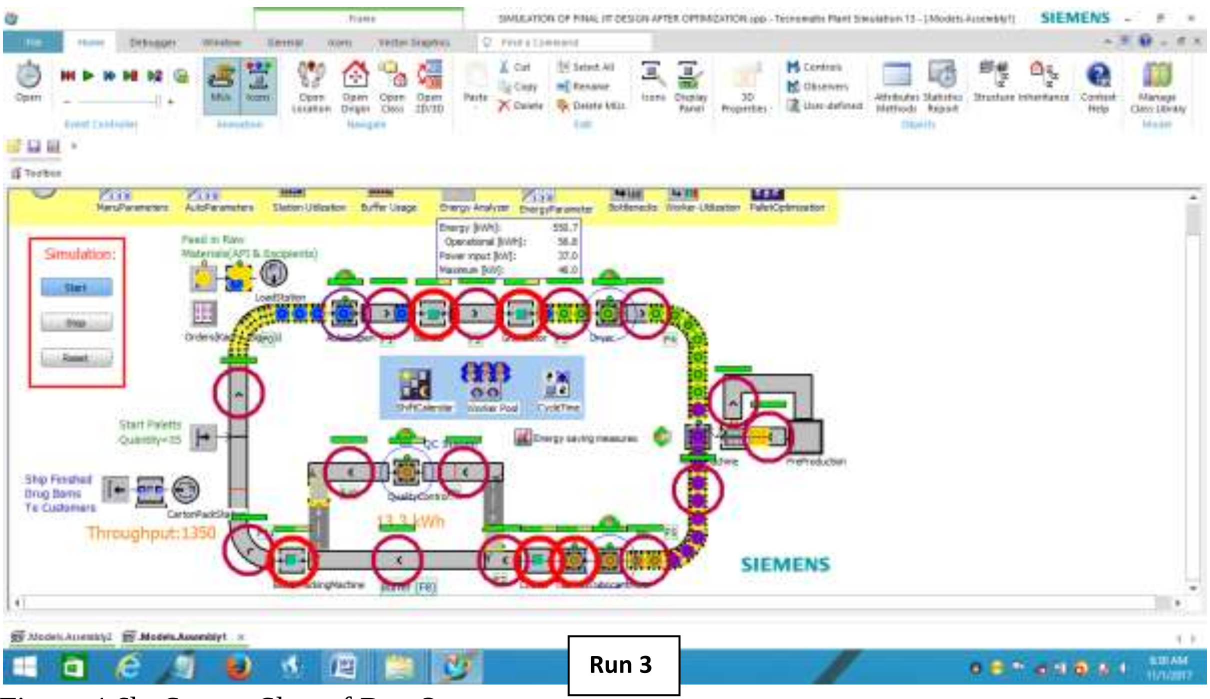


Figure 4.6b: Screen Shot of Run 3

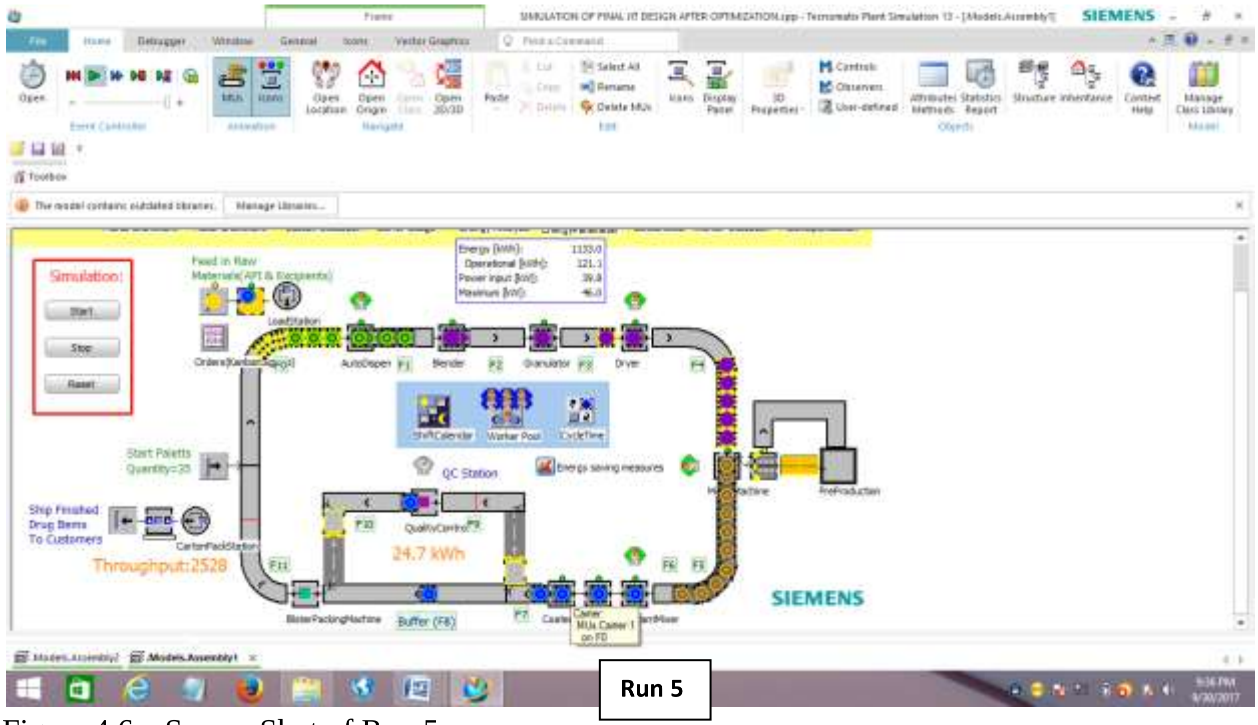


Figure 4.6c: Screen Shot of Run 5

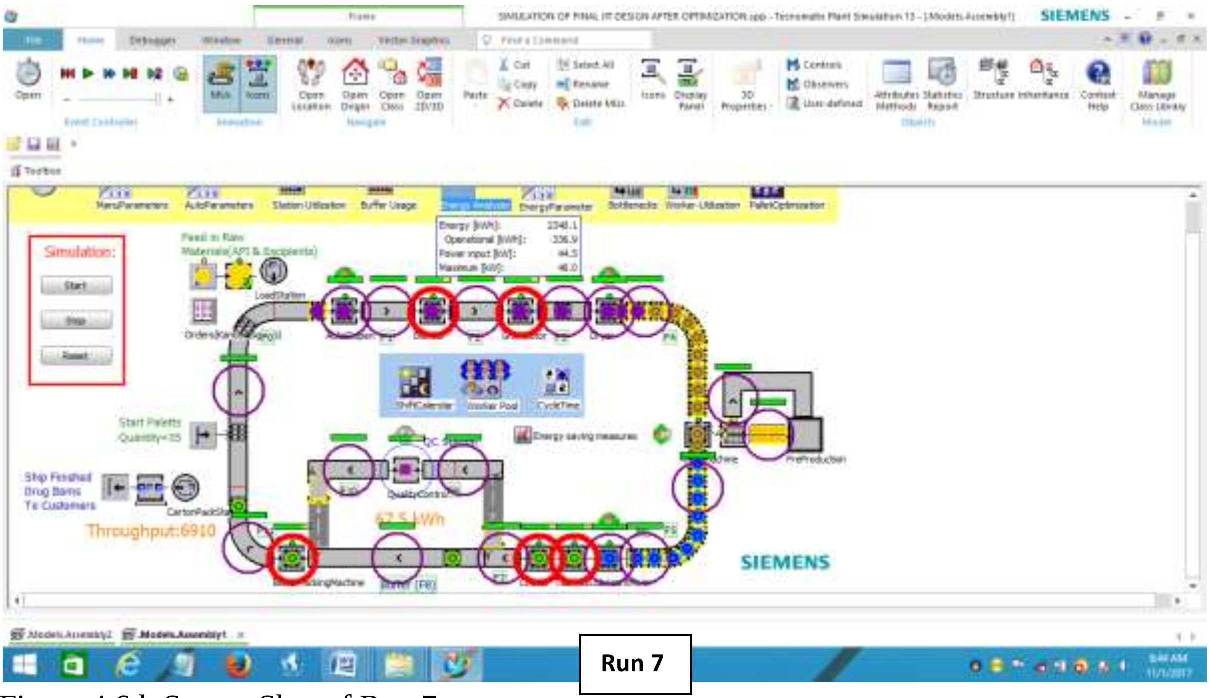


Figure 4.6d: Screen Shot of Run 7

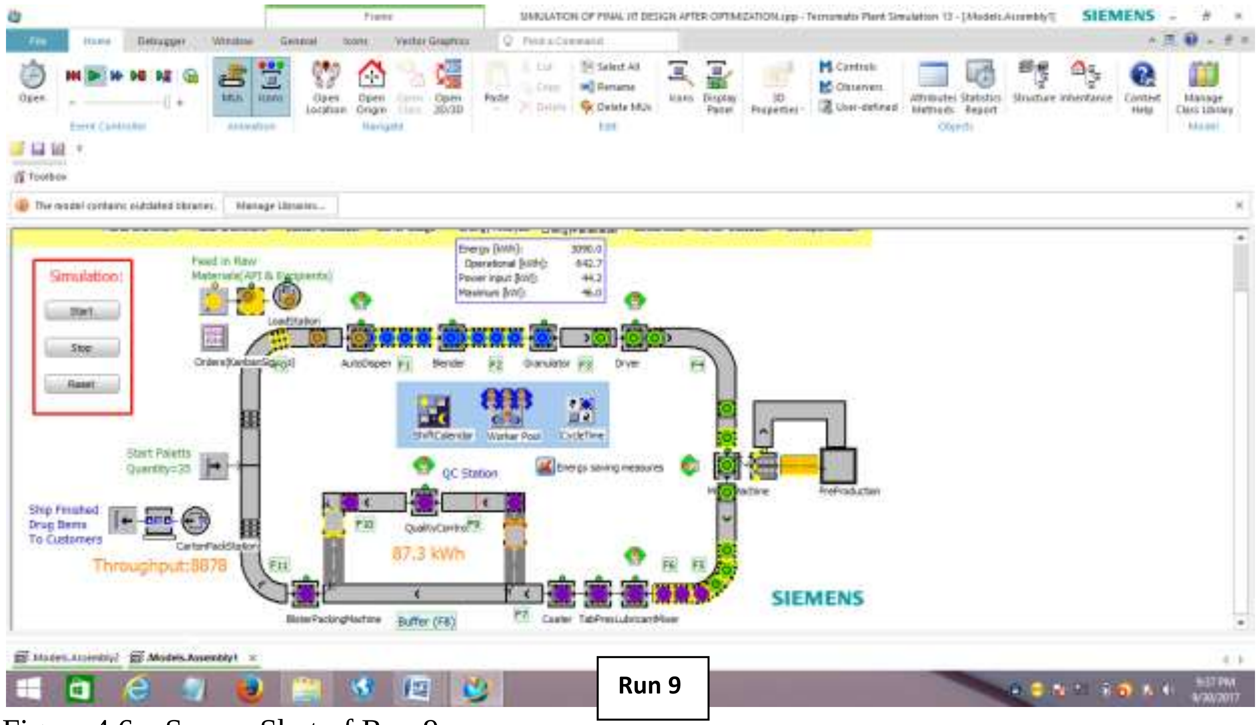


Figure 4.6e: Screen Shot of Run 9

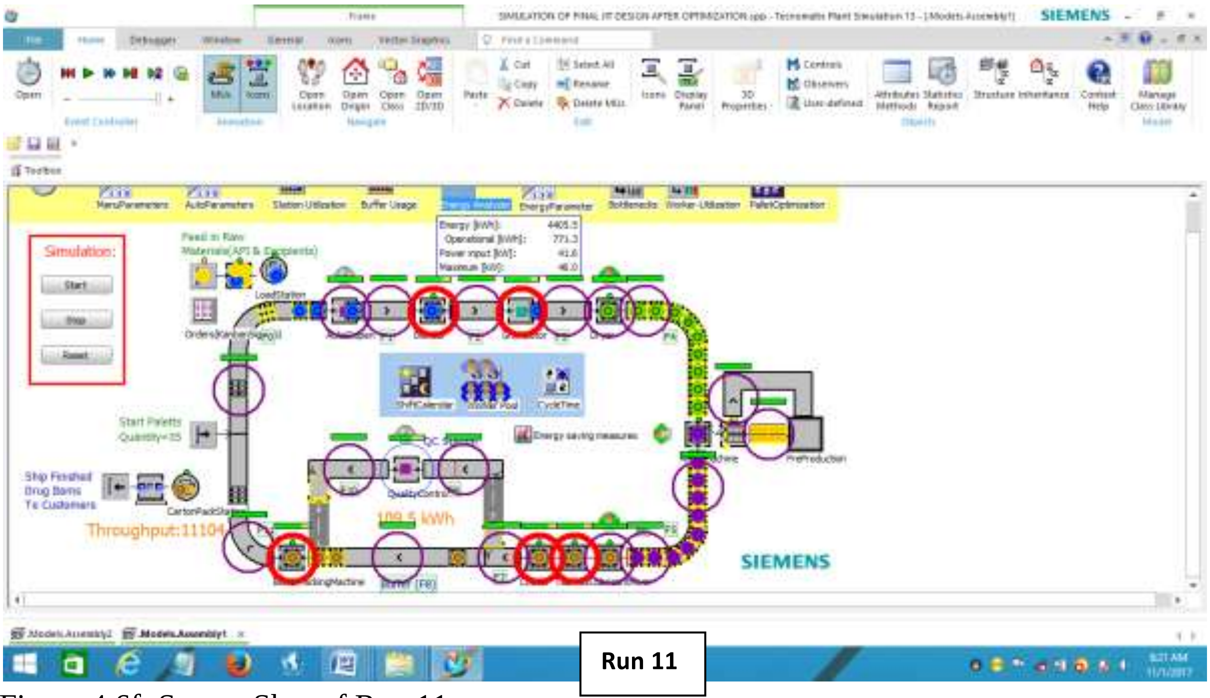


Figure 4.6f: Screen Shot of Run 11

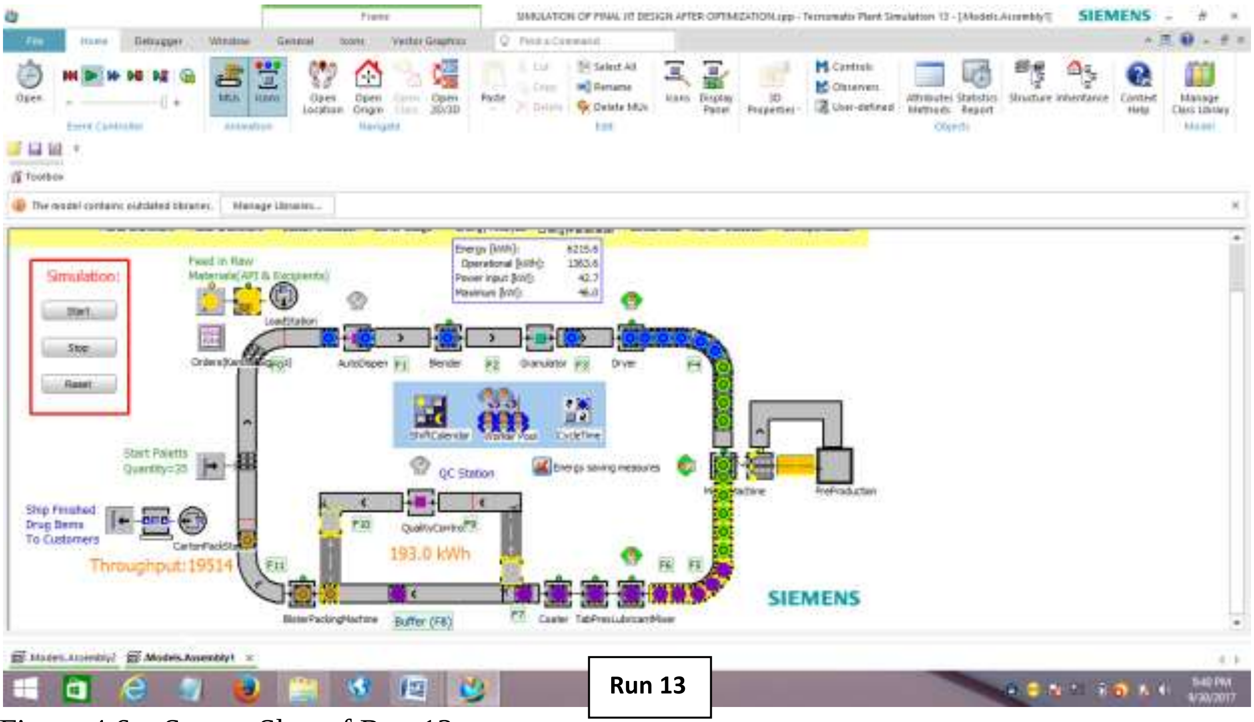


Figure 4.6g: Screen Shot of Run 13

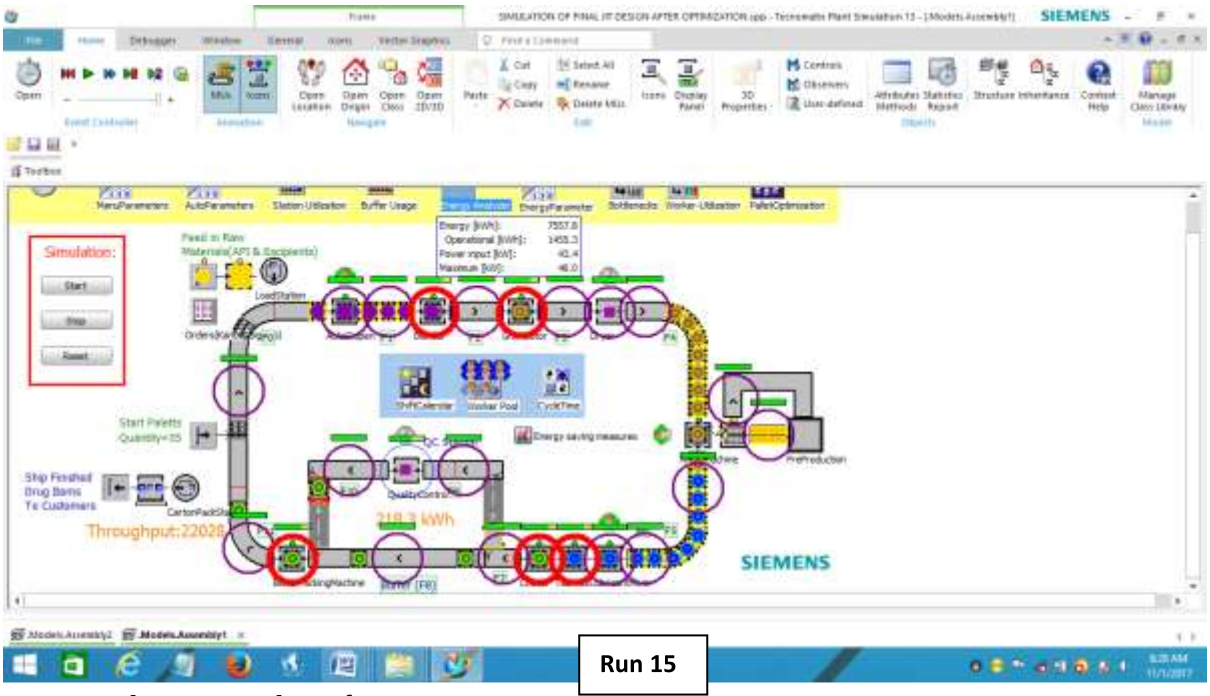


Figure 4.6h: Screen Shot of Run 15

The statistical data shown by the software after taking the 16 runs

The results obtained after 16 runs are shown in Table 4.5. The statistical analysis using these results is done with the aid of SPSS statistical software.

Table 4.5: Result Sheet for Model

RUN	Throughput (Products)
1	00450
2	01050
3	01366
4	15023
5	02528
6	20528
7	06918
8	02314
9	08876
10	21471
11	11110
12	08876
13	19514
14	11110
15	22038
16	00851

The Main Effect plot of Throughput for Signal - to - noise ratio is shown in Fig. 5.6. The line explains the effect of input parameters on the output parameters. In the Main Effect plot for the Throughput, the condition is "larger is better", because the throughput should be high for satisfying the aim of the company. In the graph generated, as the throughput should high the points above the line should be considered. The low level given by number 1 and high level is given by number 2. Hence, from the graph, the optimal solution is obtained. Hence, the low level of Setup Time is above the line, low level of Machine Alteration is above the line and High level of Shift Alteration is above the line. The Shift Alteration shows higher effect on the Throughput. To get the optimum solution for Throughput, Setup Time and Machine,

Alteration should be lower and Shift Alteration should be higher.

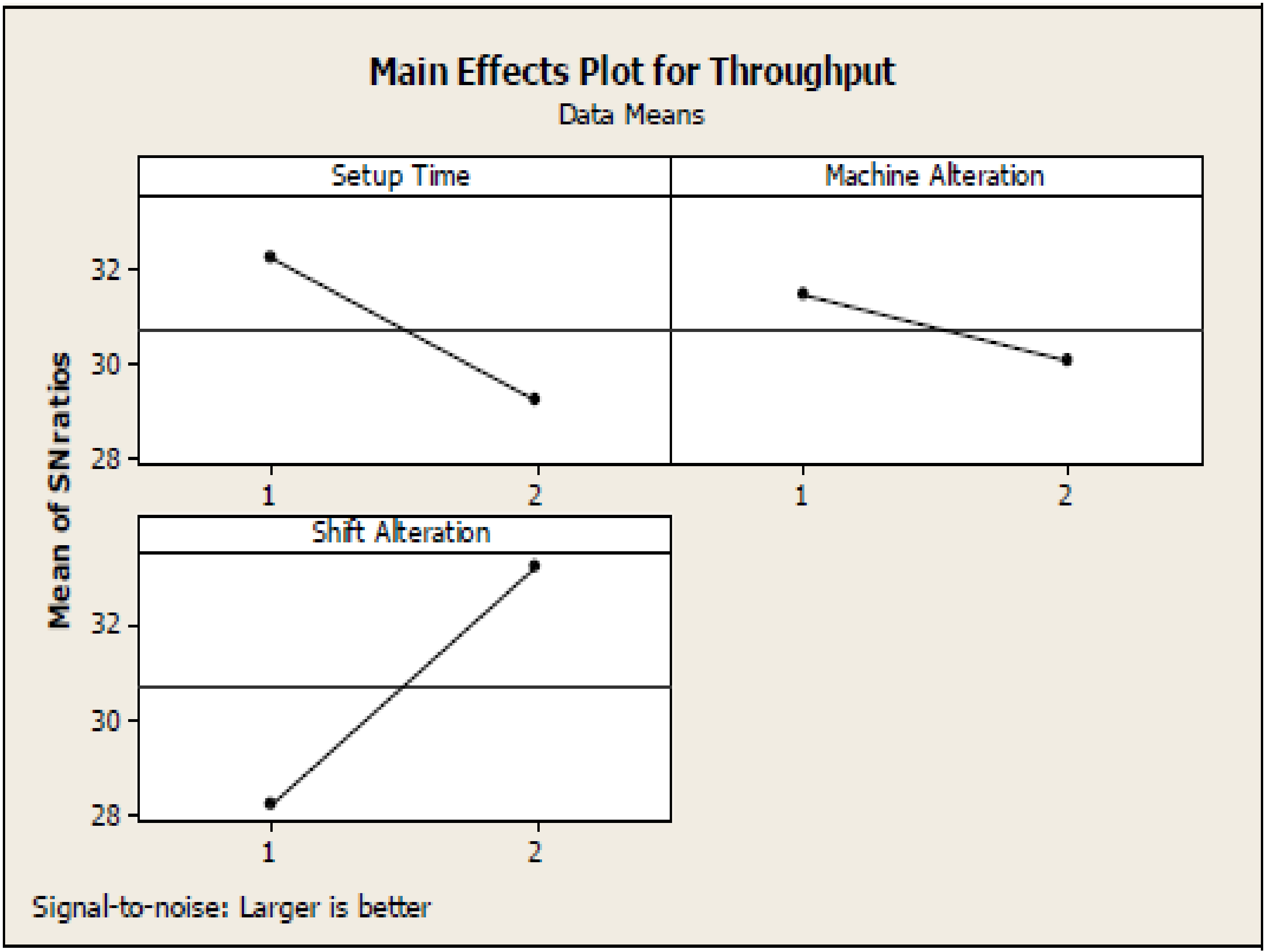


Figure 4.6i: Screen Shot of Main Effect Plot for Throughput

4.1.7 Behavior Analysis of the Production Control

A plot of the production rate and total inventory level on the 'I_1 - I_2' plane are shown in Figure 4.7 and Figure 4.8 respectively where I_1 and I_2 are the loop invariants.

In the production rate plot, a set of iso-curves were drawn. Any point on the production rate iso-curve corresponds to a combination of (I_1, I_2) that determines a specific production rate. The production rate plot looks similar to the production plot for the buffer space allocation. In the total inventory level plot in Figure 4.8, these combinations have different values. The one that has the lowest value is the solution of optimizing total inventory level.

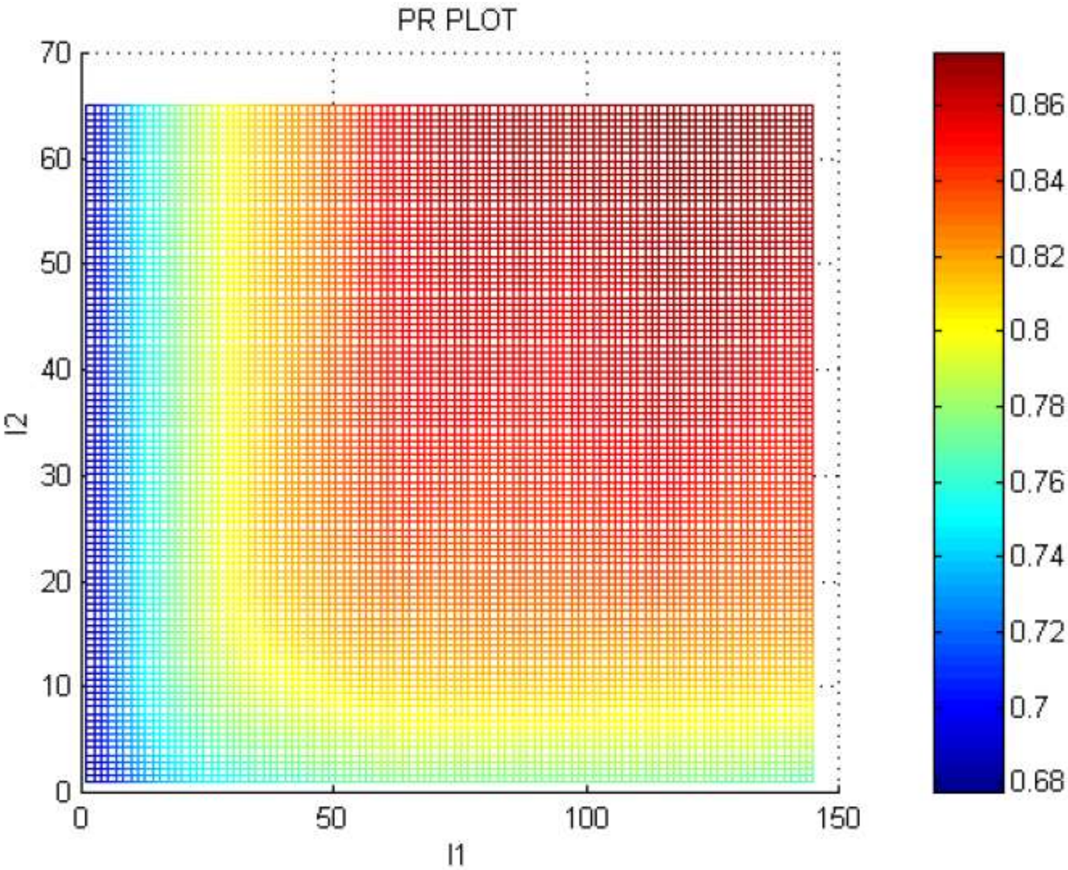


Figure 4.7: Production rate plot

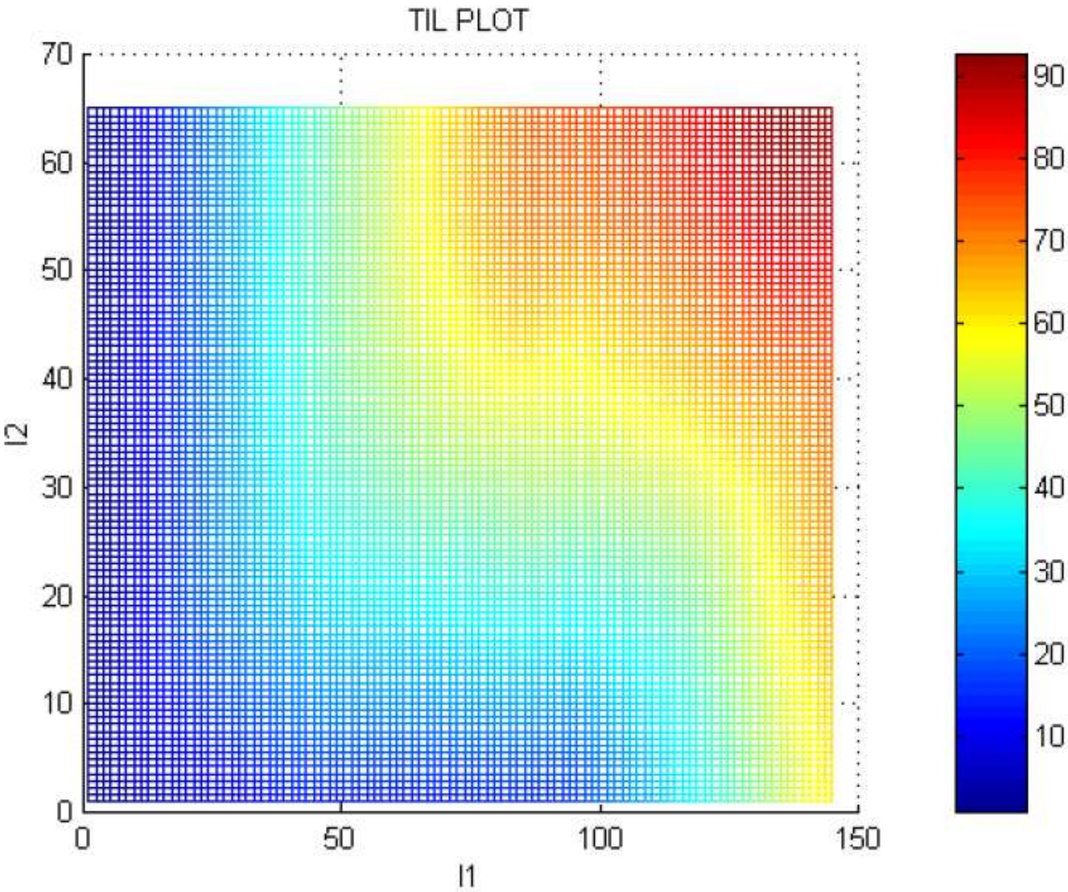


Figure 4.8: Total inventory level plot

Figure 4.9 and Figure 4.10, this research study illustrated an iso-curve mapping method to determine the loop invariants which optimize total inventory level.

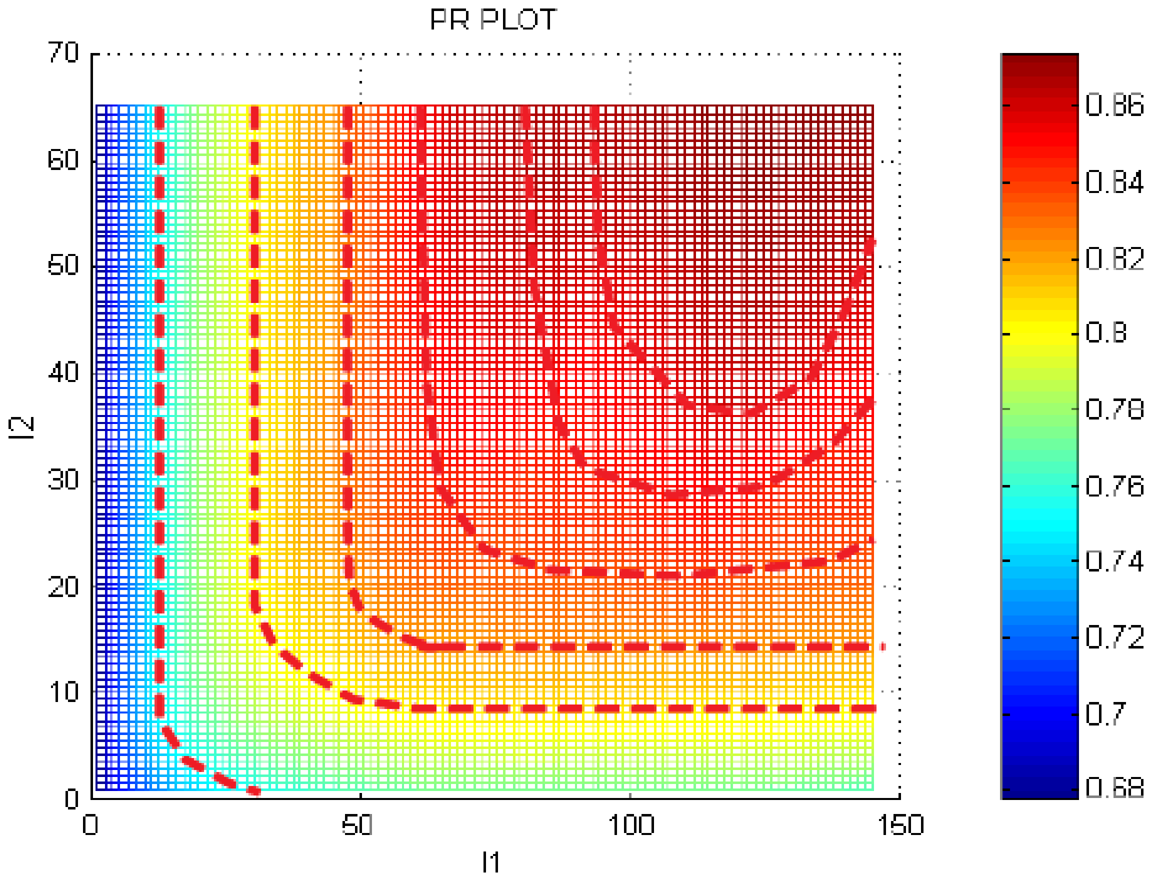


Figure 4.9: Optimal loop invariants of the Drug Process Plant loop control

Target production rates are identified by the corresponding iso-curve in the production rate plot. The iso-curve is mapped to the total inventory level plot and a point which has the lowest value is identified. If there exists multiple points, the one which has the least gradient is selected.

In Figure 4.9 and Figure 4.10, a set of production rate iso-curves are drawn on the production rate plot. These iso-curves are mapped to the total inventory level plot. On each mapped curve, a point of the optimal combination of (I_1; I_2) is illustrated. These points are linked into a dot-arrowed-curve in the total inventory level plot. This curve is defined as optimal invariant curve.

As shown in Figure 4.10, when the production rate is low ($P < 0.75$), the overlapped portion corresponds to the lower-left part of the optimal invariant curve. According to the direction of the optimal invariant curve, increasing I_1 is more effective at increasing the production rate while minimizing the increase of total inventory level than increasing I_2 by the same amount.

This indicates that, when the production rate is low, the Drug Process Plant Kanban loop has dominant effect on production rate control.

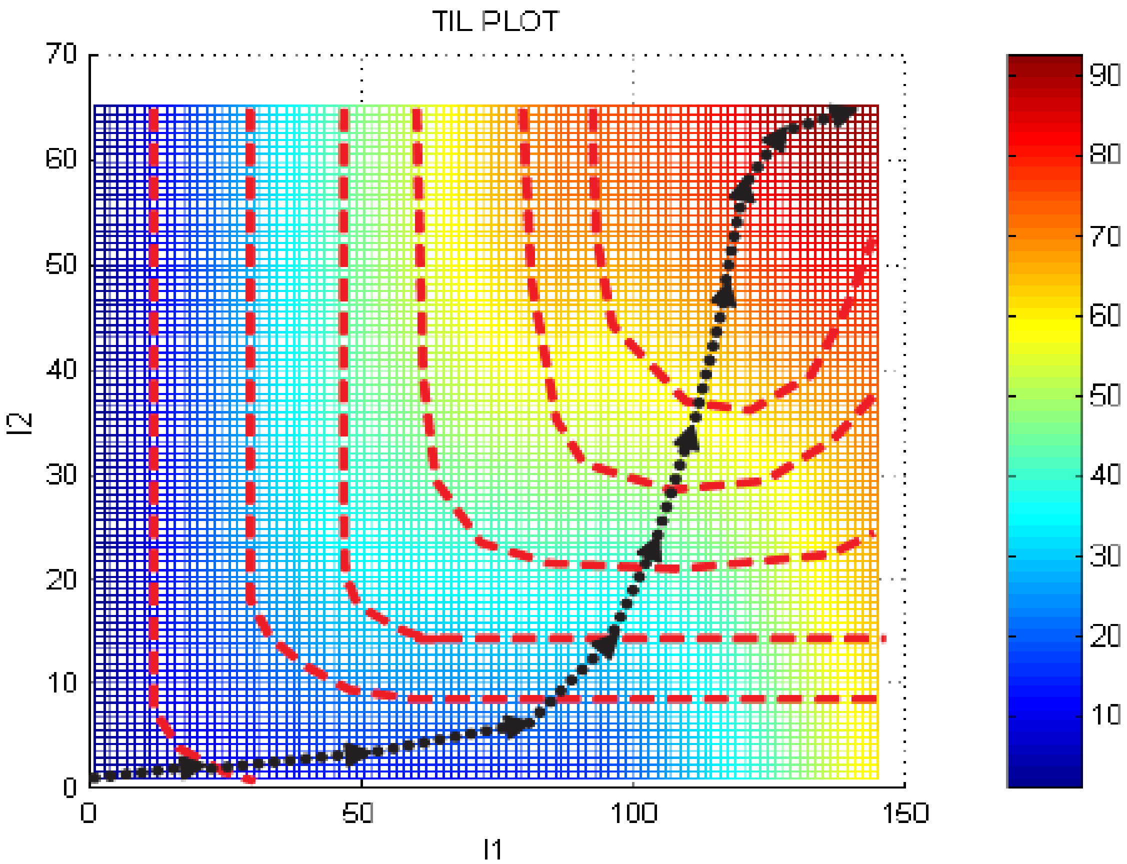


Figure 4.10: Optimal Kanban Loop Invariant Curve of the Drug Process Plant

When production rate is intermediate (0.77 < P < 0.82), the corresponding part of optimal invariant curve indicates that the Drug Process Plant Kanban loop almost has no effect. However, when production rate is high (P > 0.85), the Drug Process Plant Kanban loop retakes the dominant position in controlling production rate and total inventory level when production rate is high.

4.1.8 Sensitivity Analysis

The total inventory cost function is snapshot of the real solutions in which the model parameters (total demand of finished product, finished product demand changing rate, ordering cost, holding cost, etc) are assumed to be static values. It is reasonable to study the sensitivity, i.e. the effects of making changes in the model parameters over a given optimum solution. In this section, numerical sensitivity of the system parameters and input variables are evaluated. The analysis shows the general behavior of the system and illustrates the characteristics of the parameters through the nature of the curvature. The results provide the sensitivity of the model parameters on the total inventory cost and demonstrate the critical point for the cost minimization.

4.1.8.1 Effect of finished product demand on the inventory cost at different raw material orders

In a JIT-Kanban based production system, the finished product demand (D_F) is an important factor. Finished product demand determines the on-hand inventory, especially when finished product demand shifts significantly affect the overall inventory cost. Therefore, it is necessary to perform a sensitivity analysis based on the variation of finished product demand. Keeping the other parameters of the total inventory cost function remain unchanged, the effect of D_F over the total inventory cost is shown in Figure 4.11. It is observed that when the demand of finished product increases, the total inventory cost also increase in a linear fashion, and the optimal raw material orders increases somewhat.

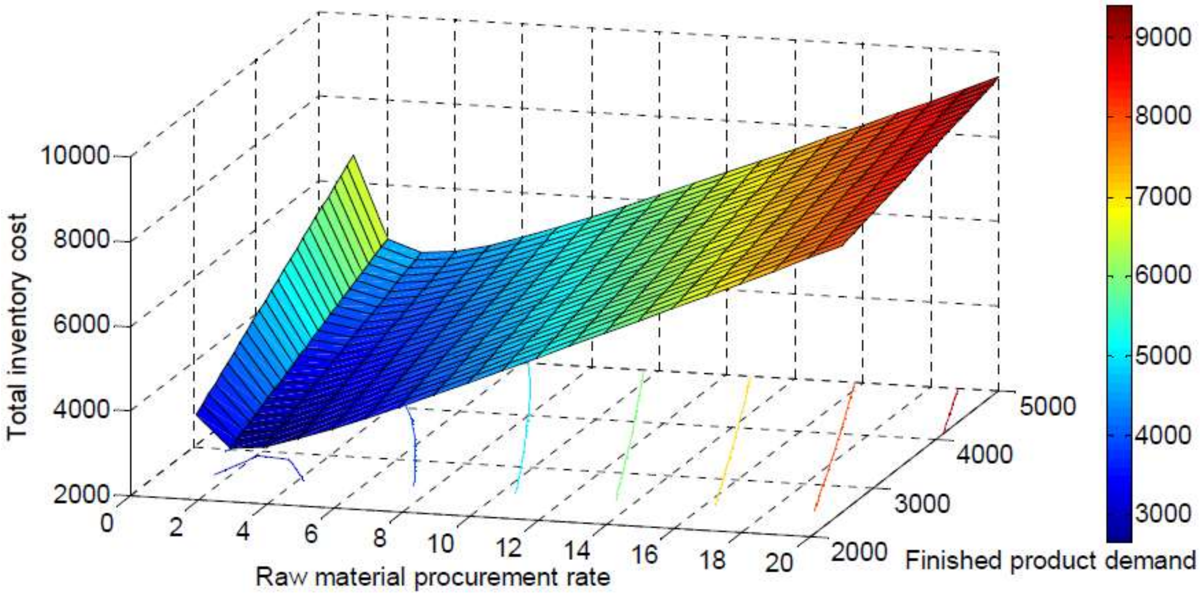


Figure 4.11: Effect of finished product demand on total inventory cost and raw material procurement rate

4.1.8.2 Effect of finished product demand rate on the total inventory cost at different raw material orders

Figure 4.12 shows the finished product demand changing rate and raw material procurement rate VS. The total inventory cost by applying the parametric values and varying the raw material procurement rate from 1 to 20 and finished product demand changing rate from 4 to 20. It is observed that when the demand changing rate of finished product increases, the total inventory cost is decreased inversely but the optimal raw material orders increases.

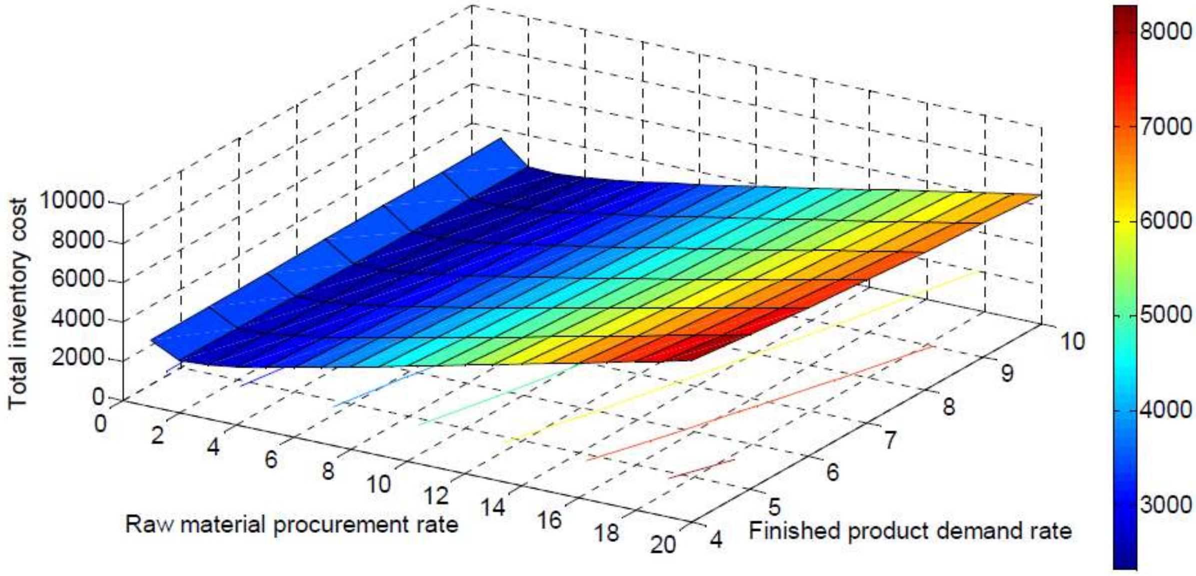


Figure 4.12: Effect of finished product demand rate on both total inventory cost and raw material procurement rate

4.2 Comparative Analysis of the Effect of the New JIT System on Key Manufacturing Performance Measures under Different Experimental Condition Groups

This research demonstrates that the design of the JIT system can significantly affect key manufacturing performance measures. Market, operational, and financial performance measures are utilized in this study in terms of demand fulfillment rate (DFR), cycle-time (CT), and net operating income (NOI) respectively.

This section presents the results and statistical analyses of the data collected from the ARENA simulation experiment. The initial data were downloaded into Excel and then uploaded into SPSS for statistical analysis. After screening the data for missing data and outliers, Multivariate Analysis of Variance (MANOVA) was performed to determine whether or not a factor and/or its interaction is statistically significant in determining overall performance. The results were further analyzed using a more detailed Univariate Analysis of Variance (ANOVA) post-hoc tests. The remainder of this chapter is organized as follows: the first section presents the raw data collection and descriptive statistics, the second section presents the assumption testing for MANOVA, the third section presents the results of MANOVA and individual ANOVOA, the fourth section discusses the results by experimental factor.

4.2.1 Raw Data and Descriptive Statistics

The product costs were first determined in the simulation model by using different manufacturing system alternatives: Mass Production System (MPS), Materials Requirements

Planning System (MRP), and Just in Time Manufacturing System (JIT). The product cost data were then input into the Integer Linear Programming (ILP) model to determine the optimal product mix, which was then input into the simulation model for use in the product mix decision. Average performance data were collected for 60 replications of 30 days each for 27 experimental condition groups, representing three different Manufacturing Systems (MAS) (Mass Production System (MPS), Materials Requirements Planning System (MRP), and Just in Time Manufacturing System (JIT)), three levels of manufacturing overhead (low, medium, high), and three levels of product mix complexity (low, medium, high) for a total of 1620 data points. Table 4.6 shows the number of observations by experimental factor.

Table 4.6: Total Number Between-Subjects Factors

		N
MAS	1	540
	2	540
	3	540
MOH	1	540
	2	540
	3	540
MIX	1	540
	2	540
	3	540

4.2.2 Data Screening and Assumption Tests

Prior to the actual multivariate statistical analysis, the data were screened and its quality assessed. There are four main purposes for screening data prior to conducting a multivariate analysis. The first of these deals with the accuracy of the data collected, the second deals with missing data and the pattern of missing data, the third deals with assessing the effect of extreme values, i.e. outliers, and finally the fit between the data and the assumptions of the specific procedure must be assessed. Because the data were generated through an ARENA simulation model and manually entered into an Excel spreadsheet for sorting and calculations uploading into SPSS, the possibility of researcher error in transferring the data exists.

The raw data uploaded into SPSS can be seen in Appendix E. Table 4.7 shows that there were in fact no missing data at the time of the initial upload into SPSS. For each dependent variable there are exactly 1620 observations.

Table 4.7: Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
DFR_2	1620	100.0%	0	.0%	1620	100.0%
CT_2	1620	100.0%	0	.0%	1620	100.0%
NOI_2	1620	100.0%	0	.0%	1620	100.0%

A visual review of the data prior to uploading into SPSS revealed no missing data, and any unrealistic values were checked against the original ARENA data reports and corrected as necessary. With regards to the accounting calculation for net operating income (NOI), there were occasional offsetting extreme values between replications (accounting periods) due simply to timing differences. In these instances, which numbered no more than three instances per experimental condition group, the extreme values were replaced with the average net value of the two points.

Multivariate outliers consist of unusual combinations of scores on two or more variables and are often subtle and more difficult to detect than univariate outliers. Therefore, the univariate outliers were identified for each group using box plots and stem and leaf plots. Univariate outliers are defined as cases with unusual or extreme values at one or both ends of a sample distribution. There are three fundamental causes for outliers: 1) data entry errors were made by the research, 2) the subject is not a member of the population for which the sample is intended, or 3) the subject is simply different from the remainder of the sample.

It is important to note that both ANOVA and MANOVA are robust to moderate violations of normality, provided the violation is created by skewness and not by outliers. The real danger of outliers is that they can significantly distort the results of statistical tests, due to the fact that many statistical procedures rely on squared deviations from the mean. Therefore, an observation falling far from the rest of the distribution mean could potentially exert a great deal of influence on the results of the statistical test. A single outlier, if extreme enough could influence a false significance or insignificance as well as seriously affect the values of correlation coefficients.

In this section, results of the univariate outlier screening is presented for each dependent variable within each group. Univariate outliers were detected by means of graphical methods.

Since the number of outlying cases for each variable in each group was fairly small, i.e. less than 5 in all groups, and the sample size is relatively large, i.e. 60 replications, the outliers can either be deleted or altered to a value that is within the extreme value of the tail of the accepted distribution. In order to ensure the equality of sample size between experimental condition groups, and robustness to minor violations of normality and homoscedasticity, the latter option was chosen.

Three general assumptions of multivariate statistical testing were made. The first of these assumptions is that of a normal sample distribution. Prior to examining multivariate normality, univariate normality was tested.

Moreover, because data were collected for 60 replications for each of the 27 experimental groups (3 experiment factors with 3 levels each), there are a total of 1,620 data points utilized for this analysis. With equal or unequal sample sizes and only a few DVs, a sample size of 20 in the smallest cell was sufficient to ensure robustness to violations of univariate and multivariate normality. Therefore, given equal sample sizes of 60 in each group, normality was assumed under the central limit theorem.

Univariate normality refers to the extent to which all observations in the sample for a given variable in a given group are distributed normally. Among the non-graphical test that can be used are the chi-square goodness of fit and the Kolmogorov-Smirnov test. The chi-square test suffers from the defect of depending on the number of intervals used for the grouping. Therefore, the Kolmogorov-Smirnov statistic with Lilliefos significance level was utilized to test univariate normality for each dependent variable in each group. The Kolmogorov-Smirnov statistic tests the null hypothesis the population is normally distributed and an associated significance level serves as an indication that the variable is not normally distributed. The Kolmogorov-Smirnov test statistics for each variable in each experimental condition group, with insignificance in all cases indicate normality of distributions.

The second assumption, linearity, presupposes that there is a straight line relationship between any two variables. It is a critical assumption in multivariate analyses due to the fact that many of the techniques are based on linear combinations of the variables. The Pearson correlation coefficient (r) is the most commonly used bivariate correlation technique, measuring the association between two quantitative variables. Table 4.8 shows significance of this measure for all bivariate combinations of the dependent variables, indicating a significant linear relationship.

Table 4.8 Correlations

		DFR_2	CT_2	NOI_2
DFR_2	Pearson Correlation	1	-.578**	-.406**
	Sig. (2-tailed)	.	.000	.000
	N	1620	1620	1620
CT_2	Pearson Correlation	-.578**	1	.590**
	Sig. (2-tailed)	.000	.	.000
	N	1620	1620	1620
NOI_2	Pearson Correlation	-.406**	.590**	1
	Sig. (2-tailed)	.000	.000	.
	N	1620	1620	1620

**. Correlation is significant at the 0.01 level (2-tailed).

The final assumption of homoscedasticity is that the variability in scores for one continuous variable will be roughly the same across all values of another continuous variable. This concept is analogous to the univariate assumption of homogeneity of variance. Homoscedasticity is closely related to the assumption of normality, because if the assumption of multivariate normality is met, two variables must be homoscedastic (Golhar & Satish, 2013). Although subjective in nature, homoscedasticity is sometimes best assessed through the examination of bivariate scatterplots.

Figure 4.13 presents the bivariate scatterplots for the three dependent variables. The output for the three dependent variables indicates a non-elliptical shapes between DFR_2 and the other two variables CT_2 and NOI_2. The bivariate scatter plots between CT_2 and NOI_2, on the other hand, show a somewhat elliptical pattern. Since the use of bivariate scatterplots is fairly subjective in examining linearity (Mertler & Vannatta, 2014), we will not place reliance on this test. However, reliance can be placed on the Pearson's correlation coefficients above, indicating that a linear relationship does indeed exist.

In multivariate cases, homoscedasticity may be assessed statistically using Box's M test for equality of variance-covariance matrices. This test evaluates the hypothesis that covariance matrices are equal, and if the observed significance level for the Box's M test is small, i.e. $p<.05$, one should reject H0.

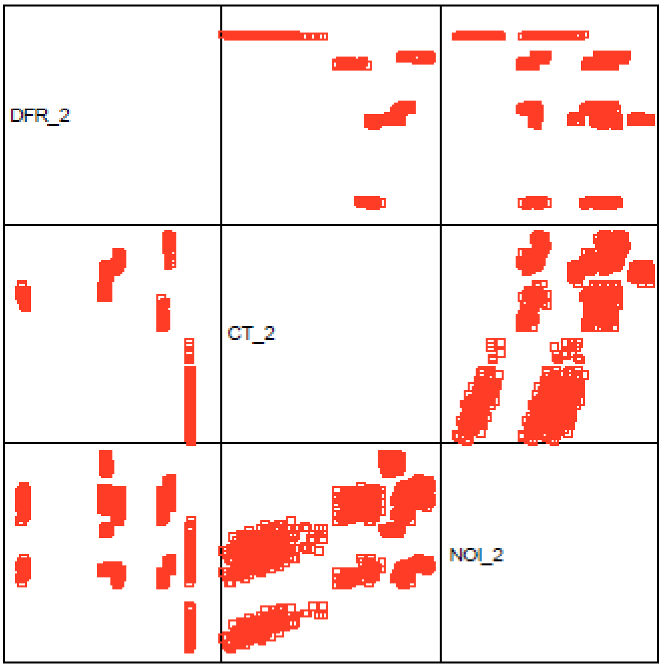


Figure 4.13: Bivariate Scatterplots

Box's test in Table 4.9 is significant, so Pillai's Trace statistic will be used in evaluating the multivariate tests.

Table 4.9: Box's Test of Equality of Covariance Matrices

Box's M	5136.282
F	32.294
df1	156
df2	1173890
Sig.	.000

Tests the null hypothesis that the observed covariance matrices of the dependent variables are equal across groups.
a.Design: Intercept+MAS+MOH+MIX+MAS * MOH+MAS *MIX+MOH * MIX+MAS * MOH * MIX

4.2.3 MANOVA Results

The collected experimental data were first analyzed using a factorial MANOVA procedure. This analysis is meant to determine if the combination of dependent variables – the performance measures: demand fulfillment rate (DFR_2), average cycle time (CT_2), and net operating income (NOI_2) – is significantly affected by the independent variables. The experimental factors include Manufacturing System (MAS), product mix complexity (MIX), and manufacturing overhead levels (MOH). As shown in Figure 4.14, the treatment effects are all significant as are all the bivariate interactions. Moreover, the effect sizes are generally very high.

Measures of effect size in MANOVA and ANOVA are measures of the degree of association between the effect, either the main effect or any interactions, and the dependent variable(s). It is the proportion of variance in the dependent variable that is attributable to each effect. There are several commonly used measures for effect size, the most common being Eta Squared ($ή^2$) and Partial Eta Squared ($ήp^2$). One of the problems with $ή^2$ is that the values of each effect are dependent upon the number of other effects and the magnitude of those effects. Partial Eta Squared presents an alternative computation of Eta Squared for each individual effect (Golhar & Satish, 2013). Partial Eta Squared is defined as: $ήp^2$ = SSeffect / (SSeffect + SSerror), and is a standard output in SPSS. It should be noted that sums are $ήp^2$ values are not additive, i.e. they do not sum the amount of dependent variable variance accounted for by the independent variables, and therefore it is possible for the sum of $ήp^2$ values to be greater than zero. The $ήp^2$ values presented in Figure 4.14 clearly show high effect size for all three experimental factors (main effects), especially for Manufacturing System and product mix complexity, which explains 81% and 96% of the variability in the dependent variable combination respectively.

Manufacturing overhead level was associated with 49% of the variability in the dependent variable combination. Although it is low when compared with the other two main effects, it still shows a high relationship.

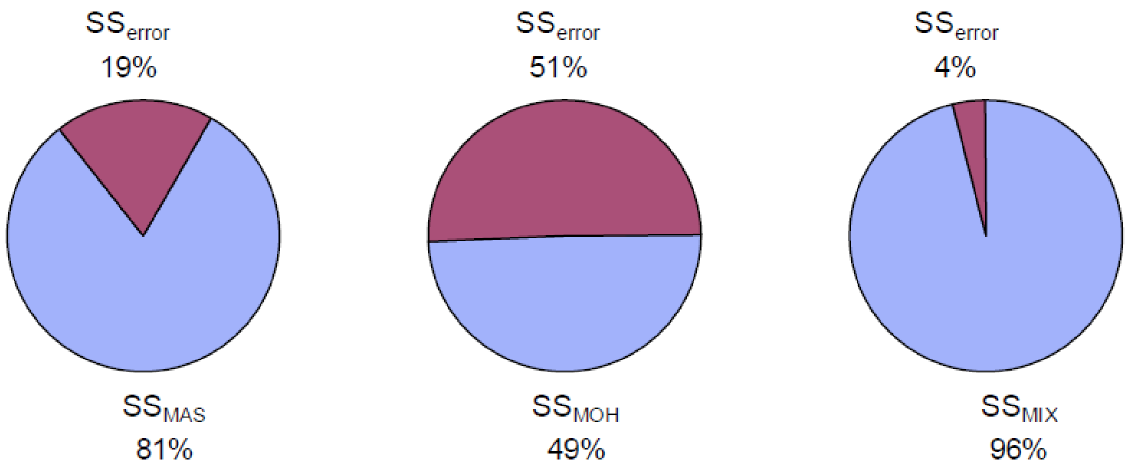


Figure 4.14: Partial Eta Squared Values for MAS, MOH, and MIX Effects

The $ήp^2$ values presented in Figure 4.15 clearly show high effect size for the two-way interaction of Manufacturing System and product mix complexity and a significant, albeit it rather low, effect size for manufacturing overhead level and product mix complexity. The amount of variance in the dependent variable combination explained by these interactions was 73% and 7% respectively. The two-way combination of Manufacturing System and manufacturing overhead level as well as the three way interaction of Manufacturing System, manufacturing overhead level, and product mix complexity was insignificant with less than 1% in effect size.

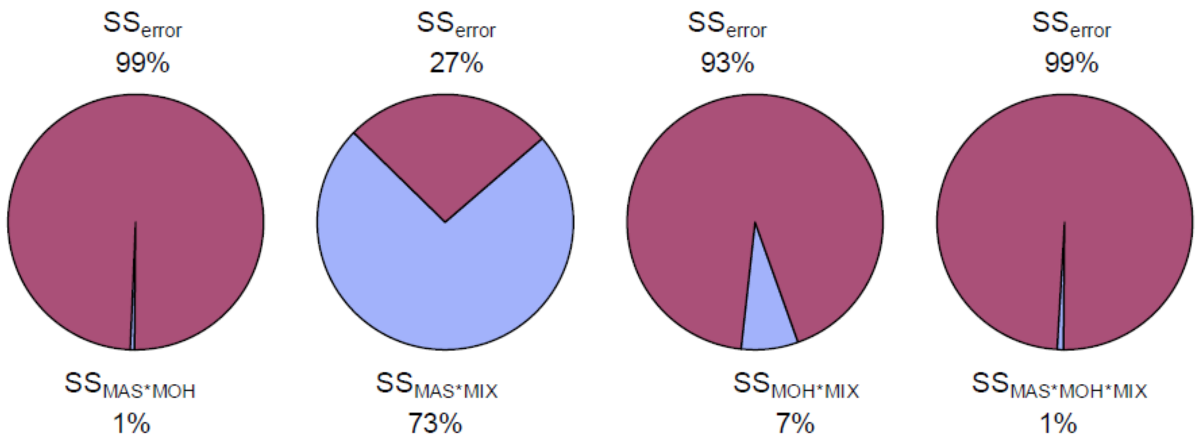


Figure 4.15: Partial Eta Squared Values for MAS, MOH, and MIX Interaction Effects

MANOVA results in Table 4.10 indicate that Manufacturing System (Pillai's Trace=1.62, F(6, 3184)=2268.712, p=.000, $ήp^2$=.810), manufacturing overhead level (Pillai's Trace=.984, F(6, 3184)=514.306, p=.000, $ήp^2$=.492), and product mix complexity (Pillai's Trace=1.925, F(6, 3184)=13603.070, p=.000, $ήp^2$ =.962) significantly affect the combined DV of demand fulfillment rate, average cycle time, and of demand fulfillment rate, average cycle time, and net operating income. net operating income. In addition, the bivariate combinations of Manufacturing System and manufacturing overhead levels (Pillai's Trace=0.019, F(12, 4779)=2.52, p=.000, $ήp^2$=.006), Manufacturing System and product mix complexity (Pillai's Trace=2.20, F(12, 4779)=1095.489, p=.000, $ήp^2$=.733), and manufacturing overhead level and product mix complexity (Pillai's Trace=0.220, F(12, 4779)=31.495, p=.000, $ήp^2$=.073) are all found to significantly affect the combined DV

However, multivariate effect sizes are small for the combinations of Manufacturing System and manufacturing overhead level as well as the combination of manufacturing overhead level and product mix complexity. The three-way interaction of Manufacturing System, manufacturing overhead level, and product mix complexity were not found to have a significant effect on the combined DV of demand fulfillment rate, average cycle time, and net operating income.

Table 4.10: Multivariate Tests

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Intercept	Pillai's Trace	1.000	23118783.276[a]	3.000	1591.000	.000	1.000
	Wilks' Lambda	.000	23118783.276[a]	3.000	1591.000	.000	1.000
	Hotelling's Trace	43592.929	23118783.276[a]	3.000	1591.000	.000	1.000
	Roy's Largest Root	43592.929	23118783.276[a]	3.000	1591.000	.000	1.000
MAS	Pillai's Trace	1.621	2268.712	6.000	3184.000	.000	.810
	Wilks' Lambda	.001	16101.286[a]	6.000	3182.000	.000	.968
	Hotelling's Trace	370.873	98281.457	6.000	3180.000	.000	.995
	Roy's Largest Root	369.217	195931.096[b]	3.000	1592.000	.000	.997
MOH	Pillai's Trace	.984	514.306	6.000	3184.000	.000	.492
	Wilks' Lambda	.016	3703.096[a]	6.000	3182.000	.000	.875
	Hotelling's Trace	62.719	16620.609	6.000	3180.000	.000	.969
	Roy's Largest Root	62.719	33283.011[b]	3.000	1592.000	.000	.984
MIX	Pillai's Trace	1.925	13603.070	6.000	3184.000	.000	.962
	Wilks' Lambda	.000	83260.044[a]	6.000	3182.000	.000	.994
	Hotelling's Trace	1872.499	496212.261	6.000	3180.000	.000	.999
	Roy's Largest Root	1860.086	987085.721[b]	3.000	1592.000	.000	.999
MAS * MOH	Pillai's Trace	.019	2.552	12.000	4779.000	.002	.006
	Wilks' Lambda	.981	2.566	12.000	4209.682	.002	.006
	Hotelling's Trace	.019	2.579	12.000	4769.000	.002	.006
	Roy's Largest Root	.019	7.702[b]	4.000	1593.000	.000	.019
MAS * MIX	Pillai's Trace	2.200	1095.489	12.000	4779.000	.000	.733
	Wilks' Lambda	.001	5231.569	12.000	4209.682	.000	.913
	Hotelling's Trace	213.949	28342.331	12.000	4769.000	.000	.986
	Roy's Largest Root	210.259	83735.577[b]	4.000	1593.000	.000	.995
MOH * MIX	Pillai's Trace	.220	31.495	12.000	4779.000	.000	.073
	Wilks' Lambda	.780	34.513	12.000	4209.682	.000	.079
	Hotelling's Trace	.282	37.330	12.000	4769.000	.000	.086
	Roy's Largest Root	.282	112.208[b]	4.000	1593.000	.000	.220
MAS * MOH * MIX	Pillai's Trace	.020	1.343	24.000	4779.000	.122	.007
	Wilks' Lambda	.980	1.350	24.000	4614.985	.118	.007
	Hotelling's Trace	.021	1.358	24.000	4769.000	.114	.007
	Roy's Largest Root	.020	4.049[b]	8.000	1593.000	.000	.020

a. Exact statistic

b. The statistic is an upper bound on F that yields a lower bound on the significance level.

c. Design: Intercept+MAS+MOH+MIX+MAS * MOH+MAS * MIX+MOH * MIX+MAS * MOH * MIX

Univariate ANOVA and Scheffe post hoc tests were conducted as follow-up tests. ANOVA results indicate that demand fulfillment rate differs significantly for Manufacturing System (F(2, 1593)=290159.67, p=.000, $ήp^2$=.997), product mix complexity (F(2, 1593)=1471806.2, p=.000, $ήp^2$=.999), and the two-way interaction of Manufacturing System and product mix complexity (F(2, 1593)=82837.12, p=.000, $ήp^2$=.995). Average cycle-time differs significantly for Manufacturing System (F(2, 1593)=960.591, p=.000, $ήp^2$=.547), product mix complexity ($F(2, 1593)=20756.710$, $p=.000$, $ήp^2=.963$), and the two-way interaction of Manufacturing System and product mix complexity ($F(2, 1593)=591.132$, $p=.000$, $ήp^2=.597$).

Net operating income differs significantly for Manufacturing System ($F(2, 1593)=1704.381$, $p=.000$, $ήp^2=.682$), manufacturing overhead level ($F(2, 1593)= 31768.716$, $p=.000$, $ήp^2=.976$), and product mix complexity ($F(2, 1593)=20449.024$, $p=.000$, $ήp^2=.963$); the two-way interactions of Manufacturing System and manufacturing overhead level ($F(2, 1593)=5.061$, $p=.000$, $ήp^2 =.013$), Manufacturing System and product mix complexity ($F(2, 1593)=679.384$, $p=.000$, $ήp^2 =.630$), and manufacturing overhead level and product mix complexity ($F(2, 1593)=71.264$, $p=.000$, $ήp^2=.152$); and moderately in the three-way interaction of Manufacturing System, manufacturing overhead level, and product mix complexity ($F(2, 1593)=2.49$, $p=.011$, $ήp^2=.012$). As expected, manufacturing overhead level had an amplification effect and only significantly affected the performance measure of net operating income. As shown in Table 4.11, post-hoc Scheffe tests show significant differences between the three levels of manufacturing overhead and net operating income. This effect presents some interesting implications for manufacturing systems, which will be discussed in greater detail in the final section of this chapter. As well, the amplification effect of manufacturing overhead level can be seen on the charts of cumulative net operating income at the very end of this chapter.

Table 4.11: Net Operating Income Post-Hoc Test

Scheffe[a,b,c]

MOH	N	Subset		
		1	2	3
3	540	68.81071		
2	540		92.52141	
1	540			98.55130
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = 4.201.
a. Uses Harmonic Mean Sample Size = 540.000.
b. The group sizes are unequal. The harmonic mean of the group sizes is used.
Type I error levels are not guaranteed.
c. Alpha = .05.

Manufacturing overhead level did not have a significant impact on demand fulfillment rate ($F(2, 1593)=.038$, $p=.962$, $ήp^2 =.000$) or average cycle-time ($F(2, 1593)=.014$, $p=.986$, $ήp^2$

=.000), nor do any of its interactions significantly affect demand fulfillment rate or average cycle-time. The two-way interactions of Manufacturing System and manufacturing overhead level have an insignificant impact on demand fulfillment rate (F(2, 1593)=.056, p=.994, ήp^{2} =.000) and average cycle-time (F(2, 1593)=.006, p=1.000, ήp^{2} =.000). The interactions of manufacturing overhead level and product mix complexity also have an insignificant effect on demand fulfillment rate (F(2, 1593)=.012, p=1.00, ήp^{2} =.000) and average cycle-time (F(2, 1593)=.005, p=1.000, ήp^{2} =.000). Finally, the three-way interactions of manufacturing system, manufacturing overhead level, and product mix complexity had an insignificant affect on demand fulfillment rate (F(2, 1593)=.057, p=1.00, ήp^{2} =.000) and average cycle-time (F(2, 1593)=.008, p=1.000, ήp^{2}=.000). Table 4.12 presents the summary of the between-subjects effects for this model.

Table 4.12: Test of Between Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	DFR_2	62.838[a]	26	2.417	148280.04	.000	1.000
	CT_2	45262856.302[b]	26	1740879.089	1761.510	.000	.966
	NOI_2	465888.411[c]	26	17918.785	4264.884	.000	.986
Intercept	DFR_2	1053.052	1	1053.052	64607878	.000	1.000
	CT_2	466080178.4	1	466080178.361	471603.69	.000	.997
	NOI_2	12157090.348	1	12157090.348	2893532.4	.000	.999
MAS	DFR_2	9.459	2	4.729	290159.66	.000	.997
	CT_2	1898679.810	2	949339.905	960.591	.000	.547
	NOI_2	14321.816	2	7160.908	1704.381	.000	.682
MOH	DFR_2	1.254E-06	2	6.272E-07	.038	.962	.000
	CT_2	27.157	2	13.578	.014	.986	.000
	NOI_2	266950.628	2	133475.314	31768.716	.000	.976
MIX	DFR_2	47.978	2	23.989	1471806.2	.000	.999
	CT_2	41027206.507	2	20513603.254	20756.710	.000	.963
	NOI_2	171831.926	2	85915.963	20449.024	.000	.963
MAS * MOH	DFR_2	3.661E-06	4	9.152E-07	.056	.994	.000
	CT_2	23.795	4	5.949	.006	1.000	.000
	NOI_2	85.047	4	21.262	5.061	.000	.013
MAS * MIX	DFR_2	5.401	4	1.350	82837.117	.000	.995
	CT_2	2336834.240	4	584208.560	591.132	.000	.597
	NOI_2	11417.652	4	2854.413	679.384	.000	.630
MOH * MIX	DFR_2	7.801E-07	4	1.950E-07	.012	1.000	.000
	CT_2	21.054	4	5.264	.005	1.000	.000
	NOI_2	1197.652	4	299.413	71.264	.000	.152
MAS * MOH * MIX	DFR_2	7.380E-06	8	9.225E-07	.057	1.000	.000
	CT_2	63.738	8	7.967	.008	1.000	.000
	NOI_2	83.690	8	10.461	2.490	.011	.012
Error	DFR_2	2.596E-02	1593	1.630E-05			
	CT_2	1574342.494	1593	988.288			
	NOI_2	6692.942	1593	4.201			
Total	DFR_2	1115.916	1620				
	CT_2	512917377.2	1620				
	NOI_2	12629671.701	1620				
Corrected Total	DFR_2	62.864	1619				
	CT_2	46837198.796	1619				
	NOI_2	472581.353	1619				

a. R Squared = 1.000 (Adjusted R Squared = 1.000)
b. R Squared = .966 (Adjusted R Squared = .966)
c. R Squared = .986 (Adjusted R Squared = .986)

The results of the univariate testing above are further summarized below:

MASa = 0

As shown in Table 4.12, the main factor for the manufacturing system was found to significantly affect all three manufacturing performance measures.

MOHo = 0

As shown in Table 4.12, the main factor for the manufacturing overhead level was found to significantly affect net operating income, but not the other two manufacturing performance measures.

MASa*MOHo = 0

As shown in Table 4.12, the interaction for the manufacturing systems (MAS) and manufacturing overhead level (MOH) was fond to significantly affect net operating income, but not the other two manufacturing performance measures.

MIXm = 0

As shown in Table 4.12, the main factor for product mix complexity was fond to significantly affect all three manufacturing performance measures.

MASa*MIXm = 0

As shown in Table 4.12, the interaction for the (MIX) and product mix complexity was found to significantly affect all three manufacturing performance measures.

MOHo*MIXm = 0

As shown in Table 4.12, the interaction for the manufacturing overhead level and product mix complexity was fond to significantly affect net operating income, but not the other two manufacturing performance measures.

MASa*MOHo*MIXm = 0

As shown in Table 4.12, the interaction for the manufacturing system, manufacturing overhead level (MOH), and product mix complexity was found to significantly affect net operating income, but not the other two manufacturing performance measures.

4.2.4 Practical Implications

Because the primary focus of this study is to examine the impact of the new JIT system on manufacturing performance in the context of a time-based competitive environment, it is necessary to take a more detailed look at this impact on each individual performance measure. The three performance measures were chosen because they represent both internal and external and financial and non-financial measures of performance. Table 4.13 presents a summary of the results in performance measures by manufacturing system alternative.

Table 4.13: Multiple Comparisons by MAS

Scheffe

Dependent Variable	(I) MAS	(J) MAS	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
DFR_2	1	2	-.16799907*	.000245697	.000	-.16860104	-.16739710
		3	-.15545861*	.000245697	.000	-.15606058	-.15485664
	2	1	.16799907*	.000245697	.000	.16739710	.16860104
		3	.01254046*	.000245697	.000	.01193849	.01314244
	3	1	.15545861*	.000245697	.000	.15485664	.15606058
		2	-.01254046*	.000245697	.000	-.01314244	-.01193849
CT_2	1	2	-29.211410*	1.91319765	.000	-33.89883996	-24.52397938
		3	53.468745*	1.91319765	.000	48.78131487	58.15617545
	2	1	29.211410*	1.91319765	.000	24.52397938	33.89883996
		3	82.680155*	1.91319765	.000	77.99272454	87.36758512
	3	1	-53.468745*	1.91319765	.000	-58.15617545	-48.78131487
		2	-82.680155*	1.91319765	.000	-87.36758512	-77.99272454
NOI_2	1	2	-6.3592155*	.124743740	.000	-6.66484388	-6.05358703
		3	-.10501750	.124743740	.702	-.41064593	.20061092
	2	1	6.35921545*	.124743740	.000	6.05358703	6.66484388
		3	6.25419795*	.124743740	.000	5.94856952	6.55982637
	3	1	.10501750	.124743740	.702	-.20061092	.41064593
		2	-6.2541979*	.124743740	.000	-6.55982637	-5.94856952

Based on observed means.

*. The mean difference is significant at the .05 level.

Demand fulfillment rate represents an external (market) non-financial measure of manufacturing performance. It represents the percentage of demand that is ultimately fulfilled by the production system. As presented in Table 4.14, the highest performance in terms of this measure was Materials Requirements Planning System (MRP) (MAS_2) with a rate of 86.6% of demand filled and Just in Time Manufacturing System (JIT) (MAS_3) with 85.4% of demand filled. The worst performance was Mass Production System (MPS) (MAS_1) with 69.8% of demand filled. Although the difference between MRP and JITin terms of demand fulfillment rate was statistically significant, from a practical perspective, this difference may not justify the high cost of implementing an MRP system.

Table 4.14: Demand Fulfillment Rate by MAS

Scheffe[a,b,c]

MAS	N	Subset		
		1	2	3
1	540	.69842651		
3	540		.85388512	
2	540			.86642558
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = 1.630E-05.
a. Uses Harmonic Mean Sample Size = 540.000.
b.The group sizes are unequal.
The harmonic mean of the group sizes is used.
Type I error levels are not guaranteed.
c. Alpha = .05.

As discussed at length in Chapters 2, the primary non-financial measure of success for a JIT manufacturing system is cycle-time, or the total time from receipt of an order to the shipment of the product to the customer. Reducing cycle-time is the primary focus of time-based competition, and is therefore a key internal measure of success. As presented in Table 4.15, the best performance was JIT manufacturing system with an average cycle time of 491.00 minute. The second best performance along this key measure was MPS with an average cycle-time of 544.47 minutes, followed by MRP with an average cycle time of 573.68 minutes.

Table 4.15: Cycle-Time by MAS

Scheffe[a,b,c]

MAS	N	Subset		
		1	2	3
3	540	490.9973		
1	540		544.4661	
2	540			573.6775
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = 988.288.
a. Uses Harmonic Mean Sample Size = 540.000.
b.The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.
c. Alpha = .05.

Net operating income represents the primary internal measure of financial performance. As presented in Table 4.16, the best performance in terms of this performance measure was MRP with an average net operating income of 90.83 (thousands) per accounting period (replication). It should be noted that JIT manufacturing system performed slightly better than MPS over the long run, 84.58 and 84.47 respectively, but the difference was not statistically significant.

Table 4.16: Net Operating Income by MAS

Scheffe[a,b,c]

MAS	N	Subset 1	Subset 2
1	540	84.47306	
3	540	84.57808	
2	540		90.83228
Sig.		.702	1.000

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = 4.201.
a. Uses Harmonic Mean Sample Size = 540.000.
b.The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.
c. Alpha = .05.

Table 4.17: Multiple Comparisons by Product Mix Complexity

Scheffe

Dependent Variable	(I) MIX	(J) MIX	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
DFR_2	1	2	.15082359*	.000245697	.000	.15022161	.15142556
		3	.41631103*	.000245697	.000	.41570906	.41691300
	2	1	-.15082359*	.000245697	.000	-.15142556	-.15022161
		3	.26548745*	.000245697	.000	.26488548	.26608942
	3	1	-.41631103*	.000245697	.000	-.41691300	-.41570906
		2	-.26548745*	.000245697	.000	-.26608942	-.26488548
CT_2	1	2	-352.30321*	1.9131977	.000	-356.990639	-347.615779
		3	-320.63793*	1.9131977	.000	-325.325364	-315.950503
	2	1	352.30321*	1.9131977	.000	347.6157787	356.9906393
		3	31.665276*	1.9131977	.000	26.97784547	36.35270605
	3	1	320.63793*	1.9131977	.000	315.9505030	325.3253636
		2	-31.665276*	1.9131977	.000	-36.35270605	-26.97784547
NOI_2	1	2	-18.783746*	.124743740	.000	-19.08937396	-18.47811711
		3	-23.975737*	.124743740	.000	-24.28136503	-23.67010817
	2	1	18.783746*	.124743740	.000	18.47811711	19.08937396
		3	-5.1919911*	.124743740	.000	-5.49761949	-4.88636264
	3	1	23.975737*	.124743740	.000	23.67010817	24.28136503
		2	5.19199106*	.124743740	.000	4.88636264	5.49761949

Based on observed means.
*. The mean difference is significant at the .05 level.

As shown in the Table 4.17 (Tests of Between-Subjects Effects), product mix complexity and its combination with manufacturing system has a significant effect on all three of the performance measures. As summarized in Table 4.17, product mix complexity has a significant impact on all three performance measures.

Table 4.18: Demand Fulfillment Rate by MIX Level

Scheffe[a,b,c]

MIX	N	Subset		
		1	2	3
3	540	.57897957		
2	540		.84446702	
1	540			.99529061
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed. Based on Type III Sum of Squares The error term is Mean Square(Error) = 1.630E-05.
a.Uses Harmonic Mean Sample Size = 540.000.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.
c. Alpha = .05.

As presented in Table 4.18, product mix complexity has a significant effect on the demand fulfillment rate measure. Average demand fulfillment rate was 99.5% under a love level of product mix complexity and drops to 84.5% under medium level and 57.9% under a high level of product mix complexity.

Table 4.19: Cycle-Time by MIX Level

Scheffe[a,b,c]

MIX	N	Subset		
		1	2	3
1	540	312.0666		
3	540		632.7045	
2	540			664.3698
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed. Based on Type III Sum of Squares.
The error term is Mean Square(Error) = 988.288.
a. Uses Harmonic Mean Sample Size = 540.000.
b.The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.
c. Alpha = .05.

As presented in Table 4.19, product mix complexity has a significant effect on the average cycle-time measure. Average cycle-time was 312.1 minutes under a low level of product mix complexity and increases to 632.7 minutes under medium level and 664.4 minutes under a high level of product mix complexity.

Table 4.20: Net Operating Income by MIX Level

Scheffe[a,b,c]

MIX	N	Subset		
		1	2	3
1	540	72.37465		
2	540		91.15839	
3	540			96.35038
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = 4.201.
a. Uses Harmonic Mean Sample Size = 540.000.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.
c. Alpha = .05.

As presented in Table 4.20, product mix complexity has a significant effect on net operating income. Average net operating income was 72.37 (thousands) under a low level of product mix complexity and increases to 91.16 under medium level and 96.35 under a high level of product mix complexity.

4.3 Summary of Research Results

This study applied a simulation modeling methodology to design a JIT system for drug process plant. It equally examined the impact of different manufacturing system alternatives, manufacturing overhead levels, and product mix complexity levels on manufacturing performance measures. The manufacturing performance measures examined included internal and external as well as financial and non-financial measures of success. These measures were demand fulfillment rate, cycle time, and net operating income. Table 4.21 summarizes the results of this study in terms of these three manufacturing performance measures by manufacturing system alternative and combined weighted score. The combined weighted score is a composite measure of the three primary manufacturing performance measures, whereby two points are assigned to the best performing manufacturing system, one point to the second best performance, no points to the worst performance. Therefore a perfect score of 6 would indicate that the manufacturing system scored the highest along all three manufacturing performance measures.

Table 4.21: Summary of MAS Performance by Experimental Condition Group

MOH Level	MIX Level	Performance Measure											
		Demand Fulfillment Rate			Cycle Time			Net Operating Income			Combined Weighted Score (Maxium 6)		
Low	Low	1	MRP	99.8%	1	JIT	304.91	1	MRP	86.188	1	MRP	5
		2	JIT	99.6%	2	MRP	305.13	2	MPS	85.660	2	JIT	3
		3	MPS	99.2%	3	MPS	326.38	3	JIT	85.603	3	MPS	2
	Medium	1	MRP	91.6%	1	JIT	549.88	1	MRP	105.922	1	MRP	4
		2	JIT	89.1%	2	MPS	698.46	2	MPS	101.416	2	JIT	3
		3	MPS	72.6%	3	MRP	745.55	3	JIT	101.405	3	MPS	2
	High	1	MRP	68.5%	1	MPS	608.89	1	MRP	115.412	1	MRP	4
		2	JIT	67.5%	2	JIT	619.20	2	JIT	103.579	2	JIT	3
		3	MPS	37.7%	3	MRP	670.13	3	MPS	101.771	3	MPS	2
Medium	Low	1	MRP	99.8%	1	JIT	304.91	1	MRP	78.087	1	MRP	5
		2	JIT	99.6%	2	MRP	305.13	2	MPS	77.803	2	JIT	3
		3	MPS	99.2%	3	MPS	325.38	3	JIT	77.480	3	MPS	1
	Medium	1	MRP	91.6%	1	JIT	548.21	1	MRP	100.462	1	MRP	4
		2	JIT	89.1%	2	MPS	698.46	2	MPS	95.799	2	JIT	3
		3	MPS	72.6%	3	MRP	745.55	3	JIT	95.319	3	MPS	2
	High	1	MRP	68.5%	1	MPS	608.89	1	MRP	112.319	1	MRP	4
		2	JIT	67.5%	2	JIT	619.15	2	JIT	98.462	2	JIT	3
		3	MPS	37.7%	3	MRP	670.13	3	MPS	96.620	3	MPS	2
High	Low	1	MRP	99.8%	1	JIT	304.91	1	MRP	53.781	1	MRP	5
		2	JIT	99.6%	2	MRP	305.46	2	MPS	53.507	2	JIT	3
		3	MPS	99.2%	3	MPS	326.38	3	JIT	53.258	3	MPS	1
	Medium	1	MRP	91.6%	1	JIT	548.88	1	MRP	76.283	1	MRP	4
		2	JIT	89.1%	2	MPS	698.46	2	MPS	72.467	2	JIT	3
		3	MPS	72.6%	3	MRP	745.89	3	JIT	71.352	3	MPS	2
	High	1	MRP	68.5%	1	MPS	608.89	1	MRP	89.038	1	MRP	4
		2	JIT	67.5%	2	JIT	618.94	2	MPS	74.866	2	MPS	3
		3	MPS	37.7%	3	MRP	670.13	3	JIT	74.744	3	JIT	2

As can be seen in Table 4.21, none of the manufacturing systems excelled across all three measures indicating that each alternative has its own limitations in terms of performance that must be considered in decision making. This is an important point to note, especially for manufacturing systems.

As can be seen in Figure 4.16, all three manufacturing system alternatives performed nearly equally well when the product mix complexity (MIX) was low. As product mix complexity increased, all three saw a decrease in demand fulfillment rate. However, the falloff in demand fulfillment rate occurred at a far greater rate under Mass Production System (MPS) as compared to the two other manufacturing system alternatives. Although Materials Requirements Planning System (MRP) performed the best across all levels of product mix complexity, Just in Time Manufacturing System (JIT) performed nearly as well along this crucial customer service measure. Because a major focus of this study was to examine the impact of manufacturing system alternatives within the context of today's increasingly time-based competitive environment, the internal manufacturing performance measure of cycle time is of primary importance.

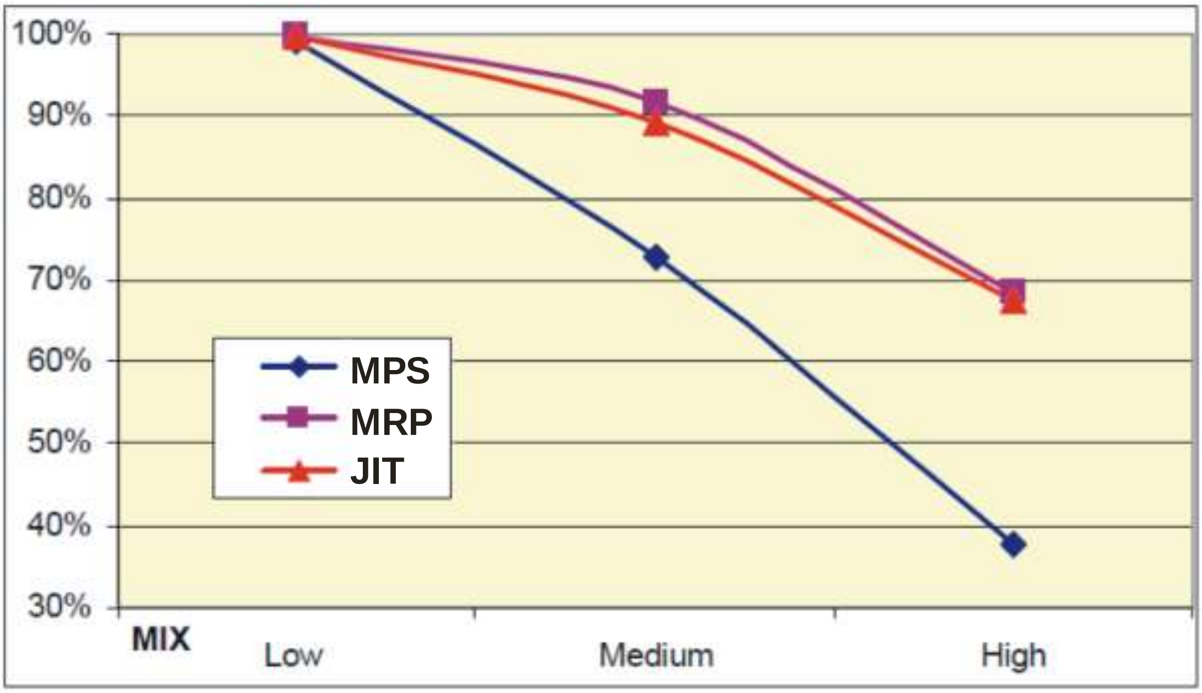


Figure 4.16: Average Demand Fulfillment Rate by MAS

As discussed earlier, cycle-time is the primary success measure for a time-based competitor. In terms of this strategic measure, Just in Time Manufacturing System (JIT) performed the best at nearly all setting of product mix complexity.

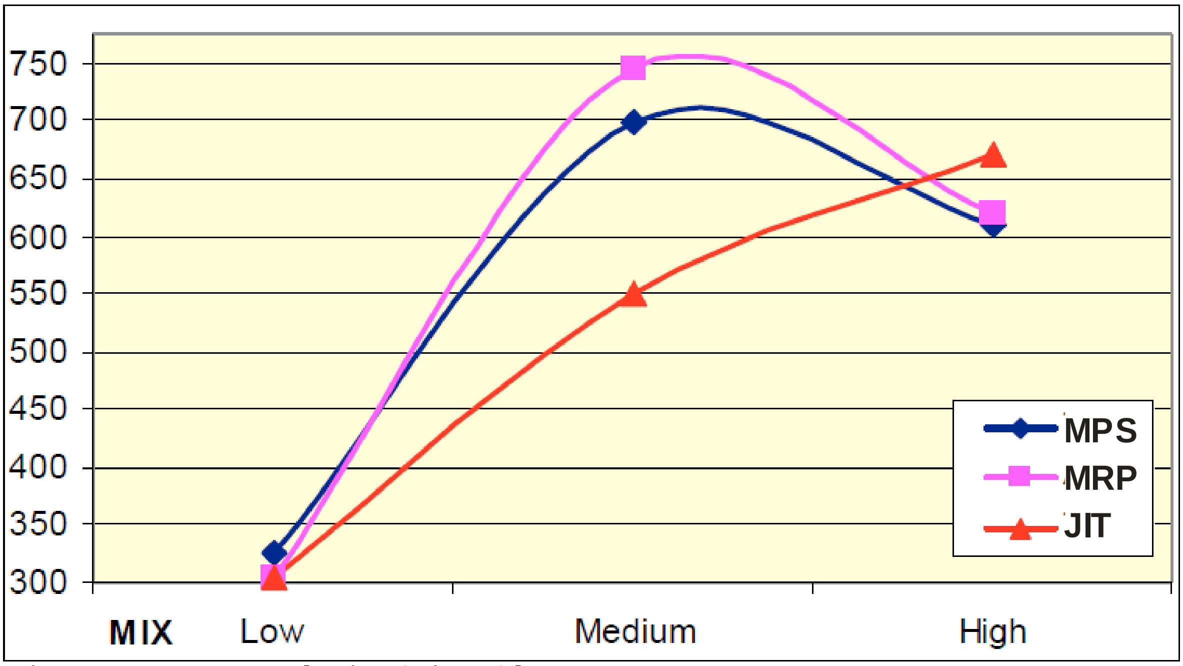


Figure 4.17: Average Cycle-Time (Minutes) by MAS

Just in Time Manufacturing System (JIT) drove a product mix decision that better balanced the manufacturing line and resulted in the lowest average cycle-times for all products. It is interesting to note that Materials Requirements Planning System (MRP), which generally outperformed vis-à-vis the other two manufacturing performance measures, was least effective in terms of cycle times. It is important to note that the variability of cycle-times across the various levels of product mix complexity was much less than the variability under the Mass Production System (MPS) and Materials Requirements Planning System (MRP). This may have important implications for the JIT manufacturing system that is concerned with consistently delivering faster cycle times under varying levels of product mix complexity demanded by the market.

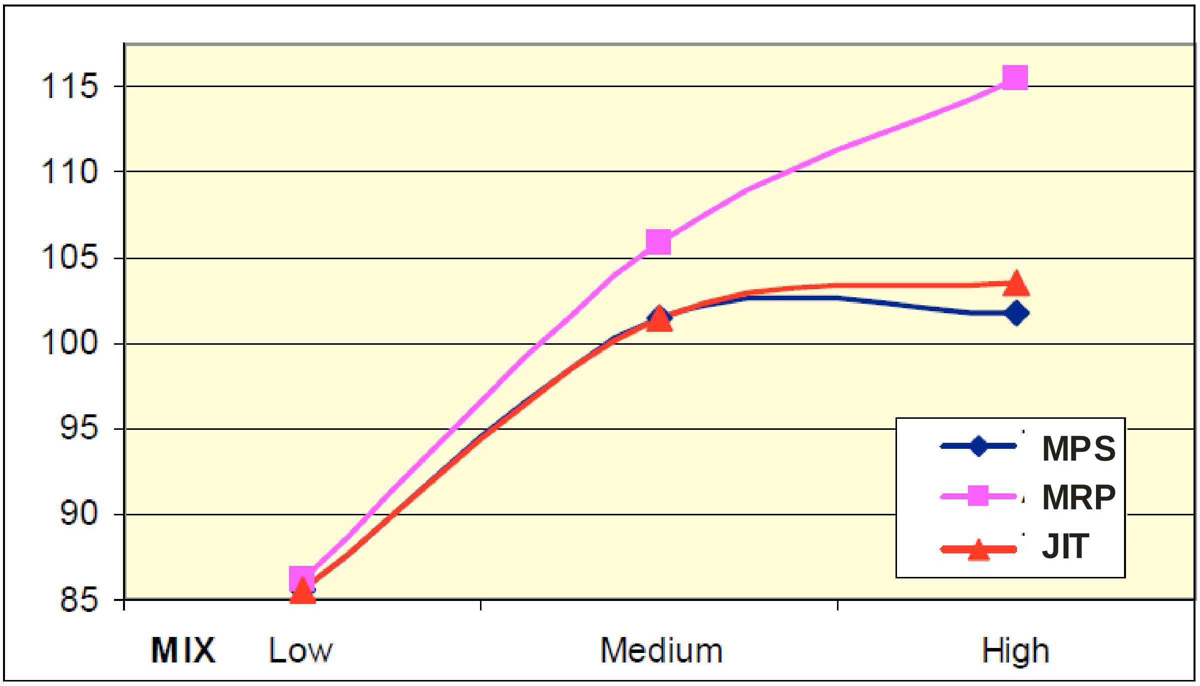


Figure 4.18: Average Net Operating Income by MAS
(Low Manufacturing Overhead Level)

Net operating income is the only financial measure of manufacturing success included in this study, and an argument could certainly be made that it is the bottom line and the most important measure. Figures 4.18 through 4.20 present the average net operating income measures for the various manufacturing system alternatives under differing levels of product mix complexity demand and differing levels of manufacturing overhead. Materials Requirements Planning System (MRP) clearly outperformed the two other manufacturing system alternatives along this measure. Mass Production System (MPS) and Just in Time Manufacturing System (JIT) performed nearly equally well under low and medium demand settings for product mix complexity. As the product mix complexity increases; however, Mass Production System (MPS) begin to fall behind Just in Time Manufacturing System (JIT).

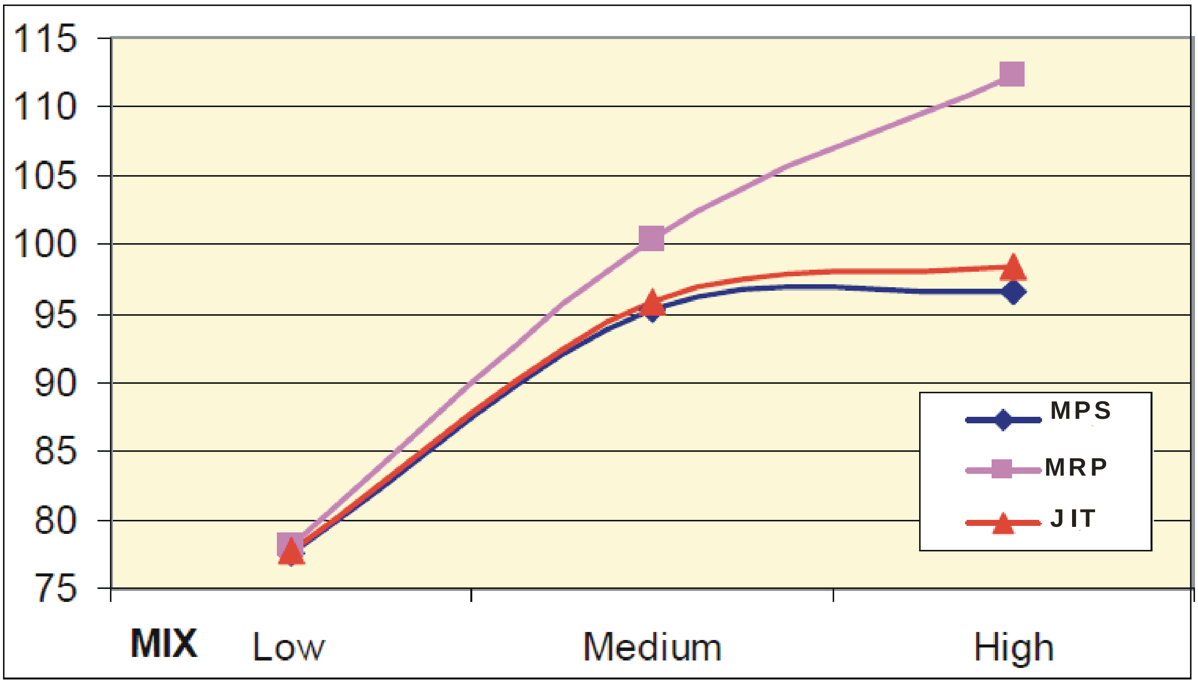


Figure 4.19: Average Net Operating Income by MAS (Medium Manufacturing Overhead Level)

Figure 4.19 shows essentially the same results, with Materials Requirements Planning System (MRP) clearly outperforming the other two manufacturing system alternatives. The difference between Mass Production System (MPS) and Just in Time Manufacturing System (JIT) again is not as great under medium levels of product mix complexity but increases with high levels of product mix complexity.

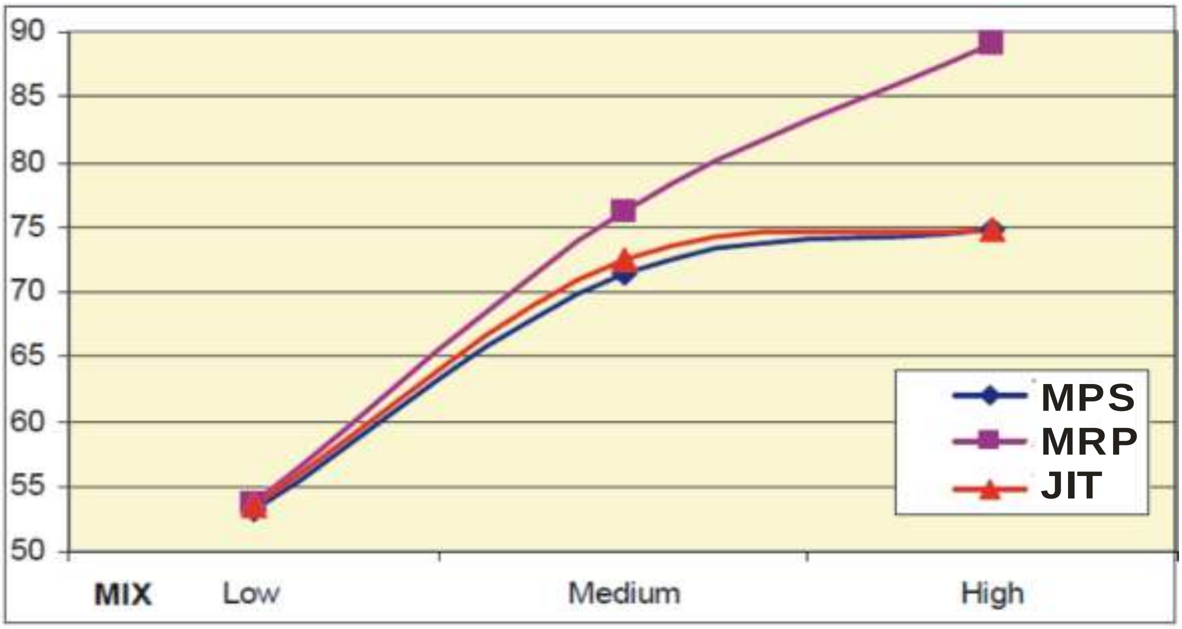


Figure 4.20: Average Net Operating Income by MAS (High Manufacturing Overhead Level)

Figure 4.20 again shows very similar results, with Materials Requirements Planning System (MRP) clearly outperforming the other two manufacturing system alternatives. Overall, average net operating income is at its lowest given the higher levels of manufacturing overhead. The difference between Mass Production System (MPS) and Just in Time Manufacturing System (JIT) again is not as great under medium levels of product mix complexity but increases with high levels of product mix complexity.

The results in the figures above present particularly interesting implications for manufacturing systems. The increase of demand for more complex and higher priced products presents an opportunity for increased revenues. However, as discussed in Chapter 2, it often presents the paradox as these products may also drive higher overall manufacturing costs. Higher levels of manufacturing overhead had no significant effect on the product mix decision; however, total costs and differences between the various manufacturing system alternatives are amplified. As the manufacturing overhead level setting increases, the slope of the cumulative net operating income curve decreases. The implication for both management and engineers is that the choice of manufacturing system alternative becomes increasingly important as product mix complexity increases and may be amplified as manufacturing overhead levels increase.

Figure 4.21 - Figures 5.29 presents cumulative NOI under various experimental conditions. As can be seen in Figures 5.21-5.29, higher levels of product mix complexity drive increasing long-term variances in cumulative net operating income. Review of manufacturing system performance under the nine experimental conditions (three levels of manufacturing overhead by three levels of product mix complexity) shows no significant difference in cumulative net operating income when product mix complexity is low. Materials Requirements Planning System (MRP) begins to significantly outperform the other two manufacturing system alternatives at a medium demand setting for product mix complexity. This difference becomes more pronounced as product mix complexity is set at a high level. At this high setting, Just in Time Manufacturing System (JIT) begins to slowly outperform Mass Production System (MPS).

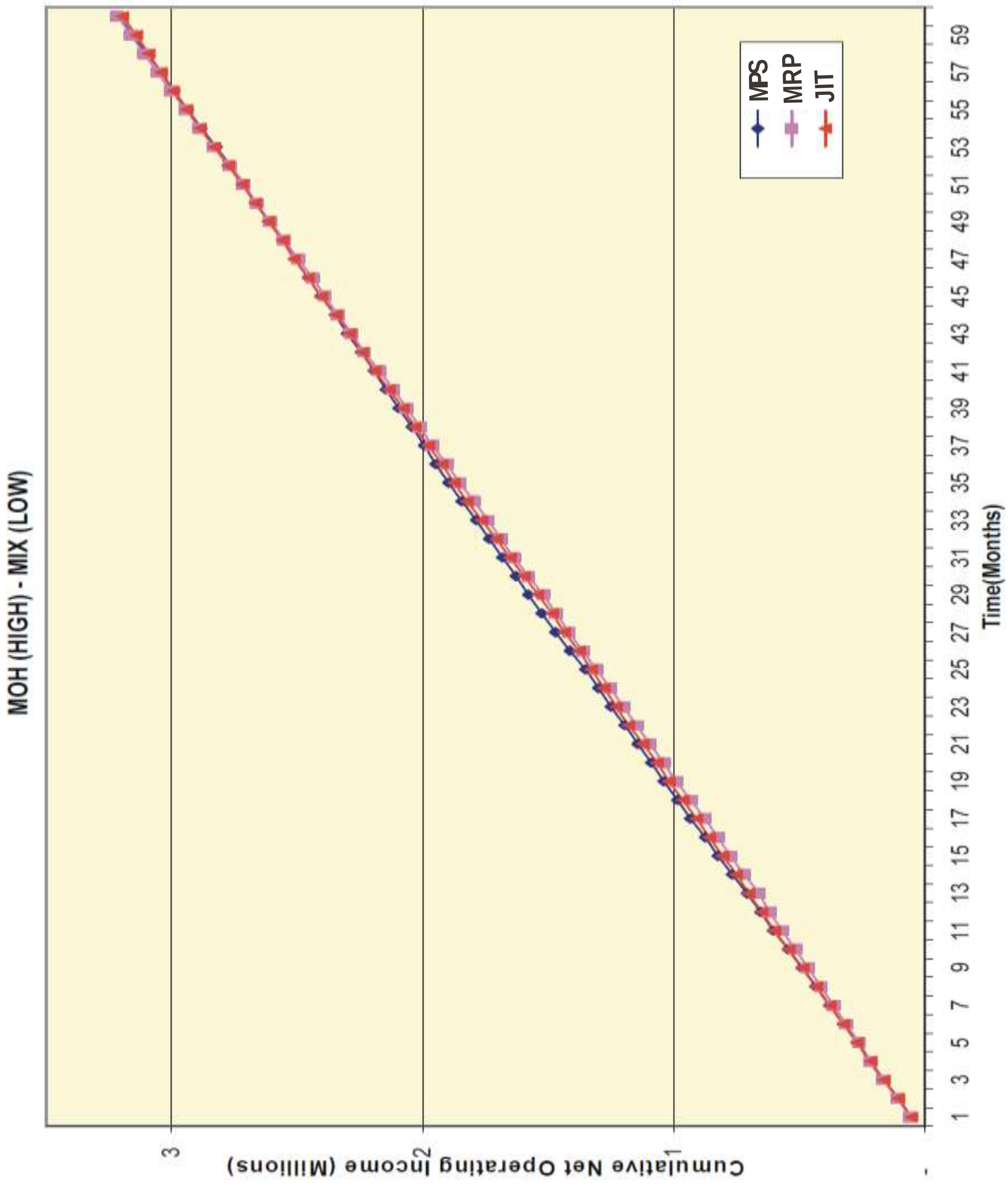


Figure 4.21: Cumulative Net Operating Income by MAS (Experimental Condition Group 1)

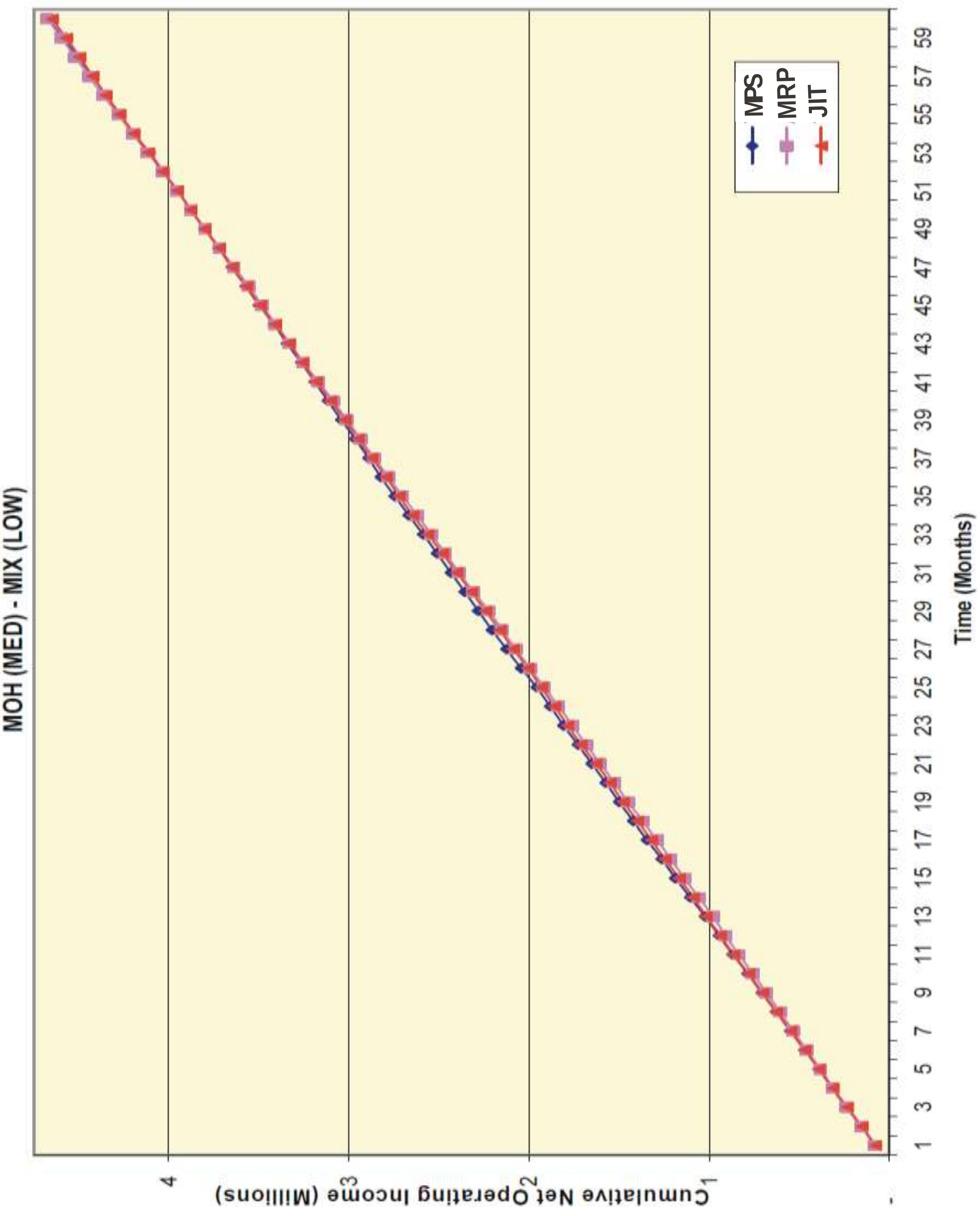


Figure 4.22: Cumulative Net Operating Income by MAS (Experimental Condition Group 2)

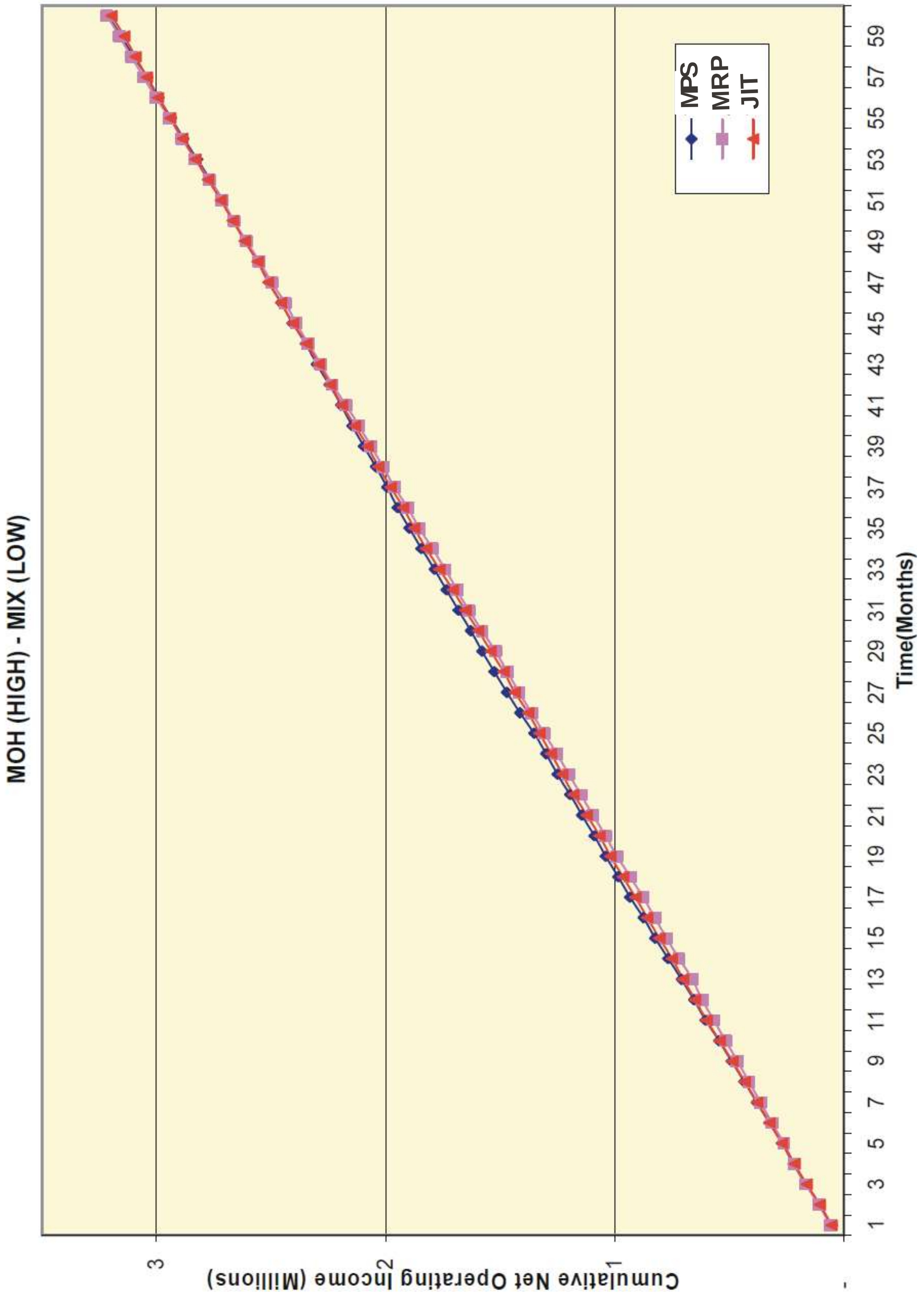


Figure 4.23: Cumulative Net Operating Income by MAS (Experimental Condition Group 3)

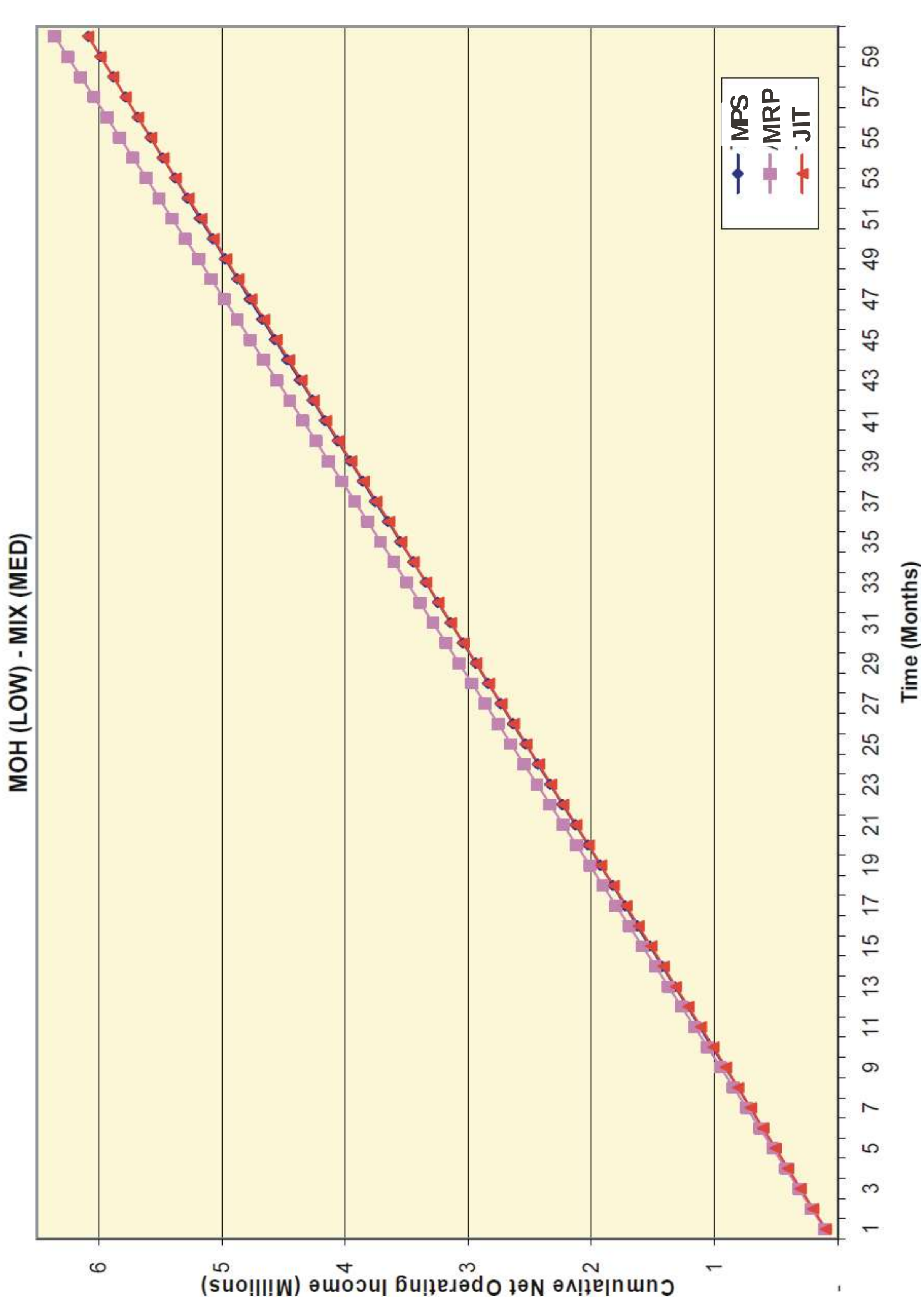


Figure 4.24: Cumulative Net Operating Income by MAS (Experimental Condition Group 4)

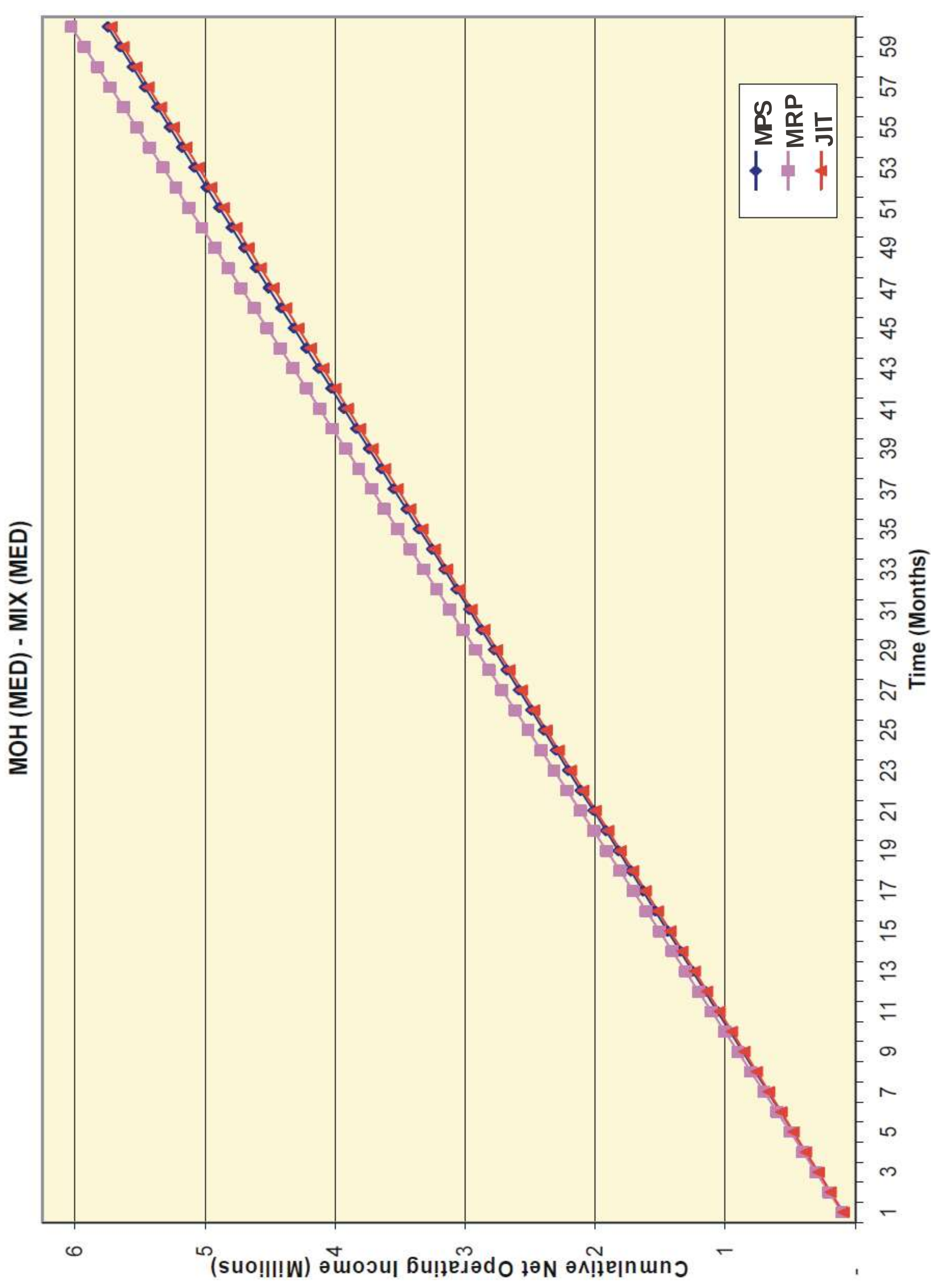


Figure 4.25: Cumulative Net Operating Income by MAS (Experimental Condition Group 5)

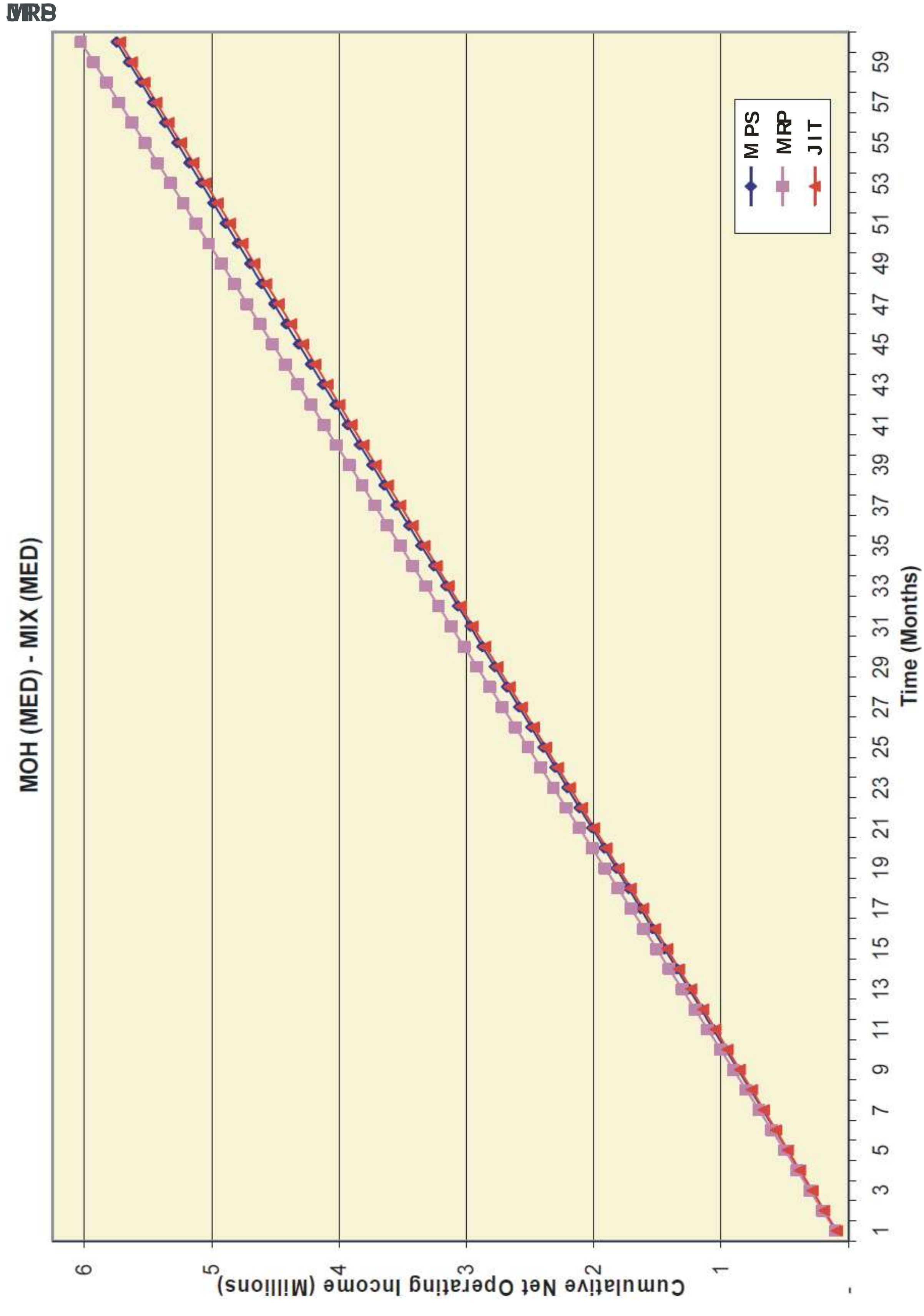


Figure 4.26: Cumulative Net Operating Income by MAS (Experimental Condition Group 6)

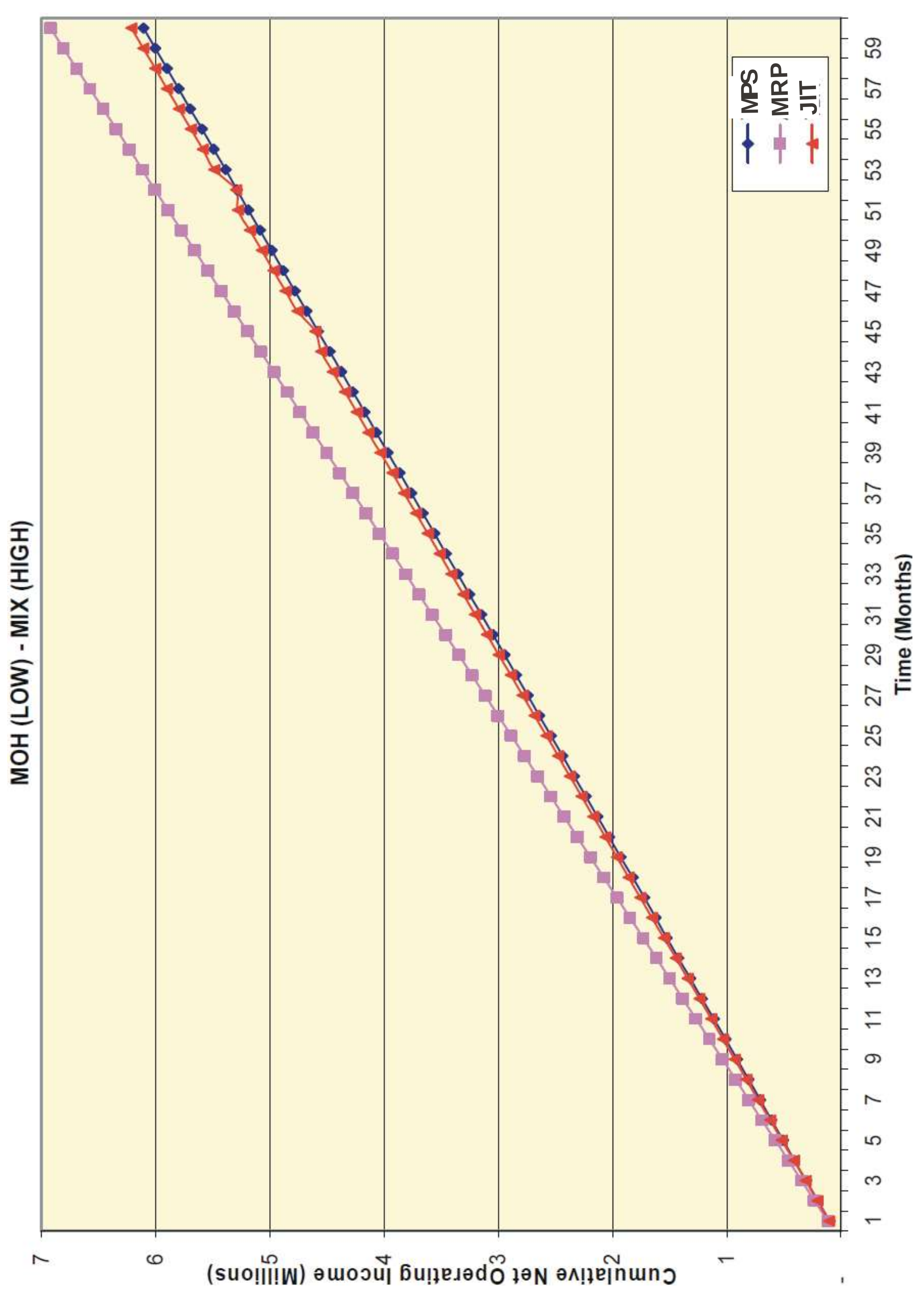


Figure 4.27: Cumulative Net Operating Income by MAS (Experimental Condition Group 7)

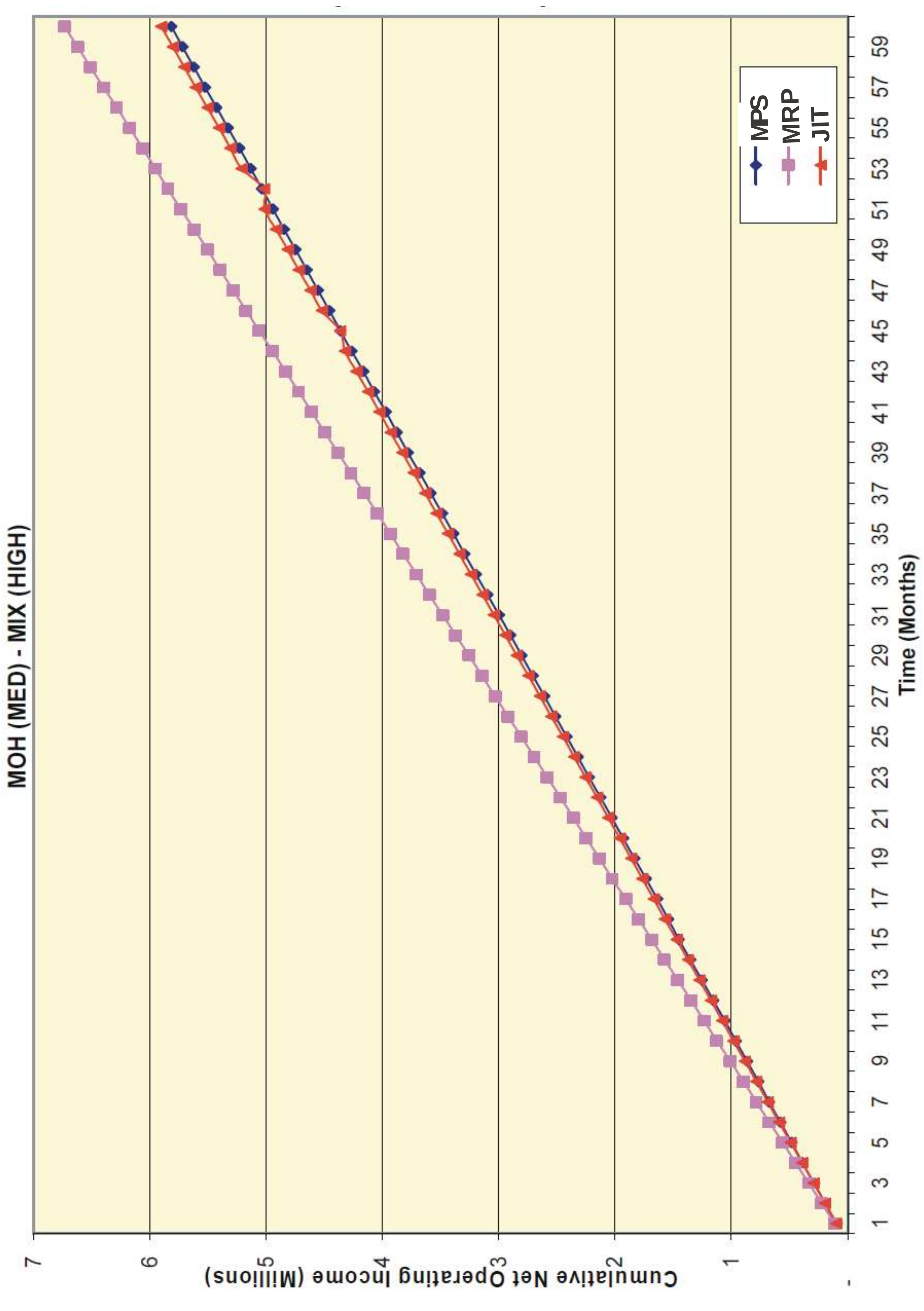


Figure 4.28: Cumulative Net Operating Income by MAS (Experimental Condition Group 8)

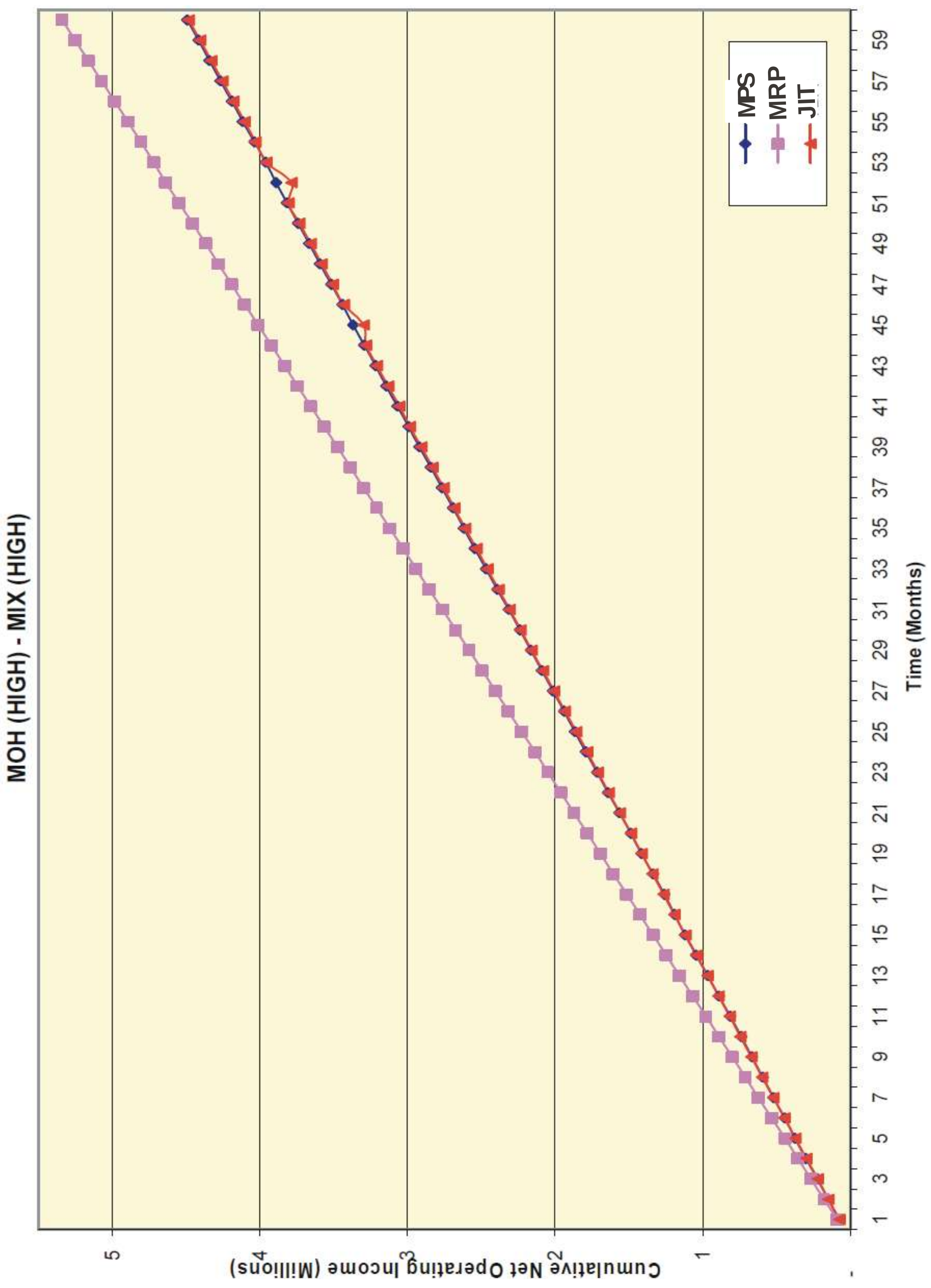


Figure 4.29: Cumulative Net Operating Income by MAS (Experimental Condition Group 9)

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusion

This work has proved that JIT is one of the most suitable engineering concepts for today's business because it meets the paradigms of contemporary businesses such as rapid changes in demand and more customised products. This system is also based on aspects of continuous improvement such as continually reducing costs, defect, inventory and lead time. Since the system has never-ending objectives, it is suitable for companies that want to survive in tomorrow's business world. The two-way as well as the three way interaction of manufacturing system and manufacturing overhead level, and product mix complexity was insignificant with less than 1% in effect size. Manufacturing overhead level had an amplification effect and only significantly affected the performance measure of net operating income. Product mix complexity had an insignificant affect on demand fulfillment rate ($F(2, 1593)=.057$, $p=1.00$, $ή^{p2} =.000$) and average cycle-time ($F(2, 1593)=.008$, $p=1.000$, $ή^{p2}=.000$).

The JIT system does not just involve lowering inventory reduction or using Kanbans, but the most necessary elements of implementing a JIT system are empowering people and developing a humanised production system. These elements can be achieved only if a proper environment exists within the JIT company such as effective employee involvement and management commitment. Therefore, the role of management is then crucial for cultivating the environment.

The simulation of a JIT system can provide better insight into the effects of factors contributing to its successful implementation. Some factors such as the number of Kanbans, trigger points, the scheduling rules and location of the buffers that are difficult to evaluate in practice can be evaluated using the simulation. However, due to the capability of the software that was dedicated to the conventional push system, some figures generated from the simulation may need some interpretation before being applied in actual situations. Another problem in using simulations is the complexity of the model and the more accurate the system, the more complex the model. Unfortunately, the more complex model is usually difficult to interpret and it requires more time to develop and verify the model. Nine journal papers were published during work on this dissertation and are shown in Appendix F.

5.2 Contribution to Knowledge

- In line with the first objective of this work, computer based production control systems was designed and implemented for Juhel Nigeria Ltd using kanban loops which integrate information flow with material flow. The single-card pull system applied in this research coupled with the use of the trigger point results in simpler mechanisms for operating the system.
- In order to achieve the second objective of this work, a discrete event simulation model was developed and designed to study the Just-in-Time Supply Delivery System (JSS) of the drug process plant.
- In line with third, fourth, fifth and sixth research objectives, this research work has shown that JIT implementation could achieve up to 26.7% increase in Net Operating Income (NOI), 39.4% increase in Demand Fulfillment Rate (DFR), 39.5% increase in inventory and 36.8% increase in WIP for Juhel Nigeria Ltd. The model developed for this Drug Process Plant led to 19.2% decrease in cycle time, 32.7% drop in Throughput Time and 20.9% cut in Flow Time.
- In line with the seventh research objective, the JIT common frequency routing and meta-heuristics applied in this work provided many enhancements, especially those associated with inventory reduction at the end buffer, shorter customer lead time and better visual control. Some issues such as setup time reduction, process variability reduction and product mix that are crucial issues for successful JIT implementation were optimized in this research work.

5.3 Recommendations

Based on the simulation study, there are some interesting points which appear and make necessary the following recommendations:

1. The number of Kanbans should be as close as possible to the average of the periodical orders since the effects of increasing the number of Kanbans on the flow time and the Work in Process (WIP) were minor. On the contrary, a shortage as an effect of reducing Kanbans produces a significant effect on the performance of the system in terms of the buffer levels and the lead times. Therefore, supervisors should ensure that the number of Kanbans is sufficient to run the system.
2. Trigger points can be used to reduce the customer lead times up until a certain level. However, after the threshold, the effect of increasing the trigger point is not significant.

3. The effect of a change of scheduling rules in improving the lead time and the utilisation of facilities is minor. This may be caused by the type of manufacturing processes employed i.e. process flow since all items move to the same production route.

4. In terms of buffer locations, statistically we cannot prove that the proposed locations which tried to balance the lead time for each block are better than the existing design. The investigation should be continued for other locations and criteria in order to search the best location of buffers. However, this could not be conducted because of software limitations.

5.4 Suggestions for Future Research

Because the scope of this study is somewhat limited, as outlined in the preceding discussion, further research will be needed. The following discussion proposes some possibilities for both advancing and extending this research.

i. As mentioned above, one specific limitation of this study was that it considered only one particular simulated manufacturing environment, albeit under differing manufacturing overhead levels and with differing demand levels of product mix complexity. Future experiments should be conducted in a variety of operating environments to enhance the generalizability of the findings.

ii. As was mentioned above, one of the greatest strengths of simulation modeling is the malleability of the model itself, especially with newer software packages such as ARENA. The simulation model can be endlessly reconfigured to increase complexity and to incorporate additional realism. One suggestion is to take a systems dynamic approach building learning into the simulation model itself over the length of the simulation run. System dynamic model learning could be incorporated both on the supply process and demand sides to study the behavior of systems and the impact of alternative policies.

iii. JIT implementation cannot provide significant benefits if setup time and variability remain high as well as if the company is not able to optimise the production facilities by product mix. However, in the future, those issues should be taken into account if the Drug Process Plant wants to expand the system for use with other items.

iv. Based on the literary evidence achieved in this work, a system-dynamics conceptual framework is suggested for further investigation and future research. In this framework, the Manufacturing System (MAS) has a moderating effect, via the decision making process, on the relationship between JIT strategies and manufacturing performance. System dynamics is an approach to studying complex systems, through the use of feedback loops. Stocks and flows are the basic building blocks, connected by feedback loops which create the nonlinearity found so frequently in modern day problems. The use of an appropriate MAS, which best reflects the time-based competitive reality, will reinforce the practices of JIT strategy over time. Conversely, the choice of inappropriate MAS, which does not reflect the importance of throughput-time, will undermine JIT manufacturing system strategy and may prove a fetter to its advancement.

v. On the supply side, it would be interesting to develop a product mix determination using dynamic integer goal programming as opposed to simply integer linear programming in a static environment. Manufacturing performance measures as driven by the various Manufacturing System alternatives can be fed into the goal program through a feedback look, thereby continually driving change in product cost and product mix decision. The choice of Manufacturing System affects the product cost, which in turn affects the product mix decision, which affects manufacturing performance measures, which is fed back into the Manufacturing System itself.

vi. From a demand perspective, incorporating learning into the different product demand distributions would add an additional level of realism. Given a competitive market, it is quite likely that any demand lost to the market may be permanently lost, i.e. a particular customer may never order again from a particular supplier. Breaking down product demands into individual customer demands, with differing levels of customer service requirements and differing sensitivities to stock outs and price increases would add a great deal of complexity and realism to the simulation model.

vii. While the preceding suggestions could rather easily be built into any simulation modeling study, another interesting extension of this research would be to model an actual manufacturing facility and apply the findings post hoc to the actual manufacturing system. This would give the opportunity not only to collect real data for developing demand and process distributions, but would also add a new dimension to the kind of case study methodology often employed in research.

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APPENDICES

Appendix A1

SIMAN LANGUAGE CODE FOR EXISTING DRUG PROCESS PLANT MODEL

Appendix A1 presents the actual SIMAN language code for the existing drug process plant simulation model used in this experiment.

```
BEGIN;
:
      !---------------- Initialisation of System UNNAMED1------------------
                                   !Initial Customer enters placed at drug process
          CREATE,     1,0:                     plant
                :
                 NEXT(Go to the customer planning section);
          CREATE,     1,0:              !Initial parts at system2
                :
                NEXT(system2);
          CREATE,     1,0:                  !Initial order
                :
                           NEXT(Searching);
        CREATE?,      1,0:
                :
        NEXT( Free terminal?,);
          CREATE,     1,0:
                :
        NEXT( System login2,1);
          CREATE,     1,0:
                :
      NEXT( Search the Kanban cards);
          CREATE,     1,0:
                :
       NEXT( Go to requisite folder,
             Data found?);
          CREATE,     1,0:
                :
          NEXT( Search again?;
          CREATE,     1,0:
      NEXT( checks whether order has
         reached production date);
          CREATE,     1,0:
                :
       NEXT( Production complete?);
          CREATE,     1,0:
                :
       NEXT( Production complete?);
                CREATE,       1,0:
                      :
       Has order reached production
                date?,
          CREATE,     1,0:
                :
         NEXT( Search again?);

         CREATE,     1,0:
               :
     NEXT(  Go to the storage area );
       CREATE,       1,0:
               :
        NEXT(UNNAMED6);
     Search again?,      1,0:
               :
     NEXT(  Present Kanban card and
```

```
                list of items);
        Has order reached
        production date?,          1,0:
                        :
              NEXT(  Enter query?);
               CREATE,          1,0:
                        :
        NEXT Search again; Production
                 complete;?);
               CREATE,          1,0:
                        :
         NEXT(  Confirm list of items);
               CREATE,          1,0:
                        :
         NEXT Search again Production
                 complete;?);
               CREATE,          1,0:
                        :
              NEXT(   System logou);
   CREATE:      UNIF(1440,1584,2):
               MARK(Arrtime1);
   ASSIGN:      Type=DISC(0.1,1,0.4,2,0.9,3,1.0,4): !Arrival of green Kanbans
               Priority=1:
               X(10)=X(10)+1:
               X(20)=X(20)+Type;
   BRANCH, 1:
               IF,(X(20).ge.2).and.(X(10).eq.1),Label1:
               IF,(X(20).ge.10).and.(X(10).ge.2),label1:
               ELSE,Label2;
    Label1     ASSIGN:      X(20)=0;
                                                  !Send Kanbans to The preceding
          DUPLICATE:   1, query1;                 block

               BRANCH,
    Label2   1:
                    IF,Type.eq.1,Labela:
                    IF,Type.eq.2,labelb:
                    IF,Type.eq.3,Labelc:
                    ELSE,Labeld;
    labela
    DUPLICATE:              1,Customer;
            COUNT:       JPF113155_R9_Q30:DISPOSE;
    labelb
    DUPLICATE:              2,Customer;
            COUNT:       JPF113155_R9_Q60:DISPOSE;
            DUPLICATE
    labelc  :                3,Customer;
            COUNT:       JPF113155_R9_Q90:DISPOSE;
    labeld
    DUPLICATE:              4,Customer;
            COUNT:       JPF113155_R9_Q120:DISPOSE;

      system2          QUEUE,         system 1:   !Queues for Finished parts at storage
                  DETACH;
                    MATCH:          query2,Block3:
                                                  system2;
    ! --------------- Arrivals of orders for drug items ----------------------

   CREATE:      UNIF(2520,3024):
               MARK(Arrtime2);
   ASSIGN:      Type=DISC(.2,5,.5,6,.75,7,1.0,8):   ! Arrival of High-volume Kanbans
               Priority=Type;
   BRANCH, 1:
               IF,Type.eq.5,Labela1:
               IF,Type.eq.6,labelb1:
               IF,Type.eq.7,Labelc1:
               ELSE,Labeld1;
END;
```

Appendix A2

SIMAN LANGUAGE CODE FOR JIT MANUFACTURING SYSTEM MODEL

Appendix A2 presents the actual SIMAN language code for the JIT simulation model used in this experiment.

```
;
;
;       Model statements for module: Create 1
;


94$          CREATE,          1,HoursToBaseTime(0.0),Part
A:HoursToBaseTime(EXPO(.5)):NEXT(95$);


95$            ASSIGN:          Part A Order Arrival.NumberOut=Part A Order
Arrival.NumberOut + 1:NEXT(88$);

;
;
;       Model statements for module: Record 29
;
88$            COUNT:           Record Total Part A Demand,1:NEXT(0$);

;
;
;       Model statements for module: Assign 1
;
0$ ASSIGN: Rework Time=TRIA(20,60,80): Unload Time=TRIA(0.5,1.5,1.75): Load Time=TRIA(1.5,2,2.5): Transport
                        Velocity=UNIF(25,35): Picture=Picture.Blue Ball:
                        Sealer Time=TRIA(16, 18, 20):
Prep Time=TRIA(14,18,22):NEXT(Part A);


Part A       QUEUE,          Part A Order.Queue,16,21$:MARK(Arrive
Time):DETACH;


;
;
;    Model statements for module: Record 7
;
21$          COUNT:          Record Part A Demand Unfilled,1:NEXT(91$);

;
;
;    Model statements for module: Record 32
;
91$ TALLY: Record DFR Part A,1 - ( NC(Record Part A Demand Unfilled) / NC(Record Total Part A Demand) ),1
                    :NEXT(22$);

;
;
;    Model statements for module: Dispose 6
;
22$ ASSIGN: Part A Demand Unfilled.NumberOut=Part A Demand Unfilled.NumberOut + 1;
98$          DISPOSE:          Yes;



;
;
;    Model statements for module: Create 2
```

```
;

99$                    CREATE,     1,HoursToBaseTime(0.0),Part
B:HoursToBaseTime(EXPO(2)):NEXT(100$);


100$                   ASSIGN:     Part B Order Arrival.NumberOut=Part B Order
Arrival.NumberOut + 1:NEXT(89$);

;
;
;     Model statements for module: Record 30
;
89$           COUNT:           Record Total Part B Demand,1:NEXT(1$);

;
;
;     Model statements for module: Assign 2
;
1$ ASSIGN: Rework Time=TRIA(40,80,100): Unload Time=TRIA(0.5,1.5,2):
                     Load Time=TRIA(1.5,2,3): Transport Velocity=UNIF(20,30): Picture=Picture.Yellow Ball: Prep
                     Time=TRIA(12,18,24):
                     Sealer Time=TRIA(18,20,22):NEXT(Part B);

Part B        QUEUE,           Part B Order.Queue,5,23$:DETACH;

;
;
;     Model statements for module: Record 8
;
23$           COUNT:           Record Part B Demand Unfilled,1:NEXT(92$);

;
;
;     Model statements for module: Record 33
;
92$ TALLY: Record DFR Part B,1 - ( NC(Record Part B Demand Unfilled) / NC(Record Total Part B Demand) ),1
                     :NEXT(24$);

;
;
;     Model statements for module: Dispose 7
;
24$ ASSIGN: Part B Demand Unfilled.NumberOut=Part B Demand Unfilled.NumberOut + 1;
103$          DISPOSE:         Yes;

;
;
;     Model statements for module: Create 4
;

104$          CREATE,          1,HoursToBaseTime(0.0),Part
C:HoursToBaseTime(EXPO(8)):NEXT(105$);


105$          ASSIGN:          Part C Order Arrival.NumberOut=Part C Order
Arrival.NumberOut + 1:NEXT(90$);

;
;
;     Model statements for module: Record 31
;
90$           COUNT:           Record Total Part C Demand,1:NEXT(10$);

;
```

```
;
;     Model statements for module: Assign 4
;
10$ ASSIGN: Rework Time=TRIA(120,180,300): Unload Time=TRIA(1,2.5,5):
                    Load Time=TRIA(2,3,5): Transport Velocity=UNIF(10,30): Picture=Picture.Green Ball: Sealer
                    Time=TRIA(68,72,78):
                    Prep Time=TRIA(64,90,124):NEXT(Part C);

Part C          QUEUE,          Part C Order.Queue,1,25$:DETACH;


;
;
;     Model statements for module: Record 9
;
25$             COUNT:          Record Part C Demand Unfilled,1:NEXT(93$);

;
;
;     Model statements for module: Record 34
;
93$ TALLY: Record DFR Part C,1 - ( NC(Record Part C Demand Unfilled) / NC(Record Total Part C Demand) ),1
                    :NEXT(26$);

;
;

;     Model statements for module: Dispose 8
;
26$ ASSIGN: Part C Demand Unfilled.NumberOut=Part C Demand Unfilled.NumberOut + 1;
108$            DISPOSE:        Yes;

;
;
;     Model statements for module: Enter 1
;


11$             STATION,        Prep Arrival.Station;
109$            DELAY:          Unload Time,,Transfer:NEXT(111$);

111$            FREE:           Prep Cart:NEXT(2$);

;
;
;     Model statements for module: Process 2
;
2$              ASSIGN:         Prep Process.NumberIn=Prep Process.NumberIn + 1:
                    Prep Process.WIP=Prep Process.WIP+1;
149$            STACK,          1:Save:NEXT(123$);

123$            QUEUE,          Prep Process.Queue;
122$            SEIZE,          1,VA:
                    Part Prep,1:NEXT(121$);

121$            DELAY:          Prep Time,,VA:NEXT(164$);

164$            ASSIGN:         Prep Process.WaitTime=Prep Process.WaitTime +
Diff.WaitTime;
128$            TALLY:          Prep Process.WaitTimePerEntity,Diff.WaitTime,1;
130$            TALLY:          Prep Process.TotalTimePerEntity,Diff.StartTime,1;
```

```
154$            ASSIGN:           Prep Process.VATime=Prep Process.VATime +
Diff.VATime;
155$            TALLY:            Prep Process.VATimePerEntity,Diff.VATime,1;
120$            RELEASE:          Part Prep,1;
169$            STACK,            1:Destroy:NEXT(168$);

168$            ASSIGN:           Prep Process.NumberOut=Prep Process.NumberOut + 1:
                          Prep Process.WIP=Prep Process.WIP-1:NEXT(27$);

;
;
;     Model statements for module: Station 12
;

27$             STATION,          Prep Station;
173$            DELAY:            0.0,,VA:NEXT(41$);

;
;
;     Model statements for module: Request 1
;
41$             QUEUE,            Request Cart 1 to Prep Station.Queue;
            REQUEST,          1:Sealer Cart(SDS),50:NEXT(44$);

;
;
;     Model statements for module: Delay 2
;
44$             DELAY:            Load Time,,Transfer:NEXT(43$);
;
;
;     Model statements for module: Transport 2
;
43$             TRANSPORT:           Sealer Cart,Sealer Arrival.Station,Transport Velocity;

;
;
;     Model statements for module: Enter 2
;

12$             STATION,          Sealer Arrival.Station;
175$            DELAY:            Unload Time,,Transfer:NEXT(177$);

177$            FREE:           Sealer Cart:NEXT(3$);

;
;
;     Model statements for module: Process 3
;

3$             ASSIGN:           Sealer Process.NumberIn=Sealer Process.NumberIn + 1:
                          Sealer Process.WIP=Sealer Process.WIP+1;
215$            STACK,            1:Save:NEXT(189$);

189$            QUEUE,            Sealer Process.Queue;
188$            SEIZE,          1,VA:
                          Sealer,1:NEXT(187$);
```

```
187$            DELAY:            Sealer Time,,VA:NEXT(230$);

230$            ASSIGN:           Sealer Process.WaitTime=Sealer Process.WaitTime +
Diff.WaitTime;
194$            TALLY:            Sealer Process.WaitTimePerEntity,Diff.WaitTime,1;
196$            TALLY:            Sealer Process.TotalTimePerEntity,Diff.StartTime,1;
220$            ASSIGN:           Sealer Process.VATime=Sealer Process.VATime +
Diff.VATime;
221$            TALLY:            Sealer Process.VATimePerEntity,Diff.VATime,1;
186$            RELEASE:            Sealer,1;
235$            STACK,            1:Destroy:NEXT(234$);

234$            ASSIGN:           Sealer Process.NumberOut=Sealer Process.NumberOut + 1:
                          Sealer Process.WIP=Sealer Process.WIP-1:NEXT(4$);

;
;
;     Model statements for module: Decide 1
;
4$            BRANCH,            1:
                          If,Entity.Type==Part A,13$,Yes:
                          If,Entity.Type==Part B,14$,Yes:
                          If,Entity.Type==Part C,15$,Yes:
                          Else,20$,Yes;

;
;
;     Model statements for module: Dispose 5
;
20$ ASSIGN: Dispose of Sealer Exceptions.NumberOut=Dispose of Sealer Exceptions.NumberOut + 1;
239$            DISPOSE:            Yes;

;
;
;     Model statements for module: Decide 3

;
13$             BRANCH,       1:
                          With,4/100,240$,Yes:
                          Else,241$,Yes;
240$             ASSIGN:           Failed Sealer Inspection Part A.NumberOut True=Failed
Sealer Inspection Part A.NumberOut True + 1
                          :NEXT(28$);

241$             ASSIGN:           Failed Sealer Inspection Part A.NumberOut False=Failed
Sealer Inspection Part A.NumberOut False + 1
                          :NEXT(29$);

;
;     Model statements for module: Station 13
;

28$            STATION,            Failed Parts Station;
244$            DELAY:            0.0,,VA:NEXT(47$);

;
;
```

```
;      Model statements for module: Request 2
;
       47$         QUEUE,               Request Cart to Failed Parts.Queue;
                 REQUEST,              1:Cart 2(SDS),50:NEXT(45$);

;
;
;      Model statements for module: Delay 3
;
45$              DELAY:                Load Time,,Transfer:NEXT(46$);

;
;
;      Model statements for module: Transport 3
;
46$              TRANSPORT:              Cart 2,Rework Arrival.Station,Transport Velocity;

;
;

;      Model statements for module: Station 14
;


29$              STATION,              Good Parts Station;
248$              DELAY:               0.0,,VA:NEXT(50$);

;
;
;      Model statements for module: Request 3
;
50$              QUEUE,                Request Cart to Good Parts.Queue;
                 REQUEST,              1:Cart 2(SDS),50:NEXT(52$);

;
;
;      Model statements for module: Delay 4
;
52$              DELAY:                Load Time,,Transfer:NEXT(49$);

;
;
;      Model statements for module: Transport 4
;
49$              TRANSPORT:              Cart 2,Shipped Parts Arrival.Station,Transport Velocity;

;
;
;      Model statements for module: Decide 4
;
14$                BRANCH,        1:
                             With,6/100,250$,Yes:
                             Else,251$,Yes;
250$               ASSIGN:             Failed Sealer Inspection Part B.NumberOut True=Failed
Sealer Inspection Part B.NumberOut True + 1
                             :NEXT(28$);


251$               ASSIGN:             Failed Sealer Inspection Part B.NumberOut False=Failed
Sealer Inspection Part B.NumberOut False + 1
                             :NEXT(29$);

;
;
;      Model statements for module: Decide 5
```

```
;
15$                  BRANCH,        1:
                               With,10/100,252$,Yes:
                               Else,253$,Yes;
252$               ASSIGN:           Failed Sealer Inspection Part C.NumberOut True=Failed
Sealer Inspection Part C.NumberOut True + 1
                               :NEXT(28$);

253$               ASSIGN:           Failed Sealer Inspection Part C.NumberOut False=Failed
Sealer Inspection Part C.NumberOut False + 1
                               :NEXT(29$);

               QPICK,             POR:

$MPS$
                               Part C:
                               Part B:
                               Part A;
;
;

$MRP$

                               Part B:
                               Part A:
                               Part C;
;
;

$JIT$

                               Part A:
                               Part B:
                               Part C;

36$ ALLOCATE, 1:Prep Cart,Order Release Station:MARK(Arrive Time):NEXT(37$);

;
;
;     Model statements for module: Station 17
;

37$               STATION,            Order Release Station;
256$               DELAY:             0.0,,VA:NEXT(65$);


;
;
;     Model statements for module: Assign 5
;
65$               ASSIGN:             Arrival Time=TNOW:NEXT(38$);

;
;
;     Model statements for module: Move 1
;
38$               MOVE:               Prep Cart,Prep Arrival.Station,50:NEXT(40$);

;
;
;     Model statements for module: Delay 1
;
40$               DELAY:              Load Time,,Transfer:NEXT(64$);
```

```
;
;
;    Model statements for module: Decide 9
;
64$             BRANCH,        1:
                              If,NQ(Prep Process.Queue) <= 16 && NQ(Sealer Process.Queue)
<= 16,257$,Yes:
                              Else,258$,Yes;
257$            ASSIGN:             Check Prep and Sealer Queue Availability.NumberOut
True=
                              Check Prep and Sealer Queue Availability.NumberOut True +
1:NEXT(39$);

258$            ASSIGN:             Check Prep and Sealer Queue Availability.NumberOut
False=
                              Check Prep and Sealer Queue Availability.NumberOut False +
1:NEXT(63$);

;
;
;    Model statements for module: Transport 1
;
39$             TRANSPORT:           Prep Cart,Prep Arrival.Station,Transport Velocity;

;
;
;    Model statements for module: Delay 7
;
63$             DELAY:              EXPO( .5 ),,Wait:NEXT(64$);

;
;
;    Model statements for module: Enter 4
;


30$             STATION,            Rework Arrival.Station;
259$            DELAY:              Unload Time,,Transfer:NEXT(261$);

261$            FREE:             Cart 2:NEXT(5$);

;
;
;    Model statements for module: Process 4
;
5$              ASSIGN:             Rework Process.NumberIn=Rework Process.NumberIn + 1:
                              Rework Process.WIP=Rework Process.WIP+1;
299$            STACK,              1:Save:NEXT(273$);

273$            QUEUE,              Rework Process.Queue;
272$            SEIZE,            1,Other:
                              Rework,1:NEXT(271$);

271$            DELAY:              Rework Time,,Other:NEXT(314$);

314$            ASSIGN:             Rework Process.WaitTime=Rework Process.WaitTime +
Diff.WaitTime;
```

```
;
;
;     Model statements for module: Record 22
;
80$ TALLY: Record Part B Scrapped Time,INT(Arrive Time),1:NEXT(85$);

;
;
;     Model statements for module: Record 26
;
85$             COUNT:              Record Part B Scrapped,1:NEXT(87$);

;
;
;     Model statements for module: Record 24
;
82$             TALLY:              Record Part C Scrapped Time,INT(Arrival
Time),1:NEXT(86$);


;
;
;     Model statements for module: Record 27
;
86$             COUNT:              Record Part C Scrapped,1:NEXT(87$);

;
;
;     Model statements for module: Enter 7
;


35$             STATION,            Salvaged Parts Arrival.Station;
368$            DELAY:              Unload Time,,Transfer:NEXT(370$);


370$            FREE:             Cart 2:NEXT(66$);

;
;
;     Model statements for module: Decide 10
;
66$ BRANCH, 1: If,Entity.Type==Part A,68$,Yes: If,Entity.Type==Part B,7$,Yes: If,Entity.Type==Part C,69$,Yes:
                             Else,67$,Yes;
;
;
;     Model statements for module: Dispose 9
;
67$             ASSIGN:             Dispose 9.NumberOut=Dispose 9.NumberOut + 1;
381$            DISPOSE:            Yes;

;
;
;     Model statements for module: Record 12
;
68$ TALLY: Record Part A Salvaged Time,INT(Arrival Time),1:NEXT(75$);
;
;
;     Model statements for module: Record 2
;
7$ TALLY: Record Part B Salvaged Time,INT(Arrive Time),1:NEXT(76$);

;
;
;     Model statements for module: Record 14
;
69$ TALLY: Record Part C Salvaged Time,INT(Arrival Time),1:NEXT(77$);
```

Appendix A3

DYNAMIC PROGRAM CODE

```
def JIT manufac Schedule(n, values, next):
 # Initialize memoization array - Equ 1:17  memo = [0] * (n+1)

 # Set base case
  memo[n] = values[n]

 # Build memoization equ from n to 1 - Equ 18
  for i in range(n-1, 0, -1):
    memo[i] = max(v_i + memo[next[i]], memo[i+1])

 # Return solution to original problem OPT(1) - Equ 19;20
  return memo[1]
def find_number of kanban(seq):
    n = number of kanban (seq)
    max_length = 1
    best_seq_end = -1
    # keep a chain of the values of the total demand
    prev = [0 for i in range(n)]
    prev[0] = -1
    # keep a chain of the values of marginal hoding cost
    prev = [0 for i in range(n)]
    prev[0] = -1
# the length of the simu at current inventory level
    inv = [0 for i in range(n)]
    inv[0] = 1
    for i in range(1, n):
        length of simu[i] = 0
        prev[i] = -1
        # start from index i-1 and work back to 0
        for j in range(i - 1, -1, -1):
            if (qty trans/shipped[j] + 1) > length[i] and seq[j] < seq[i]:
         # there's a number before WIP level i that increases the simu at i
                length[i] = length[j] + 1
                prev[i] = j
        if mkt demand[i] > max_ mkt demand:
            max_ mkt demand = mkt demand [i]
            best_seq_end = i
    # recover the subsequence current cumulative sales = []
    qty shipped = WIP_mkt demand_end
        # recover the subsequence net operating income = []
                n product variants = selling price of product_total demand_end
                while element != -1:
         lis.append(seq[element])
         element = prev[element]
    return lis[::-1]
def knapsack(W, w, v):
    # create a W x n solution matrix to store the sub-problem results
    n = len(v)
    S = [[0 for x in range(W)] for k in range(n)]
    for x in range(1, W):
        for k in range(1, n):
       # using this notation k is the number of items in the solution and x
                              is the max weight of the solution,
            # so the initial assumption is that the optimal solution with k
                              items at weight x is at least as good
            # as the optimal solution with k-1 items for the same max
```

weight

S[k][x] = S[k-1][x]

if the current item weighs less than the max weight and the optimal solution including this item is

better than the current optimum, the new optimum is the one resulting from including the current item

if $Q^{j}_{1,k_j}[D_j]$< y^{p}_{j} **and** $\pi_j[D_j$-1][y^{p}_{j}-$Q^{j}_{1,k_j}[D_j]$]+ k_j [D_j] >$\pi_j[D_j]$[y^{p}_{j}]:

$\pi_j[D_j]$[y^{p}_{j}] = S[D_j-1][y^{p}_{j}-$Q^{j}_{1,k_j}[D_j]$] + $k_j[D_j]$

return S

```
#include<current inv>
#include<vector>
using namespace std;

int optimal knan  scheduling(int n, vector<int> entry, vector<int> exit, vector<vector<int> > processing,
vector<vector<int> > transfer)
{
   vector<vector<int> > dp(2, vector<int>(n+1));
   int i;

   //initialization
   //entry to first station
   dp[0][0]=entry[0]+processing[0][0];
   dp[1][0]=entry[1]+processing[1][0];

   for(i=1;i<n;i++)
   {
      //for being on station i of block 1
      dp[0][i]=min(dp[0][i-1],dp[1][i-1]+transfer[1][i-1])+processing[0][i];

      //for being on station i of buffer 2
      dp[1][i]=min(dp[1][i-1],dp[0][i-1]+transfer[0][i-1])+processing[1][i];
   }

   //exiting from the blistering/cartonpacking
   dp[0][n]=dp[0][n-1]+exit[0];
   dp[1][n]=dp[1][n-1]+exit[1];

   return min(dp[0][n],dp[1][n]);
}

int main()
{
   int i,n;
   vector<int> entry(2), exit(2);

   cout<<"11 ";
   cin>>n;

   vector<vector<int> > processing(2, vector<int> (n));
   vector<vector<int> > transfer(2, vector<int> (n-1));

   cout<<"Enter the entry time for dispensing and QC
        respectively"<<endl;
   cin>>entry[0]>>entry[1];


   cout<<"Enter the exit time for blistering and cartonpacking
```

```
        respectively"<<endl;
    cin>>exit[0]>>exit[1];

    cout<<"Entry the processing time at all staions on buffer 1"<<endl;
    for(i=0;i<n;i++)
    cout<<"Enter the processing time at all staions on buffer 1"<<endl;
    for(i=0;i<n;i++)
    cin>>processing[0][i];

    cout<<"Entry the processing time at all staions on buffer 2"<<endl;
    for(i=0;i<n;i++)
        cin>>processing[1][i];

    cout<<"Enter the throughput time from each station of buffer 1 to next station of buffer 2"<<endl;
    for(i=0;i<n-1;i++)
        cin>>transfer[0][i];

    cout<<"Enter the transfer time from each station of buffer 2 to next station of buffer 1"<<endl;
    for(i=0;i<n-1;i++)
        cin>>transfer[1][i];

    cout<<"The minimum cycle time required to get all the jobs done is "<<endl;
    cout<<assemblyLineScheduling(n, entry, exit, processing, transfer);


    cout<<endl;
    return 0;
}
```

Appendix B

SIMULATION STAGE 1

STAGE.MOD

```
BEGIN;
                              !Initial Finished parts at
     CREATE,           3,0:   Endbuffer
             :
     NEXT(Endbuff);
     CREATE,           1,0:   !Initial parts at Buffer2
             :
             NEXT(Buff2);

     CREATE,           1,0:   !Initial parts at Buffer1
             :
             NEXT(Buff1);

     CREATE,           1,0:   !Initial parts at Conveyor
             :
             NEXT(Conveyor);

     CREATE:   UNIF(1440,1584,2):
               MARK(Arrtime);
     ASSIGN:   Type=DISC(.1,1,.4,2,.9,3,1,4): !Arrival of Kanbans
               X(5)=X(5)+1:
               X(6)=X(6)+Type;

    BRANCH, 1:
             IF,(X(6).ge.2).and.(X(5).eq.1),Label1:
             IF,(X(6).ge.12).and.(X(5).ge.2),label1:
             ELSE,Label2;           ! send a green Kanban to board 2 (normal)

Label1ASSIGN:      X(6)=0;
                                 ! Send a yellow Kanban to The preceding block  or block
     DUPLICATE:  1, Board1;  2

Label2  BRANCH, 1:
             IF,Type.eq.1,Labela:
             IF,Type.eq.2,labelb:
             IF,Type.eq.3,Labelc:
             ELSE,Labeld;

labela DUPLICATE: 1,Customer; COUNT: Kanban30:DISPOSE;
labelb DUPLICATE: 2,Customer; COUNT: Kanban60:DISPOSE;
labelc DUPLICATE: 3,Customer; COUNT: Kanban90:DISPOSE;
labeld DUPLICATE: 4,Customer; COUNT: Kanban120:DISPOSE;

                                           !Queues for Kanban cards at Display Board
Customer  QUEUE,     CustomerQ:       2
          DETACH;
Endbuff   QUEUE,     EndbufferQ:     !Queues for Finished parts at Endbuffer
          DETACH;
          MATCH:     Endbuff,Board2:
             Customer;

Board2   QUEUE,     Board2Q:       !Queues for Kanban cards at Display Board 2
         DETACH;
Buff2    QUEUE,     Buffer2Q:      !Queues for Finished parts at Endbuffer
         DETACH;
          MATCH:    Buff2,Block3:
             Board2;

Block3   QUEUE,     Workstat3Q;     !Start processing at Block 3
```

```
        SEIZE:      Workstat3;
                    Norm(120,20)
        DELAY:      ;
        RELEASE:    Workstat3;
        DUPLICAT
        E:          1,Endbuff;
        ASSIGN:     X(10)=X(10)+30;
        COUNT:      Jobsdone;
        TALLY:      Flowtime,Tnow-Arrtime:DISPOSE;


Board1    QUEUE,         Board1Q:       !Queues for Kanban cards at Display Board 1
          DETACH;
Buff1     QUEUE,         Buffer1Q:      !Queues for materials represent 360 parts
          DETACH;
          MATCH:         Buff1,Block2:
              Board1;

Block2    QUEUE,           Workstat2Q;
          SEIZE:           Workstat2;
          DELAY:           Norm(2400,100)*.10;
          RELEASE:         Workstat2;
          DUPLICATE:       12,Buff2;
          DUPLICATE:       1,Board0;
          ASSIGN:          X(11)=X(11)+360;
          COUNT:           WIP3:DISPOSE;


Board0    QUEUE,         Board0Q:
          DETACH;
Conveyor  QUEUE,         ConveyorQ:
          DETACH;
          MATCH:         Conveyor,Block1:
              Board0;
Block1    QUEUE,           Workstat1Q;
          SEIZE:           Workstat1;
          DELAY:           Norm(240,20);
          RELEASE:         Workstat1;
          DUPLICATE:       1,Buff1;
          DUPLICATE:       1,Punch;
          ASSIGN:          X(12)=X(12)+360;
          COUNT:           WIP2:DISPOSE;

Punch     QUEUE,           PunchQ;
          SEIZE:           Punch;
          DELAY:           Norm(120,40);
          RELEASE:         Punch;
          DUPLICATE:       1,Conveyor;
          ASSIGN:          X(13)=X(13)+360;
          COUNT:           WIP1:DISPOSE;

END;
```

STAGE1.EXP

```
BEGIN;
PROJECT,    JIT manufacturing system,
             Ezema Chukwuedozie Nnaemeka;
ATTRIBUTES:      Arrtime:
            Type;
                    Workstat3
RESOURCES:       :
            Workstat2:
            Workstat1:
            Punch;
QUEUES:          CustomerQ:
            EndbufferQ:
            Buffer2Q:
            Buffer1Q:
            ConveyorQ:
            Board2Q:
            Board1Q:
            Board0Q:
            PunchQ:
            Workstat3Q:
            Workstat2Q:
            Workstat1Q;
COUNTERS:        Kanban30:
            Kanban60:
            Kanban90:
            Kanban120:
            Jobsdone:
            WIP3:
            WIP2:
            WIP1;
TALLIES:         Flowtime;
DSTATS:          NQ(CustomerQ):
            NQ(EndbufferQ):
            NQ(Buffer2Q):
            NQ(Buffer1Q):
            NQ(ConveyorQ):
            NQ(Workstat3Q):
            NQ(PunchQ):
            NR(Workstat3)*100,WS3 Utilisat.:
            NR(Workstat2)*100,WS2 Utilisat.:
            NR(Workstat1)*100,WS1 Utilisat.:
            NR(Punch)*100,Punch Utilisat.;
LAYOUTS:         "PBP-2.LAY",Type;
REPLICATE,       ,100,22400;
END;
```

STAGE1.OUT

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Department of Electronic/Computer Engineering

Replication 1 of 1

Project: JIT manufacturing system   Run execution date : 20/ 11/2016
Analyst: Ezema Chukwuedozie N.   Stage revision date: 21/ 06/2016

Replication ended at time : 20500.0

TALLY VARIABLES

Identifier	Average	Variation	Minimum	Maximum	Observations
Flowtime	10102.	.55172	304.16	21421.	109

DISCRETE-CHANGE VARIABLES

Identifier	Average	Variation	Minimum	Maximum	Final Value
NQ(CustomerQ)	1.8469	1.3855	.00000	9.0000	9.0000
NQ(EndbufferQ)	.89248	1.2828	.00000	3.0000	.00000
NQ(Buffer2Q)	3.1663	1.0935	.00000	11.000	9.0000
NQ(Buffer1Q)	.79359	.51000	.00000	1.0000	.00000
NQ(ConveyorQ)	.85126	.41801	.00000	1.0000	.00000
NQ(Workstat3Q)	.74427	1.2113	.00000	2.0000	2.0000
NQ(PunchQ)	.00000	--	.00000	.00000	.00000
WS3 Utilisat.	57.667	.85678	.00000	100.00	100.00
WS2 Utilisat.	10.529	2.9151	.00000	100.00	.00000
WS1 Utilisat.	10.112	2.9814	.00000	100.00	100.00
Punch Utilisat.	4.7614	4.4724	.00000	100.00	.00000

COUNTERS

Identifier	Count	Limit
Kanban30	6	Infinite
Kanban60	10	Infinite
Kanban90	25	Infinite
Kanban120	5	Infinite
Jobsdone	109	Infinite
WIP3	10	Infinite
WIP2	9	Infinite
WIP1	9	Infinite

Run Time: 0 min(s) 3 sec(s)
Simulation terminated by user.

STAGE2.MOD

```
BEGIN;

! ----------------- Initialisation of buffers --------------------

        CREATE,                     3,0: !Initial Finished parts at Endbuffer
                     :
                     NEXT(Endbuff);
        CREATE,                     1,0: !Initial parts at Buffer2
                     :
                     NEXT(Buff2);

        CREATE,                     1,0: !Initial parts at Buffer1
                     :
                     NEXT(Buff1);

        CREATE,                     1,0:
                     :
                     NEXT(Endbuff1);
        CREATE,                     1,0:
                     :
                     NEXT(Buff21);
        CREATE,                     1,0:
                     :
                     NEXT(Endbuff2);
        CREATE,                     1,0:
                     :
                     NEXT(Buff22);
        CREATE,                     1,0:
                     :
                     NEXT(Endbuff3);
        CREATE,                     1,0:
                     :
                     NEXT(Buff23);
        CREATE,                     1,0:
                     :
                     NEXT(Endbuff4);
        CREATE,                     1,0:
                     :
                     NEXT(Buff24);


!--------------- Arrivals of orders for items : JPF 113155/R9 ----------------

        CREATE:      UNIF(1440,1584,2):
                     MARK(Arrtime1);
        ASSIGN:      Type=DISC(0.1,1,0.4,2,0.9,3,1.0,4): !Arrival of green Kanbans
                     Priority=1:
                     X(10)=X(10)+1:
                     X(20)=X(20)+Type;

        BRANCH, 1:
                     IF,(X(20).ge.2).and.(X(10).eq.1),Label1:
                     IF,(X(20).ge.10).and.(X(10).ge.2),label1:
                     ELSE,Label2;

Label1      ASSIGN:       X(20)=0;
                                               !Send Kanbans to The preceding
        DUPLICATE:   1, Board1;                block

            BRANCH,
Label2   1:
                     IF,Type.eq.1,Labela:
                     IF,Type.eq.2,labelb:
                     IF,Type.eq.3,Labelc:
                     ELSE,Labeld;

labela                        1,Customer;
```

```
DUPLICATE:

        COUNT:      JPF113155_R9_Q30:DISPOSE;
labelb
DUPLICATE:            2,Customer;
        COUNT:      JPF113155_R9_Q60:DISPOSE;
        DUPLICATE
labelc :              3,Customer;
        COUNT:      JPF113155_R9_Q90:DISPOSE;
labeld
DUPLICATE:            4,Customer;
        COUNT:      JPF113155_R9_Q120:DISPOSE;

Customer  QUEUE,      CustomerQ:      !Queues for Kanban cards at Display Board 2
          DETACH;
Endbuff   QUEUE,      EndbufferQ:     !Queues for Finished parts at Endbuffer
          DETACH;
          MATCH:      Customer,Board2:
          Endbuff;


Board2  QUEUE,      Board2Q:      !Queues for Kanban cards at Display Board 2
        DETACH;
Buff2   QUEUE,      Buffer2Q:     !Queues for Finished parts at Endbuffer
        DETACH;
        MATCH:      Board2,Block3:
        Buff2;

! --------------- Arrivals of orders for high-volume items ----------------------

       CREATE:     UNIF(2520,3024):
                   MARK(Arrtime2);
       ASSIGN:     Type=DISC(.2,5,.5,6,.75,7,1.0,8):  ! Arrival of High-volume Kanbans
                   Priority=Type;
       BRANCH, 1:
                   IF,Type.eq.5,Labela1:
                   IF,Type.eq.6,labelb1:
                   IF,Type.eq.7,Labelc1:
                   ELSE,Labeld1;

labela1     DUPLICATE:        1, Customer1;
          COUNT:            JPM1137797_R11:DISPOSE;
labelb1     DUPLICATE:        1, Customer2;
          COUNT:            JPM113277_R3:DISPOSE;
labelc1     DUPLICATE:     1, Customer3;
          COUNT:            JPF113666_R24:DISPOSE;
labeld1     DUPLICATE:        1, Customer4;
          COUNT:            JPM1137627_R9:DISPOSE;


          ! ---- High-volume item 1 ---------

Customer1  QUEUE,                Customer1Q:     !Queues for Kanban cards at Display Board 2
             DETACH;
Endbuff1      QUEUE,             Endbuffer1Q:    !Queues for Finished parts at Endbuffer
             DETACH;
              MATCH:       Customer1,Board21:
             Endbuff1;


Board21       QUEUE,       Board21Q:           !Queues for Kanban cards at Display Board 2
             DETACH;
Buff21        QUEUE,         Buffer21Q:        !Queues for Finished parts at Endbuffer
             DETACH;
              MATCH:       Board21,Block3:
             Buff21;
```

```
! ---- High-volume item 2 ---------

Customer2  QUEUE,          Customer2Q:          !Queues for Kanban cards at Display Board 2
           DETACH;
Endbuff2   QUEUE,          Endbuffer2Q:         !Queues for Finished parts at Endbuffer
           DETACH;
           MATCH:          Customer2,Board22:
           Endbuff2;

Board22    QUEUE,          Board22Q:            !Queues for Kanban cards at Display Board 2
           DETACH;
Buff22     QUEUE,          Buffer22Q:           !Queues for Finished parts at Endbuffer
           DETACH;
           MATCH:          Board22,Block3:
           Buff22;

! ---- High-volume item 3 ---------

Customer3  QUEUE,          Customer3Q:          !Queues for Kanban cards at Display Board 2
           DETACH;
Endbuff3   QUEUE,          Endbuffer3Q:         !Queues for Finished parts at Endbuffer
           DETACH;
           MATCH:          Customer3,Board23:
           Endbuff3;

Board23    QUEUE,          Board23Q:            !Queues for Kanban cards at Display Board 2
           DETACH;
Buff23     QUEUE,          Buffer23Q:           !Queues for Finished parts at Endbuffer
           DETACH;
           MATCH:          Board23,Block3:
           Buff23;

! ---- High-volume item 4 ---------

Customer4  QUEUE,          Customer4Q:          !Queues for Kanban cards at Display Board 2
           DETACH;
Endbuff4   QUEUE,          Endbuffer4Q:         !Queues for Finished parts at Endbuffer
           DETACH;
           MATCH:          Customer4,Board24:
           Endbuff4;

Board24    QUEUE,          Board24Q:            !Queues for Kanban cards at Display Board 2
           DETACH;
Buff24     QUEUE,          Buffer24Q:           !Queues for Finished parts at Endbuffer
           DETACH;
           MATCH:          Board24,Block3:
           Buff24;

! -------------   Arrivals of orders for push-typed items ------------------------

      CREATE:    UNIF(1440,1584,2):
                 MARK(Arrtime3);
      ASSIGN:    Type=DISC(.2,9,.5,10,.8,11,1.0,12): !Arrival of Non-Kanban items
                 Priority=Type;
      BRANCH, 1:
                 IF,Type.eq.9,Push_A1:
                 IF,Type.eq.10,Push_A2:
                 IF,Type.eq.11,Push_A3:
                 ELSE,Push_A4;

Push_A1    DUPLICATE:    1, Block1;
           COUNT:        Non_Kanban_Item1:DISPOSE;
```

```
Push_A2    DUPLICATE:   1, Block1;
           COUNT:       Non_Kanban_Item2:DISPOSE;
Push_A3    DUPLICATE:   1, Block1;
           COUNT:       Non_Kanban_Item3:DISPOSE;
Push_A4    DUPLICATE:   1, Block1;
           COUNT:       Non_Kanban_Item4:DISPOSE;


! --------------  Production Processes (Block) III ---------------------


Block3     QUEUE,       Workstat3Q;        !Start processing at Block 3
           SEIZE:       Workstat3;
        ASSIGN:                  OpFactor=BatchF(Type);
        DELAY:        Norm(123,20)*OpFactor;
        RELEASE:      Workstat3;

       BRANCH, 1:
                 IF,(Type.ge.5).and.(Type.le.8),CountB3a:
                 IF,Type.ge.9,CountB3b:
                 ELSE,CountB3c;

CountB3c  DUPLICATE:  1,EndBuff:NEXT(Countr1);
 CountB3a  BRANCH, 1:
                 IF,Type.eq.5,Dupl3:
                 IF,Type.eq.6,Dupl4:
                 IF,Type.eq.7,Dupl5:
                 ELSE,Dupl6;

 Dupl3  DUPLICATE:  1,EndBuff1:NEXT(Countr2);
 Dupl4  DUPLICATE:  1,EndBuff2:NEXT(Countr2);
 Dupl5  DUPLICATE:  1,EndBuff3:NEXT(Countr2);
 Dupl6  DUPLICATE:  1,EndBuff4:NEXT(Countr2);


 Countr1    COUNT:         Total_Prod_JPF113155_R9;
            TALLY:        Flowtime1,Tnow-Arrtime1:DISPOSE;
 Countr2    DUPLICATE:  1,Block2;
            COUNT:                                              Total_Prod_High_Volume;
            TALLY:        Flowtime2,Tnow-Arrtime2:DISPOSE;
 CountB3b  COUNT:                                               Total_Prod_Non_Kanban;
            TALLY:        Flowtime3,Tnow-Arrtime3:DISPOSE;


 ! --------------  Production Processes (Block) II ---------------------


 Board1   QUEUE,       Board1Q:                      !Queues for Kanban cards at Display Board 1
          DETACH;
 Buff1    QUEUE,       Buffer1Q:                       !Queues for materials represent 360 parts
          DETACH;
          MATCH:       Board1,Block2:
          Buff1;


 Block2   QUEUE,       Workstat2Q;
          SEIZE:       Workstat2;
          ASSIGN:      OpFactor=TypeF(Type)*BatchF(Type);
          DELAY:       Norm(210.17,90)*OpFactor;
          RELEASE:     Workstat2;

       BRANCH, 1:
                 IF,(Type.ge.5).and.(Type.le.8),CountB2a:
                 IF,Type.ge.9,CountB2b:
                 ELSE,CountB2c;

 CountB2c  DUPLICATE:  12,Buff2:NEXT(Counter1);

 CountB2a  BRANCH, 1:
```

```
                  IF,Type.eq.5,Dup33:
                  IF,Type.eq.6,Dup44:
                  IF,Type.eq.7,Dup55:
                  ELSE,Dup66;

Dup33   DUPLICATE:   1,Buff21:NEXT(Counter2);
Dup44   DUPLICATE:   1,Buff22:NEXT(Counter2);
Dup55   DUPLICATE:   1,Buff23:NEXT(Counter2);
Dup66   DUPLICATE:   1,Buff24:NEXT(Counter2);


Counter1     DUPLICATE:     1,Block1;
             COUNT:             OutBlock2_JPF113155_R9:DISPOSE;

Counter2     DUPLICATE:     1,Block1;
       COUNT:          OutBlock2_High_Volume:DISPOSE;

CountB2b     DUPLICATE:     1,Block3;
              COUNT:             OutBlock2_Non_Kanban:DISPOSE;


! --------------     Production Processes (Block) I ----------------------

BLock1  QUEUE,          Workstat1Q;
          SEIZE:          Workstat1;

       BRANCH, 1:
                  IF,(Type.le.4),LopF1:
                  ELSE,LopF2;

 LopF1   ASSIGN:      OpFactor=BatchF(Type)*(3000/360):NEXT(Ldelay);
 LopF2   ASSIGN:      OpFactor=BatchF(Type);
 Ldelay   DELAY:      Norm(20,5)*OpFactor;
          RELEASE:   Workstat1;

      BRANCH, 1:
                 IF,(Type.ge.5).and.(Type.le.8),CountPa:
                 IF,Type.ge.9,CountPb:
                 ELSE,CountPc;

CountPc          DUPLICATE:              1,Buff1;
                 COUNT:                  OutBlock1_JPF113155_R9:DISPOSE;
CountPa          COUNT:                  OutBlock1_High_Volume:DISPOSE;
CountPb          DUPLICATE:              1,Block2;
                 COUNT:                  OutBlock1_Non_Kanban:DISPOSE;

END;
```

Appendix C1

SIMULATION STAGE 2

STAGE2.EXP

```
BEGIN;
PROJECT,    JIT Manufacturing System,
            Ezema Chukwuedozie Nnaemeka;
ATTRIBUTES:     Arrtime1:
            Arrtime2:
            Arrtime3:
            OpFactor:
            Type:
            Priority;
VARIABLES:      TypeF(12),1.0,1.0,1.0,1.0,1.50,
            1.50,1.00,1.50,1.50,1.50,1.50,
            1.50:
            BatchF(12),1,1,1,1,3.80,6.0,5.0,
            2.0,3.3,3.3,3.3,3.3;
SCHEDULES:      1,1*EXPO(10080),0*720:
            2,1*20160,0*240;
RESOURCES:      Workstat3,SCHED(2):
            Workstat2,SCHED(1):
            Workstat1,SCHED(2);
QUEUES:         CustomerQ:
            EndbufferQ:
            Buffer2Q:
            Buffer1Q:
            Board2Q:
            Board1Q:
            Customer1Q:
            Endbuffer1Q:
            Board21Q:
            Buffer21Q:
            Customer2Q:
            Endbuffer2Q:
            Board22Q:
            Buffer22Q:
            Customer3Q:
            Endbuffer3Q:
            Board23Q:
            Buffer23Q:
            Customer4Q:
            Endbuffer4Q:
            Board24Q:
            Buffer24Q:
            Workstat3Q:
            Workstat2Q:
            Workstat1Q;
COUNTERS:       JPF113155_R9_Q30:
            JPF113155_R9_Q60:
            JPF113155_R9_Q90:
            JPF113155_R9_Q120:
            JPM1137797_R11:
            JPM113277_R3:
            JPF113666_R24:
            JPM1137627_R9:
            Non_Kanban_Item1:
            Non_Kanban_Item2:
            Non_Kanban_Item3:
            Non_Kanban_Item4:
            Total_Prod_JPF113155_R9:
            Total_Prod_High_Volume:
            Total_Prod_Non_Kanban:
            OutBlock2_JPF113155_R9:
```

```
		OutBlock2_High_Volume:
		OutBlock2_Non_Kanban:
		OutBlock1_JPF113155_R9:
		OutBlock1_High_Volume:
		OutBlock1_Non_Kanban;
TALLIES:	Flowtime1:
		Flowtime2:
		Flowtime3;

DSTATS:		NQ(CustomerQ):
		NQ(Customer1Q):
		NQ(Customer2Q):
		NQ(Customer3Q):
		NQ(Customer4Q):
		NQ(EndbufferQ):
		NQ(Endbuffer1Q):
		NQ(Endbuffer2Q):
		NQ(Endbuffer3Q):
		NQ(Endbuffer4Q):
		NQ(Buffer2Q):
		NQ(Buffer21Q):
		NQ(Buffer22Q):
		NQ(Buffer23Q):
		NQ(Buffer24Q):
		NQ(Buffer1Q):
		NQ(Workstat3Q):
		NQ(Workstat2Q):
		NQ(Workstat1Q):
		NR(Workstat3)*100,WS3 Utilisat.:
		NR(Workstat2)*100,WS2 Utilisat.:
		NR(Workstat1)*100,WS1 Utilisat.;
REPLICATE,	10,100,40320;
END;
```

STAGE2.OUT

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Department of Electronic/Computer Engineering

Summary for Replication 1 of 10

Project: JIT Manufacturing System   Run execution date : 20/ 11/2016
Analyst: Ezema Chukwuedozie Nnaemeka   Model revision date: 20/ 11/2016

Replication ended at time : 30210.0

TALLY VARIABLES

Identifier	Average	Variation	Minimum	Maximum	Observations
Flowtime1	345.61	.75480	77.560	1560.5	65
Flowtime2	620.40	.39371	231.96	1199.7	15
Flowtime3	2025.0	.31462	1239.0	3702.0	14

DISCRETE-CHANGE VARIABLES

Identifier	Average	Variation	Minimum	Maximum	Final Value
NQ(CustomerQ)	.01516	8.0591	.00000	1.0000	.00000
NQ(Customer1Q)	.00000	--	.00000	1.0000	.00000
NQ(Customer2Q)	.00000	--	.00000	1.0000	.00000
NQ(Customer3Q)	.00000	--	.00000	1.0000	.00000
NQ(Customer4Q)	.00000	--	.00000	1.0000	.00000
NQ(EndbufferQ)	2.3812	.43261	.00000	3.0000	3.0000
NQ(Endbuffer1Q)	.95655	.21237	.00000	1.0000	1.0000
NQ(Endbuffer2Q)	.88730	.35640	.00000	1.0000	1.0000
NQ(Endbuffer3Q)	.93669	.25998	.00000	1.0000	1.0000
NQ(Endbuffer4Q)	.98574	.12028	.00000	1.0000	1.0000
NQ(Buffer2Q)	6.0154	.60006	.00000	14.000	5.0000
NQ(Buffer21Q)	.83660	.44194	.00000	1.0000	1.0000
NQ(Buffer22Q)	.58340	.84504	.00000	1.0000	1.0000
NQ(Buffer23Q)	.74884	.57914	.00000	1.0000	.00000
NQ(Buffer24Q)	.89441	.34360	.00000	1.0000	1.0000
NQ(Buffer1Q)	.82898	.45420	.00000	1.0000	1.0000
NQ(Workstat3Q)	.44130	2.0574	.00000	4.0000	.00000
NQ(Workstat2Q)	.54409	1.1588	.00000	2.0000	1.0000
NQ(Workstat1Q)	.00613	12.733	.00000	1.0000	.00000
WS3 Utilisat.	55.690	.89200	.00000	100.00	.00000
WS2 Utilisat.	88.548	.35962	.00000	100.00	100.00
WS1 Utilisat.	8.4997	3.2810	.00000	100.00	.00000

COUNTERS

Identifier	Count	Limit
JPF113155_R9_Q30	4	Infinite
JPF113155_R9_Q60	7	Infinite
JPF113155_R9_Q90	14	Infinite
JPF113155_R9_Q120	2	Infinite
JPM1137797_R11	2	Infinite
JPM113277_R3	6	Infinite
JPF113666_R24	5	Infinite
JPM1137627_R9	2	Infinite
Non_Kanban_Item1	3	Infinite
Non_Kanban_Item2	6	Infinite
Non_Kanban_Item3	3	Infinite
Non_Kanban_Item4	3	Infinite
Total_Prod_JPF113155_R	65	Infinite
Total_Prod_High_Volume	15	Infinite

Total_Prod_Non_Kanban	14	Infinite
OutBlock2_JPF113155_R9	6	Infinite
OutBlock2_High_Volume	14	Infinite
OutBlock2_Non_Kanban	14	Infinit e
OutBlock1_JPF113155_R9	6	Infinite
OutBlock1_High_Volume	14	Infinite
OutBlock1_Non_Kanban	15	Infinite

Appendix C2

RESULTS OF THE SIMULATION SUB-MODELS

This appendix C2 contains the results of the six simulation sub-models namely: Supplier Sub Model, Route Sub-Model, Kanban Sub Model, Production Sub Model, Consumption Sub Model and Plant Sub Model (Fig. 3.28 – Fig. 3.33).

Project:JIT Manufacturing Simulation Run execution date : 20/11/2016

Analyst:Ezema Chukwuedozie .N Model revision date: 20/11/2016

Replication ended at time : 192000.0
Statistics were cleared at time: 20000.0

Statistics accumulated for time: 172000.0

TALLY VARIABLES

Identifier	Average	Half Width	Minimum	Maximum	Observations
Route Process.TotalTim	400.00	.00000	400.00	400.00	431
Supplier Process Load.	49.997	.01743	49.416	50.569	430
Supplier Process Dock.	49.999	.01510	49.515	50.508	430
Consumption Process.To	49.996	.00690	49.211	50.812	3397
Plant Process Dock.VAT	199.99	.02319	199.32	200.49	430
Route Process.VATimePe	400.00	.00000	400.00	400.00	431
Production Process.VAT	50.782	2.2691	.02786	383.82	3360
Production Process.Tot	1672.4	(Corr)	6.3602	4307.9	3360
Production Process.Wai	1621.6	(Corr)	.00000	4255.5	3360
Supplier Process Load.	49.997	.01743	49.416	50.569	430
Plant Process Docking.	.00000	.00000	.00000	.00000	430
Consumption Process.VA	49.996	.00690	49.211	50.812	3397
Plant Process Dock.Tot	199.99	.02319	199.32	200.49	430
Plant Process Load.VAT	50.000	.00000	50.000	50.000	430
Supplier Process Dock.	49.999	.01510	49.515	50.508	430
Plant Process Docking.	199.99	.01757	199.35	200.55	430
Plant Process Docking.	199.99	.01757	199.35	200.55	430
Plant Process Load.Tot	50.000	.00000	50.000	50.000	430
PALLETS.VATime	--	--	--	--	0
PALLETS.NVATime	--	--	--	--	0
PALLETS.WaitTime	--	--	--	--	0
PALLETS.TranTime	--	--	--	--	0
PALLETS.OtherTime	--	--	--	--	0
PALLETS.TotalTime	--	--	--	--	0
PARTS.VATime	258.43	(Corr)	49.211	749.61	6794
PARTS.NVATime	.00000	.00000	.00000	.00000	6794
PARTS.WaitTime	27708.	(Corr)	.00000	96715.	6794
PARTS.TranTime	700.00	.00000	.00000	1400.0	6794
PARTS.OtherTime	.00000	.00000	.00000	.00000	6794
PARTS.TotalTime	3759.0	(Corr)	49.668	8287.8	6794
Conveyor.VATime	--	--	--	--	0
Conveyor.NVATime	--	--	--	--	0
Conveyor.WaitTime	--	--	--	--	0
Conveyor.TranTime	--	--	--	--	0
Conveyor.OtherTime	--	--	--	--	0
Conveyor.TotalTime	--	--	--	--	0
KANBAN.VATime	--	--	--	--	0
KANBAN.NVATime	--	--	--	--	0
KANBAN.WaitTime	--	--	--	--	0
KANBAN.TranTime	--	--	--	--	0
KANBAN.OtherTime	--	--	--	--	0
KANBAN.TotalTime	--	--	--	--	0
CYCLE.VATime	--	--	--	--	0
CYCLE.NVATime	--	--	--	--	0
CYCLE.WaitTime	--	--	--	--	0
CYCLE.TranTime	--	--	--	--	0
CYCLE.OtherTime	--	--	--	--	0
CYCLE.TotalTime	--	--	--	--	0
Consumption Hold Suppl	1875.6	(Corr)	.00000	2430.7	3397
Production Hold Order.	42648.	(Corr)	20018.	46404.	3360

Production Process.Que	1621.6	(Corr)	.00000	4255.5	3360
Supplier Hold Kanban.Q	329.91	.49206	49.515	400.75	4195
Production Batch.Queue	77.314	3.5287	.00000	510.84	3360
Kanban Hold Transport.	225.93	(Corr)	3.8518	388.33	842
Consumption Hold Palle	467.13	(Corr)	79.667	1022.0	708
Supplier Hold Pickup.Q	49.998	.01733	49.416	50.569	839
Consumption Hold Part.	73.765	(Insuf)	.05601	200.08	18
Plant Hold Kanban.Queu	50.000	.00000	50.000	50.000	840
Production Hold Transp	1748.2	(Corr)	8.9555	3552.9	834
Consumption Seize.Queu	1502.0	(Corr)	.00000	4889.1	3397
Plant Hold Trailer.Que	650.00	.03688	649.02	651.03	431
Plant Request.Queue.Wa	.00000	.00000	.00000	.00000	430
Kanban Hold Order.Queu	1173.2	(Corr)	861.49	2001.3	840
Plant Process Docking.	.00000	.00000	.00000	.00000	430

DISCRETE-CHANGE VARIABLES

Identifier	Average	Half Width	Minimum	Maximum	Final Value
Supply Level for Consu	36.791	(Corr)	.00000	43.000	3.0000
PALLETS.WIP	.00000	(Insuf)	.00000	.00000	.00000
PARTS.WIP	1067.2	(Corr)	1015.0	1118.0	1107.0
Conveyor.WIP	10.000	(Insuf)	10.000	10.000	10.000
KANBAN.WIP	31.000	(Insuf)	31.000	31.000	31.000
CYCLE.WIP	1.0000	(Insuf)	1.0000	1.0000	1.0000
PRODUCTION RESOURCE.Nu	.99254	.01230	.00000	1.0000	1.0000
PRODUCTION RESOURCE.Nu	1.0000	(Insuf)	1.0000	1.0000	1.0000
PRODUCTION RESOURCE.Ut	.99254	.01230	.00000	1.0000	1.0000
CONSUMPTION RESOURCE.N	.99525	.00571	.00000	1.0000	1.0000
CONSUMPTION RESOURCE.N	1.0000	(Insuf)	1.0000	1.0000	1.0000
CONSUMPTION RESOURCE.U	.99525	.00571	.00000	1.0000	1.0000
PLANT RESOURCE.NumberB	.49999	(Corr)	.00000	1.0000	1.0000
PLANT RESOURCE.NumberS	1.0000	(Insuf)	1.0000	1.0000	1.0000
PLANT RESOURCE.Utiliza	.49999	(Corr)	.00000	1.0000	1.0000
Consumption Hold Suppl	36.791	(Corr)	.00000	43.000	3.0000
Production Hold Order.	867.33	(Corr)	821.00	900.00	883.00
Production Process.Que	31.675	(Corr)	.00000	78.000	16.000
Supplier Hold Kanban.Q	8.0470	(Corr)	.00000	10.000	7.0000
Production Batch.Queue	1.5125	.05257	.00000	4.0000	3.0000
Kanban Hold Transport.	1.1027	(Corr)	.00000	2.0000	.00000
Consumption Hold Palle	1.9124	(Corr)	.00000	6.0000	.00000
Supplier Hold Pickup.Q	.24389	.00484	.00000	2.0000	.00000
Consumption Hold Part.	.00772	(Insuf)	.00000	1.0000	.00000
Plant Hold Kanban.Queu	.24419	.00535	.00000	2.0000	2.0000
Production Hold Transp	8.5656	(Corr)	.00000	18.000	15.000
Consumption Seize.Queu	30.719	(Corr)	.00000	92.000	85.000
Plant Hold Trailer.Que	1.6250	(Corr)	1.0000	2.0000	1.0000
Plant Request.Queue.Nu	.00000	(Insuf)	.00000	.00000	.00000
Kanban Hold Order.Queu	5.7382	(Corr)	4.0000	9.0000	8.0000
Plant Process Docking.	.00000	(Insuf)	.00000	.00000	.00000

OUTPUTS

Identifier	Value
Plant Process Docking	430.00
Production Process Num	3360.0
Supplier Process Dock	430.00
Supplier Process Dock	21499.
Plant Process Load Num	431.00
Production Process Acc	1.7063E+05
Production Process Num	3360.0
Plant Process Load Acc	21500.
Route Process Number O	431.00
Production Process Acc	5.4488E+06
Plant Process Docking	430.00
Supplier Process Load	430.00
Route Process Accum VA	1.7240E+05
Supplier Process Dock	430.00
Consumption Process Nu	3397.0
Plant Process Docking	.00000
Plant Process Dock Num	430.00
Plant Process Load Num	430.00
Supplier Process Load	21498.
Plant Process Dock Num	430.00
Supplier Process Load	430.00
Consumption Process Ac	1.6984E+05

Consumption Process Nu	3397.0
Route Process Number I	431.00
Plant Process Docking	85999.
Plant Process Dock Acc	85997.
PALLETS.NumberIn	.00000
PALLETS.NumberOut	.00000
PARTS.NumberIn	7673.0
PARTS.NumberOut	7634.0
Conveyor.NumberIn	.00000
Conveyor.NumberOut	.00000
KANBAN.NumberIn	.00000
KANBAN.NumberOut	.00000
CYCLE.NumberIn	.00000
CYCLE.NumberOut	.00000
PRODUCTION RESOURCE.Ti	3360.0
PRODUCTION RESOURCE.Sc	.99254
CONSUMPTION RESOURCE.T	3397.0
CONSUMPTION RESOURCE.S	.99525
PLANT RESOURCE.TimesUs	430.00
PLANT RESOURCE.Schedul	.49999
System.NumberOut	6794.0

Run execution date : 20/11/2016

Analyst:Ezema Chukwuedozie .N

Model revision date: 20/11/2016

OUTPUTS

Identifier	Average	Half-width	Minimum	Maximum	# Replications
Plant Process Docking	430.00	.00000	430.00	430.00	5
Production Process Num	3386.6	31.524	3360.0	3428.0	5
Supplier Process Dock	430.00	.00000	430.00	430.00	5
Supplier Process Dock	21497.	3.5410	21493.	21499.	5
Plant Process Load Num	431.00	.00000	431.00	431.00	5
Production Process Acc	1.6810E+05	3082.4	1.6435E+05	1.7063E+05	5
Production Process Num	3389.6	37.425	3360.0	3436.0	5
Plant Process Load Acc	21500.	.00000	21500.	21500.	5
Route Process Number O	431.00	.00000	431.00	431.00	5
Production Process Acc	3.2507E+06	1.7475E+06	1.7222E+06	5.4488E+06	5
Plant Process Docking	430.00	.00000	430.00	430.00	5
Supplier Process Load	430.00	.00000	430.00	430.00	5
Route Process Accum VA	1.7240E+05	.00000	1.7240E+05	1.7240E+05	5
Supplier Process Dock	430.00	.00000	430.00	430.00	5
Consumption Process Nu	3390.6	43.154	3345.0	3440.0	5
Plant Process Docking	.00000	.00000	.00000	.00000	5
Plant Process Dock Num	430.00	.00000	430.00	430.00	5
Plant Process Load Num	430.00	.00000	430.00	430.00	5
Supplier Process Load	21500.	6.4986	21494.	21506.	5
Plant Process Dock Num	430.00	.00000	430.00	430.00	5
Supplier Process Load	430.00	.00000	430.00	430.00	5
Consumption Process Ac	1.6952E+05	2167.9	1.6724E+05	1.7201E+05	5
Consumption Process Nu	3390.6	43.154	3345.0	3440.0	5
Route Process Number I	431.00	.00000	431.00	431.00	5
Plant Process Docking	85998.	1.2219	85997.	85999.	5
Plant Process Dock Acc	86000.	3.9167	85997.	86005.	5
PALLETS.NumberIn	.00000	.00000	.00000	.00000	5
PALLETS.NumberOut	.00000	.00000	.00000	.00000	5
PARTS.NumberIn	7652.4	62.890	7565.0	7696.0	5
PARTS.NumberOut	7628.6	93.710	7532.0	7739.0	5
Conveyor.NumberIn	.00000	.00000	.00000	.00000	5
Conveyor.NumberOut	.00000	.00000	.00000	.00000	5
KANBAN.NumberIn	.00000	.00000	.00000	.00000	5
KANBAN.NumberOut	.00000	.00000	.00000	.00000	5
CYCLE.NumberIn	.00000	.00000	.00000	.00000	5
CYCLE.NumberOut	.00000	.00000	.00000	.00000	5
PRODUCTION RESOURCE.Ti	3386.6	31.524	3360.0	3428.0	5
PRODUCTION RESOURCE.Sc	.97727	.01831	.95499	.99254	5
CONSUMPTION RESOURCE.T	3390.6	43.154	3345.0	3440.0	5
CONSUMPTION RESOURCE.S	.98714	.01367	.97241	1.0000	5
PLANT RESOURCE.TimesUs	430.00	.00000	430.00	430.00	5
PLANT RESOURCE.Schedul	.49999	7.6055E-06	.49998	.50000	5
System.NumberOut	6781.2	86.308	6690.0	6880.0	5

Simulation run time: 0.27 minutes.
Simulation run complete.

Appendix D

SCIENTIFIC NAMES AND DOSAGE OF ITEMS PRODUCED BY JUHEL DRUG PROCESS PLANT

NO.	DRUG	SCIENTIFIC NAME & DOSAGE	ITEM NO. (Article N0.)
1	Paracetamol	Paracetamol 500mg	JPAP308002/R1
2	Barbimycin	Erythromycin	JPM113277/R3
3	Barbimox	Amoxicillin 500mg	JPF113666/R24
4	Jutrim	Cotrimoxazole 480mg	JPM1137627/R9
5	Cipro-J	Ciprofloxacin 500mg	JPM1137856/R3
6	Jugyl	Metronidazole 200mg	JPM113164/R2
7	Tetracyline	Tetracyline 250mg	JPM1131899/R3
8	Barbicillin	Ampicillin 250mg	JPM113148/R7A
9	Cetal	Paracetamol 120mg	JPF113155/R9
10	Barbiclox	Ampicillin+Cloxacillin 250mg	JPM1137797/R11
11	Barbimol	Paracetamol 125mg	JPM1137852/R5
12	Combifen	Paracetamol 125mg	JPM1137857/R9
13	Aspirin	Aspirin 300mg	JPM113117/R4
14	Pastin Extra	Paracetamol+Caffeine	JPM113165/R1
15	Juroxicam	Piroxicam 20mg	JPK1193069/R4
16	Asco-J-100	Ascorbic Acid 100mg	JPK1193027/R14
17	Asco-J-100	Ascorbic Acid 500mg	JPF1134353/R5
18	Vitamin-C	Vitamin C 100mg	JPM113166/R2
19	Vitamin B-Complex	Vitamin B	JPMP113222/R1
20	Folic Acid	Ciprofloxacin	JPM1137833/R4
21	Calcium Lactate	Calcium Lactate300mg	JPM1131137797/R11
22	J-Vite Multivitamins	Multivitamin	JPM1137890/R5
23	Flu-J	Paracetamol+Chloropheniramine Maleate+Ascorbic Acid 500mg/2mg/25mg	JPK1193015/R5
24	Flu-J Non Drowsy	Paracetamol+cetirizine 500mg/2.5mg	JPA1197819/R1
25	Flu-J Non Drowsy	Paracetamol+cetirizine 250mg	JPK1193030/R3
26	Predni-J	Prednisolone 5mg	JPM113118/R8
27	Chloroquine	Chloroquine Phosphate 250mg	JPF1130963/R4
28	Artemelum	Glibenclamide 5mg	JPM1137845/R5
29	Malcidal	Sulphadoxin+Pyrimethamine 500mg/25mg	JPM113163/R1
30	Gliben-J	Glibenclamide 5mg	JPM1134576/R1
31	Julisil	Compound Magnesium Trisilicate	JPM1134575/R1
32	Sodamint	Sodium Bicarbonate 300mg	JPF113762/R23
33	Chlorpheniramine Maleate	Chlorpheniramine Maleate 4mg	JPA1193006/R6
34	Cet-10	Cetirizine 10mg	JPM1137627/R8
35	Vasoprin	Acetylsalicylic Acid 75mg	JPM1137848/R2
36	Vasoprin	Acetylsalicylic Acid 250mg	JPF1137602/R1
37	Vasoprin Enteric	Acetylsalicylic Acid 75mg	JPM1137842/R2
38	Juretic	Amiloride hydrochloride+Hydrochlorothiazide 5mg/50mg	JPF113144/R6
39	Junolol	Propranolol 40mg	JPF1137101/R2
40	Julium-5	Diazepam 5mg	JPA1193280/R6
41	Juvasc	Amlodipine Besylate 5mg	JPM1137681/R2
42	Juvasc-10	Amlodipine Besylate 10mg	JPF2011004/R3
43	Juxotan	Bromazepam 3mg	JPM1131337/R3
44	Hydrex	Hydrochlorothiazide 25mg	JPM1138218/R2A

MAJOR ITEMS PRODUCED BY JUHEL DRUG PROCESS PLANT
(Quantity > 100 and Value <₦40000)

NO.	ITEM NO.	QUANTITY	VOL (%)	CUMULATIVE	VALUE	VALUE (%)	CUMULATIVE
1	JPAP308002/R1	1.770	1,20	66,32	43.146	1,74	61,74
2	JPM113277/R3	28.240	19,15	31,36	287.088	11,57	26,26
3	JPF113666/R24	24.110	16,35	47,72	240.854	9,71	35,96
4	JPM1137627/R9	9.456	6,41	54,13	207.246	8,35	44,32
5	JPM1137856/R3	2.972	2,02	56,14	132.538	5,34	49,66
6	JPM113164/R2	3.456	2,34	58,49	88.588	3,57	53,23
7	JPM1131899/R3	2.928	1,99	60,47	65.356	2,63	55,86
8	JPM113148/R7A	2.202	1,49	61,97	52.812	2,13	57,99
9	JPF113155/R9	4.652	3,16	65,12	49.815	2,01	60,00
10	JPM1137797/R11	18.000	12,21	12,21	364.375	14,69	14,69
11	JPM1137852/R5	1.944	1,32	67,64	41.278	1,66	63,40
12	JPM1137857/R9	1.410	0,96	65,60	39.011	1,57	64,97
13	JPM113117/R4	1.476	1,00	69,60	36.297	1,46	66,44
14	JPM113165/R1	1.992	1,35	70,95	34.472	1,39	67,83
15	JPK1193069/R4	1.602	1,09	72,04	32.130	1,29	69,12
16	JPK1193027/R14	1.602	1,09	73,12	32.130	1,29	70,42
17	JPF1134353/R5	2.166	1,47	74,59	31.605	1,27	71,69
18	JPM113166/R2	1.800	1,22	75,81	30.922	1,25	72,94
19	JPMP113222/R1	752	0,51	76,32	30.060	1,21	74,15
20	JPM1137833/R4	840	0,57	76,89	29.512	1,19	75,34
21	JPM1131137797/R11	1.440	0,98	77,87	29.150	1,17	76,51
22	JPM1137890/R5	1.266	0,86	78,73	28.306	1,14	77,65
23	JPK1193015/R5	1.440	0,98	79,71	27.540	1,11	78,76
24	JPA1197819/R1	1.440	0,98	80,65	27.540	1,11	79,87
25	JPK1193030/R3	1.400	0,95	81,63	27.540	1,11	80,98
26	JPM113118/R8	1.104	0,75	82,38	26.496	1,07	82,05
27	JPF1130963/R4	2.526	1,71	84,09	22.888	0,92	82,97
28	JPM1137845/R5	756	0,51	84,61	22.437	0,90	83,88
29	JPM113163/R1	1.133	0,77	85,38	20.784	0,84	84,72
30	JPM1134576/R1	666	0,45	85,83	19.924	0,80	85,52
31	JPM1134575/R1	654	0,44	86,27	19.487	0,79	86,30
32	JPF113762/R23	1.080	0,73	87,00	19.359	0,78	87,08
33	JPA1193006/R6	1.602	1,09	88,09	18.289	0,74	87,82
34	JPM1137627/R8	988	0,67	88,76	17.731	0,71	88,54
35	JPM1137848/R2	502	0,34	89,10	17.009	0,69	89,22
36	JPF1137602/R1	1.326	0,90	90,00	16.863	0,65	89,90
37	JPM1137842/R2	852	0,58	90,58	16.117	0,65	90,55
38	JPF113144/R6	1.188	0,81	91,38	16.092	0,65	91,20
39	JPF1137101/R2	732	0,50	91,88	15.616	0,63	91,83
40	JPA1193280/R6	1.602	1,09	92,97	14.581	0,59	92,42
41	JPM1137681/R2	276	0,19	93,15	12.831	0,52	92,93
42	JPF2011004/R3	876	0,59	93,75	12.256	0,49	93,43
43	JPM1131337/R3	504	0,34	94,09	10.816	0,44	93,86
44	JPM1138218/R2A	420	0,28	94,37	9.528	0,38	94,25
	TOTAL	**154.610**			**2,312,582**		

Appendix E

RAW DATA

Appendix E presents the raw data generated from the ARENA simulation model. These data were then loaded into an Excel spreadsheet and sorted for uploading into SPSS for further statistical analyses. What is shown in the following 18 pages are the data in the Excel spreadsheet format.

JIT LOW LOW

Replication Number	MAS	MOH	MIX	Product A Period Demand	Product A Total Demand	Product A Period Shipped	Product A Total Shipped	Product A Period DFR	Product A Total DFR	Product A Period Cycle Time	Product A Total Cycle Time
1	3	1	1	1422	1422	1419	1419	1.00	1.00	266.95	266.95
2	3	1	1	1421	2843	1404	2823	1.00	1.00	283.06	274.96
3	3	1	1	1504	4347	1489	4311	1.00	1.00	320.94	290.83
4	3	1	1	1431	5778	1421	5732	1.00	1.00	289.50	290.50
5	3	1	1	1491	7269	1456	7188	1.00	1.00	321.60	295.79
6	3	1	1	1508	8777	1513	8701	1.00	1.00	323.18	301.37
7	3	1	1	1447	10224	1436	10137	1.00	1.00	333.21	305.88
8	3	1	1	1447	11671	1436	11573	1.00	1.00	295.76	304.63
9	3	1	1	1447	13118	1436	13008	1.00	1.00	298.94	304.00
10	3	1	1	1447	14565	1436	14444	1.00	1.00	297.68	303.37
11	3	1	1	1488	16053	1483	15927	1.00	1.00	361.58	308.79
12	3	1	1	1417	17470	1406	17333	1.00	1.00	274.89	306.04
13	3	1	1	1463	18933	1451	18784	1.00	1.00	312.51	306.54
14	3	1	1	1461	20394	1449	20233	1.00	1.00	244.12	302.07
15	3	1	1	1397	21791	1385	21618	1.00	1.00	305.66	302.30
16	3	1	1	1466	23256	1454	23072	1.00	1.00	277.23	300.72
17	3	1	1	1414	24670	1393	24466	1.00	1.00	291.94	300.22
18	3	1	1	1379	26049	1382	25847	1.00	1.00	270.11	298.61
19	3	1	1	1449	27498	1438	27286	1.00	1.00	323.28	299.91
20	3	1	1	1395	28893	1382	28667	1.00	1.00	213.00	295.72
21	3	1	1	1417	30310	1411	30078	1.00	1.00	247.33	293.46
22	3	1	1	1410	31720	1400	31478	1.00	1.00	342.24	295.62
23	3	1	1	1439	33159	1429	32907	1.00	1.00	204.89	291.68
24	3	1	1	1404	34563	1385	34292	1.00	1.00	290.19	291.62
25	3	1	1	1432	35995	1413	35705	1.00	1.00	295.06	291.40
26	3	1	1	1424	37419	1424	37129	1.00	1.00	242.64	289.53
27	3	1	1	1443	38862	1427	38556	1.00	1.00	343.57	291.53
28	3	1	1	1430	40292	1421	39977	1.00	1.00	247.36	289.96
29	3	1	1	1438	41730	1424	41401	1.00	1.00	312.35	290.73
30	3	1	1	1408	43138	1402	42803	1.00	1.00	303.86	291.16
31	3	1	1	1459	44597	1448	44251	1.00	1.00	377.34	293.98
32	3	1	1	1429	46026	1414	45665	1.00	1.00	321.75	294.84
33	3	1	1	1480	47506	1472	47137	1.00	1.00	364.01	297.00
34	3	1	1	1509	49015	1507	48644	1.00	1.00	339.61	298.32
35	3	1	1	1436	50451	1430	50074	1.00	1.00	295.17	298.23
36	3	1	1	1399	51850	1386	51460	1.00	1.00	242.17	296.72
37	3	1	1	1474	53324	1454	52914	1.00	1.00	295.99	296.70
38	3	1	1	1396	54720	1389	54303	1.00	1.00	337.75	297.75
39	3	1	1	1437	56157	1426	55729	1.00	1.00	234.05	296.12
40	3	1	1	1429	57586	1421	57150	1.00	1.00	348.00	297.41
41	3	1	1	1409	58995	1403	58553	1.00	1.00	334.14	298.29
42	3	1	1	1395	60390	1370	59923	1.00	1.00	284.29	297.97
43	3	1	1	1400	61790	1398	61321	1.00	1.00	272.63	297.39
44	3	1	1	1398	63188	1381	62702	1.00	1.00	239.73	296.12
45	3	1	1	1459	64647	1443	64145	1.00	1.00	361.02	297.68
46	3	1	1	1458	66105	1445	65590	1.00	1.00	321.18	298.10
47	3	1	1	1464	67569	1459	67049	1.00	1.00	362.90	299.51
48	3	1	1	1381	68950	1375	68424	1.00	1.00	261.69	298.75
49	3	1	1	1434	70384	1434	69858	1.00	1.00	304.11	298.86
50	3	1	1	1388	71772	1378	71236	1.00	1.00	285.42	298.60
51	3	1	1	1457	73229	1447	72683	1.00	1.00	315.18	298.93
52	3	1	1	1483	74712	1467	74150	1.00	1.00	313.59	299.22
53	3	1	1	1368	76080	1358	75508	1.00	1.00	293.68	299.12
54	3	1	1	1439	77519	1432	76940	1.00	1.00	349.63	300.06
55	3	1	1	1392	78911	1385	78325	1.00	1.00	285.92	299.81
56	3	1	1	1446	80357	1437	79762	1.00	1.00	305.36	299.91
57	3	1	1	1436	81793	1417	81179	1.00	1.00	230.02	298.69
58	3	1	1	1399	83192	1389	82568	1.00	1.00	252.32	297.91
59	3	1	1	1399	84591	1388	83956	1.00	1.00	265.25	297.37
60	3	1	1	1449	86040	1440	85396	1.00	1.00	262.52	298.30

Replication Number	Product B Period Demand	Product B Total Demand	Product B Period Shipped	Product B Total Shipped	Product B Period DFR	Product B Total DFR	Product B Period Cycle Time	Product B Total Cycle Time
1	359	359	352	352	1.00	1.00	264.03	264.03
2	342	701	331	683	1.00	1.00	303.33	283.49
3	403	1104	392	1075	1.00	1.00	335.43	302.43
4	359	1463	350	1425	1.00	1.00	312.98	305.02
5	342	1805	327	1752	0.95	0.99	343.38	312.18
6	338	2143	327	2079	0.99	0.99	328.01	314.67
7	356	2499	349	2428	0.99	0.99	351.15	319.91
8	356	2855	349	2777	0.99	0.99	304.70	318.00
9	355	3210	349	3126	0.99	0.99	309.44	317.06
10	356	3566	349	3474	0.99	0.99	307.53	316.09
11	351	3917	337	3811	0.99	0.99	391.41	322.75
12	346	4263	330	4141	0.99	0.99	277.07	319.11
13	337	4600	337	4478	0.99	0.99	349.27	321.38
14	346	4946	334	4812	0.99	0.99	246.31	316.10
15	358	5304	356	5168	0.99	0.99	314.38	315.98
16	353	5657	349	5517	0.99	0.99	275.99	313.45
17	366	6023	350	5867	0.99	0.99	303.90	312.88
18	357	6380	352	6219	0.99	0.99	293.27	311.77
19	349	6729	334	6553	0.99	0.99	360.03	314.23
20	354	7083	349	6902	0.99	0.99	217.52	309.34
21	346	7429	342	7244	0.99	0.99	254.90	306.77
22	390	7819	380	7624	0.99	0.99	380.20	310.43
23	384	8203	376	8000	0.99	0.99	211.92	305.80
24	339	8542	331	8331	0.99	0.99	296.24	305.42
25	341	8883	330	8661	0.99	0.99	305.42	305.42
26	348	9231	346	9007	0.99	0.99	254.14	303.46
27	367	9598	355	9362	0.99	0.99	376.71	306.19
28	333	9931	327	9689	0.99	0.99	249.30	304.27
29	378	10309	368	10057	0.99	0.99	343.36	306.70
30	379	10688	358	10415	0.99	0.99	298.43	305.46
31	363	11051	346	10761	0.99	0.99	401.24	308.53
32	362	11413	358	11119	0.99	0.99	321.57	308.96
33	356	11769	353	11472	0.99	0.99	388.62	311.34
34	346	12115	339	11811	0.99	0.99	374.06	313.14
35	364	12479	354	12165	0.99	0.99	320.01	313.34
36	352	12831	349	12514	0.99	0.99	259.20	311.83
37	397	13228	369	12883	0.99	0.99	298.21	311.44
38	359	13587	358	13241	0.99	0.99	361.37	312.79
39	361	13948	353	13594	0.99	0.99	250.79	311.18
40	359	14307	337	13931	0.99	0.99	375.26	312.73
41	386	14693	370	14301	0.99	0.99	335.53	313.32
42	342	15035	331	14632	0.99	0.99	290.33	312.80
43	369	15404	361	14993	0.99	0.99	292.03	312.30
44	368	15772	359	15352	0.99	0.99	246.02	310.76
45	379	16151	373	15725	0.99	0.99	373.57	312.24
46	353	16504	352	16077	0.99	0.99	352.89	313.13
47	367	16871	345	16422	0.99	0.99	385.96	314.66
48	369	17240	346	16768	0.99	0.99	256.51	313.46
49	382	17622	366	17134	0.99	0.99	300.82	313.19
50	386	18008	377	17511	0.99	0.99	289.50	312.68
51	346	18354	330	17841	0.99	0.99	349.98	313.37
52	370	18724	359	18200	0.99	0.99	325.03	313.60
53	381	19105	359	18559	0.99	0.99	311.53	313.56
54	376	19481	362	18921	0.99	0.99	371.06	314.66
55	349	19830	340	19261	0.99	0.99	314.09	314.65
56	353	20183	349	19610	0.99	0.99	320.27	314.76
57	339	20522	323	19933	0.99	0.99	248.02	313.62
58	348	20870	348	20281	0.99	0.99	275.16	312.98
59	356	21226	351	20632	0.99	0.99	260.63	312.41
60	380	21606	378	21010	0.99	0.99	369.55	313.42

Replication Number	Product C Period Demand	Product C Total Demand	Product C Period Shipped	Product C Total Shipped	Product C Period DFR	Product C Total DFR	Product C Period Cycle Time	Product C Total Cycle Time
1	86	86	82	82	0.96	0.96	353.25	353.25
2	95	181	82	164	0.88	0.97	365.57	359.41
3	87	268	72	236	0.91	0.96	404.84	380.22
4	84	352	81	317	0.95	0.96	395.64	384.16
5	98	450	91	408	0.95	0.96	385.68	384.50
6	86	536	76	484	0.95	0.96	421.44	390.30
7	91	627	83	567	0.95	0.96	389.86	391.70
8	91	719	83	650	0.95	0.96	381.25	390.37
9	91	810	83	733	0.95	0.96	384.47	389.70
10	91	901	83	816	0.95	0.96	383.14	389.03
11	110	1011	88	904	0.95	0.96	449.33	394.90
12	85	1096	81	985	0.95	0.96	405.97	395.81
13	86	1182	81	1066	0.95	0.96	437.13	398.96
14	75	1257	67	1133	0.95	0.96	369.69	397.22
15	98	1355	93	1226	0.95	0.96	404.60	397.76
16	81	1436	77	1303	0.95	0.96	360.89	395.60
17	88	1524	82	1385	0.95	0.96	401.17	395.93
18	92	1616	92	1477	0.95	0.96	374.58	394.60
19	97	1713	89	1566	0.95	0.96	419.94	396.04
20	78	1791	72	1638	0.95	0.96	331.20	393.19
21	94	1885	92	1730	0.95	0.96	337.91	390.25
22	111	1996	93	1823	0.95	0.96	425.14	392.03
23	63	2059	61	1884	0.95	0.96	315.43	389.56
24	88	2147	84	1968	0.95	0.96	402.90	390.12
25	87	2234	80	2048	0.95	0.96	394.98	390.31
26	75	2309	71	2119	0.95	0.96	335.99	388.49
27	105	2414	96	2215	0.95	0.96	401.64	389.06
28	82	2496	77	2292	0.95	0.96	360.66	387.77
29	97	2593	85	2377	0.95	0.96	390.57	387.87
30	95	2688	86	2463	0.95	0.96	379.56	387.58
31	109	2797	91	2554	0.95	0.96	441.47	389.50
32	91	2888	86	2640	0.95	0.96	415.90	390.36
33	94	2982	86	2726	0.95	0.96	460.27	392.25
34	92	3074	88	2814	0.95	0.96	433.82	393.56
35	80	3154	76	2890	0.95	0.96	400.39	393.73
36	77	3231	72	2962	0.95	0.96	331.61	392.22
37	79	3310	75	3037	0.95	0.96	397.89	392.36
38	89	3399	85	3122	0.95	0.96	427.25	393.31
39	70	3469	66	3188	0.95	0.96	325.69	391.91
40	100	3569	91	3279	0.95	0.96	449.92	393.52
41	108	3677	93	3372	0.95	0.96	396.42	393.60
42	96	3773	88	3460	0.95	0.96	370.80	393.02
43	79	3852	76	3536	0.95	0.96	391.62	392.99
44	88	3940	85	3621	0.95	0.96	325.26	391.40
45	100	4040	92	3713	0.95	0.96	416.42	392.02
46	86	4126	73	3786	0.95	0.96	394.09	392.06
47	103	4229	86	3872	0.95	0.96	466.35	393.71
48	78	4307	72	3944	0.95	0.96	367.42	393.23
49	90	4397	84	4028	0.95	0.96	390.83	393.18
50	84	4481	80	4108	0.95	0.96	412.18	393.56
51	86	4567	80	4188	0.95	0.96	432.81	394.30
52	91	4658	79	4267	0.95	0.96	407.26	394.54
53	108	4766	98	4365	0.95	0.96	374.60	394.09
54	96	4862	86	4451	0.95	0.96	451.54	395.20
55	95	4957	91	4542	0.95	0.96	364.25	394.58
56	85	5042	82	4624	0.95	0.96	412.06	394.89
57	80	5122	78	4702	0.95	0.96	333.40	393.87
58	80	5202	75	4777	0.95	0.96	377.95	393.62
59	80	5282	79	4856	0.95	0.96	369.72	393.22
60	83	5365	78	4933	0.95	0.96	448.24	394.09

Replication Number	Independent Variables: MAS	MOH	MIX	Product A: Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Total Cycle Time	Product B: Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Total Cycle Time	Product C: Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Total Cycle Time
1	3	1	2	1444	1444	1433	1433	1.00	1.00	549.61	549.61	674	674	524	524	0.81	0.81	556.76	556.76	205	205	76	76	0.38	0.38	363.62	363.62
2	3	1	2	1445	2889	1428	2861	1.00	1.00	555.36	552.48	665	1339	561	1085	0.81	0.81	501.77	559.69	186	391	76	152	0.40	0.39	400.52	382.07
3	3	1	2	1445	4334	1435	4296	1.00	1.00	540.42	548.46	703	2042	509	1594	0.81	0.81	504.46	548.95	168	559	82	234	0.42	0.40	427.99	398.16
4	3	1	2	1477	5811	1470	5766	1.00	1.00	559.49	551.01	721	2763	562	2156	0.77	0.80	549.70	549.09	190	749	69	303	0.40	0.40	362.11	389.95
5	3	1	2	1450	7261	1441	7207	1.00	1.00	556.36	552.08	708	3471	554	2710	0.80	0.80	550.65	549.40	165	914	72	375	0.46	0.41	424.90	396.66
6	3	1	2	1501	8762	1479	8686	1.00	1.00	562.42	553.84	745	4216	555	3265	0.80	0.80	554.17	550.21	178	1092	59	434	0.41	0.41	389.62	396.69
7	3	1	2	1467	10229	1459	10144	1.00	1.00	566.67	555.97	740	4956	557	3822	0.80	0.80	546.28	549.64	180	1272	67	501	0.41	0.41	389.89	394.92
8	3	1	2	1467	11697	1459	11602	1.00	1.00	572.94	558.11	740	5696	557	4379	0.80	0.80	546.13	549.07	180	1451	67	567	0.41	0.41	388.35	394.15
9	3	1	2	1467	13164	1459	13061	1.00	1.00	577.20	560.24	740	6436	557	4935	0.71	0.79	543.99	548.49	180	1631	67	634	0.41	0.41	386.81	393.38
10	3	1	2	1467	14631	1459	14519	1.00	1.00	581.47	562.37	740	7174	557	5491	0.79	0.79	542.84	547.92	180	1810	67	700	0.41	0.41	385.27	392.61
11	3	1	2	1412	16043	1397	15916	1.00	1.00	536.39	560.09	662	7836	542	6033	0.79	0.79	546.70	547.99	189	1999	80	780	0.41	0.41	388.32	392.17
12	3	1	2	1443	17486	1428	17344	1.00	1.00	587.62	560.71	715	8551	574	6607	0.79	0.79	562.61	549.26	158	2157	72	852	0.41	0.41	435.13	396.80
13	3	1	2	1459	18945	1456	18800	1.00	1.00	576.06	561.90	716	9267	551	7158	0.79	0.79	569.53	550.62	193	2350	69	921	0.41	0.41	359.63	393.09
14	3	1	2	1441	20386	1422	20222	1.00	1.00	550.52	561.10	682	9949	535	7693	0.79	0.79	547.23	550.57	202	2552	80	1001	0.41	0.41	382.70	392.26
15	3	1	2	1393	21779	1394	21616	1.00	1.00	541.72	559.65	726	10675	554	8247	0.79	0.79	533.00	549.39	180	2732	76	1077	0.41	0.41	411.53	393.62
16	3	1	2	1467	23246	1452	23068	1.00	1.00	544.44	558.88	694	11369	544	8791	0.79	0.79	538.59	548.74	168	2900	70	1147	0.41	0.41	409.84	394.61
17	3	1	2	1401	24647	1388	24456	1.00	1.00	542.49	557.95	698	12067	545	9336	0.79	0.79	542.74	548.39	196	3096	81	1228	0.41	0.41	394.31	394.59
18	3	1	2	1425	26072	1424	25880	1.00	1.00	553.59	557.71	725	12792	565	9901	0.79	0.79	545.24	548.21	183	3279	75	1303	0.41	0.41	395.81	394.66
19	3	1	2	1412	27484	1397	27277	1.00	1.00	544.24	557.02	731	13523	573	10474	0.79	0.79	530.11	547.22	191	3470	78	1381	0.41	0.41	385.45	394.14
20	3	1	2	1392	28876	1369	28646	1.00	1.00	540.91	556.25	691	14214	549	11023	0.79	0.79	532.36	546.48	185	3655	80	1461	0.41	0.41	418.98	395.50
21	3	1	2	1441	30317	1438	30084	1.00	1.00	552.69	556.08	691	14905	548	11571	0.79	0.79	561.68	547.20	177	3832	77	1538	0.41	0.41	397.90	395.62
22	3	1	2	1355	31672	1348	31432	1.00	1.00	555.61	556.06	723	15628	596	12169	0.79	0.79	541.30	546.91	177	4009	83	1621	0.41	0.41	420.42	396.89
23	3	1	2	1468	33140	1460	32892	1.00	1.00	539.39	556.32	714	16342	482	12651	0.79	0.79	483.39	544.49	192	4201	82	1703	0.41	0.41	396.89	396.89
24	3	1	2	1441	34581	1436	34328	1.00	1.00	542.66	554.79	702	17044	537	13188	0.79	0.79	529.75	543.89	195	4396	76	1779	0.41	0.41	386.12	396.43
25	3	1	2	1470	36051	1453	35781	1.00	1.00	541.98	554.27	709	17753	540	13728	0.79	0.79	530.42	543.36	176	4572	71	1850	0.41	0.41	388.61	396.13
26	3	1	2	1486	37537	1466	37247	1.00	1.00	662.50	558.53	742	18495	562	14290	0.79	0.79	607.69	546.69	199	4771	64	1914	0.41	0.41	387.12	395.16
27	3	1	2	1353	38890	1444	38691	1.00	1.00	543.79	557.98	713	19208	529	14819	0.79	0.79	525.44	546.16	175	4946	76	1990	0.41	0.41	409.51	395.67
28	3	1	2	1580	40470	1480	40171	1.00	1.00	560.69	558.08	692	19900	525	15344	0.79	0.79	560.36	546.68	186	5132	72	2062	0.41	0.41	390.52	395.49
29	3	1	2	1474	41944	1459	41630	1.00	1.00	584.90	559.02	778	20678	582	15926	0.79	0.79	557.17	546.10	172	5304	64	2126	0.41	0.41	419.41	396.21
30	3	1	2	1489	43433	1475	43105	1.00	1.00	561.36	559.10	743	21421	553	16479	0.79	0.79	530.60	545.59	191	5495	69	2195	0.41	0.41	372.35	395.46
31	3	1	2	1352	44785	1338	44443	1.00	1.00	569.40	559.38	704	22125	593	17072	0.79	0.79	573.22	546.54	167	5652	85	2290	0.41	0.41	445.09	397.31
32	3	1	2	1472	46257	1475	45918	1.00	1.00	580.24	560.06	666	22791	526	17698	0.79	0.79	594.01	547.66	187	5839	72	2352	0.41	0.41	397.64	397.32
33	3	1	2	1396	47653	1379	47297	1.00	1.00	539.13	559.44	701	23492	573	18171	0.79	0.79	545.44	547.59	173	6012	76	2428	0.41	0.41	411.06	397.75
34	3	1	2	1473	49126	1468	48765	1.00	1.00	540.17	558.86	679	24171	541	18712	0.79	0.79	540.67	547.39	175	6187	69	2497	0.41	0.41	390.15	397.54
35	3	1	2	1487	50613	1463	50228	1.00	1.00	554.40	558.73	691	24862	503	19215	0.79	0.79	528.29	546.89	201	6388	77	2574	0.41	0.41	379.82	397.01
36	3	1	2	1418	52031	1419	51647	1.00	1.00	536.44	558.09	686	25548	528	19743	0.79	0.79	518.85	546.14	179	6567	80	2654	0.41	0.41	405.97	397.28
37	3	1	2	1442	53473	1429	53076	1.00	1.00	546.96	557.79	733	26281	590	20333	0.79	0.79	564.75	546.66	186	6753	68	2722	0.41	0.41	380.05	396.36
38	3	1	2	1448	54921	1441	54517	1.00	1.00	579.73	558.37	760	27041	563	20896	0.79	0.79	550.02	546.77	168	6921	71	2793	0.41	0.41	438.84	397.43
39	3	1	2	1445	56366	1428	55945	1.00	1.00	566.81	558.58	736	27777	600	21496	0.79	0.79	572.21	547.48	177	7098	65	2858	0.41	0.41	372.37	396.86
40	3	1	2	1419	57785	1414	57359	1.00	1.00	600.75	559.60	738	28515	578	22074	0.79	0.79	583.76	548.43	191	7289	70	2928	0.79	0.42	419.87	397.41
41	3	1	2	1443	59228	1436	58795	1.00	1.00	596.86	560.51	792	29307	597	22671	0.79	0.79	560.96	548.76	179	7488	58	2986	0.42	0.42	421.09	397.87
42	3	1	2	1378	60606	1368	60163	1.00	1.00	555.67	560.40	698	30005	565	23236	0.79	0.79	551.23	548.82	190	7658	80	3066	0.42	0.42	417.42	398.38
43	3	1	2	1381	61987	1367	61520	1.00	1.00	544.08	560.04	731	30736	603	23839	0.79	0.79	547.63	548.79	141	7799	72	3138	0.42	0.42	487.29	400.42
44	3	1	2	1391	63366	1375	62895	1.00	1.00	530.31	559.39	685	31421	565	24404	0.79	0.79	532.81	548.42	180	7979	79	3217	0.42	0.42	398.35	400.32
45	3	1	2	1411	64769	1395	64290	1.00	1.00	540.96	558.99	675	32096	528	24932	0.79	0.79	519.62	547.81	192	8171	87	3304	0.42	0.42	394.62	400.17
46	3	1	2	1468	66227	1462	65752	1.00	1.00	563.49	559.09	715	32811	555	25487	0.79	0.79	554.70	547.96	169	8340	65	3369	0.42	0.42	417.27	400.50
47	3	1	2	1462	67689	1451	67203	1.00	1.00	591.51	559.79	742	33563	585	26072	0.79	0.79	586.29	548.82	170	8510	66	3435	0.42	0.42	427.56	401.02
48	3	1	2	1373	69062	1349	68652	1.00	1.00	524.73	559.10	746	34298	627	26899	0.79	0.79	525.40	548.27	160	8670	74	3509	0.42	0.42	405.76	401.12
49	3	1	2	1442	70504	1436	69997	1.00	1.00	570.32	559.33	718	35016	550	27249	0.79	0.79	556.20	548.43	158	8828	73	3582	0.42	0.42	448.23	402.08
50	3	1	2	1490	71994	1468	71475	1.00	1.00	555.01	559.24	762	35778	518	27767	0.79	0.79	495.90	547.46	190	9018	67	3649	0.42	0.42	385.29	401.79
51	3	1	2	1435	73429	1413	72889	1.00	1.00	600.51	560.04	785	36563	581	28348	0.79	0.79	552.33	547.55	176	9194	73	3722	0.42	0.42	426.77	402.28
52	3	1	2	1428	74857	1421	74309	1.00	1.00	576.77	560.36	746	37309	582	28930	0.79	0.79	556.44	547.93	180	9374	74	3796	0.42	0.42	402.28	402.28
53	3	1	2	1478	76335	1466	75775	1.00	1.00	652.37	562.14	732	38041	558	29488	0.79	0.79	618.22	549.26	199	9573	69	3865	0.42	0.42	383.80	401.95
54	3	1	2	1621	77956	1512	77287	1.00	1.00	563.67	562.17	705	38746	534	30022	0.79	0.79	546.14	549.24	170	9743	61	3926	0.42	0.42	398.09	401.89
55	3	1	2	1386	79242	1373	78660	1.00	1.00	554.15	562.03	749	39495	579	30601	0.79	0.79	535.50	548.98	195	9938	81	4007	0.42	0.42	382.10	401.49
56	3	1	2	1403	80646	1391	80051	1.00	1.00	552.26	561.86	745	40240	585	31186	0.79	0.79	532.99	548.68	198	10136	77	4084	0.42	0.42	379.21	401.07
57	3	1	2	1392	82037	1386	81437	1.00	1.00	537.18	561.44	722	40962	545	31731	0.79	0.79	497.44	547.80	174	10310	84	4168	0.42	0.42	393.13	400.91
58	3	1	2	1407	83444	1396	82833	1.00	1.00	541.86	561.11	699	41661	576	32307	0.79	0.79	553.97	547.91	170	10480	76	4244	0.42	0.42	436.65	401.55
59	3	1	2	1395	84839	1383	84216	1.00	1.00	542.84	560.81	714	42375	584	32891	0.79	0.79	549.04	547.93	177	10657	75	4319	0.42	0.42	406.73	401.64
60	3	1	2	1455	86294	1440	85656	1.00	1.00	537.61	560.42	692	43067	530	33421	0.79	0.79	523.97	547.55	175	10832	76	4395	0.42	0.42	395.44	401.55

JIT LOW MED

JIT LOW HIGH

Replication Number	Independent Variables: MAS	MOH	MIX	Dependent Variables — Product A: Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Total Cycle Time
1	3	1	3	1463	1463	1466	1466	1.00	1.00	704.02	704.02
2	3	1	3	1462	2905	1431	2897	1.00	1.00	717.38	710.62
3	3	1	3	1503	4408	1489	4386	1.00	1.00	706.06	708.73
4	3	1	3	1438	5846	1409	5794	1.00	1.00	721.89	711.93
5	3	1	3	1456	7302	1445	7239	1.00	1.00	678.42	705.24
6	3	1	3	1470	8772	1454	8693	1.00	1.00	702.49	704.78
7	3	1	3	1473	10245	1449	10142	1.00	1.00	707.11	705.11
8	3	1	3	1473	11717	1449	11591	1.00	1.00	707.77	705.46
9	3	1	3	1473	13190	1449	13040	1.00	1.00	708.44	705.78
10	3	1	3	1473	14662	1449	14489	1.00	1.00	709.10	706.11
11	3	1	3	1530	16192	1536	16025	1.00	1.00	710.80	706.56
12	3	1	3	1492	17684	1488	17513	1.00	1.00	723.39	707.99
13	3	1	3	2220	19904	1395	18908	1.00	1.00	707.85	707.98
14	3	1	3	651	20555	1454	20362	1.00	1.00	710.92	708.18
15	3	1	3	1493	22048	1476	21838	1.00	1.00	713.96	708.58
16	3	1	3	1414	23462	1385	23223	1.00	1.00	717.80	709.13
17	3	1	3	1506	24968	1485	24708	1.00	1.00	706.64	708.92
18	3	1	3	1442	26410	1437	26145	1.00	1.00	716.11	709.26
19	3	1	3	1552	27962	1509	27654	1.00	1.00	706.06	709.03
20	3	1	3	1469	29431	1449	29103	1.00	1.00	701.20	708.64
21	3	1	3	1443	30874	1426	30529	1.00	1.00	714.86	708.93
22	3	1	3	1436	32310	1431	31960	1.00	1.00	717.64	709.32
23	3	1	3	1483	33793	1433	33393	1.00	1.00	708.62	709.29
24	3	1	3	1509	35302	1503	34896	1.00	1.00	707.20	709.20
25	3	1	3	1472	36774	1458	36354	1.00	1.00	712.19	709.32
26	3	1	3	1423	38197	1413	37767	1.00	1.00	707.72	709.28
27	3	1	3	1450	39647	1443	39210	1.00	1.00	712.79	709.39
28	3	1	3	1455	41102	1441	40651	1.00	1.00	707.98	709.34
29	3	1	3	1362	42464	1327	41978	1.00	1.00	719.46	709.66
30	3	1	3	1428	43892	1434	43412	1.00	1.00	715.71	709.86
31	3	1	3	1438	45330	1416	44828	1.00	1.00	711.76	709.92
32	3	1	3	1464	46794	1445	46273	1.00	1.00	707.68	709.85
33	3	1	3	1435	48229	1419	47692	1.00	1.00	705.14	709.71
34	3	1	3	1453	49682	1440	49132	1.00	1.00	716.88	709.92
35	3	1	3	1411	51093	1407	50539	1.00	1.00	706.69	709.83
36	3	1	3	1453	52546	1431	51970	1.00	1.00	716.73	710.02
37	3	1	3	1517	54063	1495	53465	1.00	1.00	713.24	710.11
38	3	1	3	1376	55439	1368	54833	1.00	1.00	713.32	710.19
39	3	1	3	1478	56917	1445	56278	1.00	1.00	706.52	710.07
40	3	1	3	1417	58334	1417	57695	1.00	1.00	709.26	710.06
41	3	1	3	1435	59769	1419	59114	1.00	1.00	721.30	710.32
42	3	1	3	1422	61191	1412	60526	1.00	1.00	732.18	710.83
43	3	1	3	1362	62553	1345	61871	1.00	1.00	714.51	710.91
44	3	1	3	1435	63988	1434	63305	1.00	1.00	718.41	711.08
45	3	1	3	1449	65437	438	63743	1.00	1.00	696.07	710.97
46	3	1	3	1383	66820	2369	66112	1.00	1.00	710.13	710.94
47	3	1	3	1357	68177	1348	67460	1.00	1.00	710.94	710.94
48	3	1	3	1397	69574	1373	68831	1.00	1.00	709.94	710.92
49	3	1	3	1490	71064	1482	70313	1.00	1.00	718.99	711.09
50	3	1	3	1433	72497	1402	71715	1.00	1.00	711.09	711.09
51	3	1	3	1414	73911	1416	73131	1.00	1.00	711.61	711.10
52	3	1	3	1483	75394	1461	74592	1.00	1.00	718.76	711.25
53	3	1	3	1404	76798	1389	75981	1.00	1.00	715.08	711.32
54	3	1	3	1537	78335	1522	77503	1.00	1.00	711.32	711.32
55	3	1	3	1508	79843	1479	78982	1.00	1.00	712.39	711.34
56	3	1	3	1369	81212	1382	80364	1.00	1.00	713.67	711.38
57	3	1	3	1425	82637	1395	81759	1.00	1.00	710.79	711.37
58	3	1	3	1430	84067	1415	83174	1.00	1.00	711.96	711.38
59	3	1	3	1466	85533	1451	84625	1.00	1.00	716.63	711.47
60	3	1	3	4373	89906	1362	85987	1.00	1.00	712.73	711.49

Replication Number	Product B: Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Total Cycle Time
1	1444	1444	692	692	0.46	0.46	444.11	444.11
2	1436	2880	688	1380	0.50	0.49	448.38	446.24
3	1370	4250	648	2028	0.49	0.49	454.00	448.72
4	1405	5655	719	2747	0.48	0.49	471.53	454.69
5	1464	7119	681	3429	0.53	0.49	413.56	446.52
6	1437	8556	707	4135	0.49	0.49	449.27	446.82
7	1433	9989	704	4839	0.49	0.49	453.61	447.81
8	1433	11423	704	5543	0.49	0.49	455.58	448.80
9	1433	12856	704	6247	0.49	0.49	457.56	449.78
10	1433	14289	704	6951	0.49	0.49	459.53	450.77
11	1443	15732	643	7594	0.49	0.49	424.91	446.58
12	1502	17234	693	8287	0.49	0.49	441.05	447.96
13	1459	18693	737	9024	0.49	0.49	464.36	449.29
14	1498	20191	711	9735	0.49	0.49	442.72	448.81
15	1441	21632	684	10419	0.49	0.49	449.11	448.83
16	1514	23146	734	11153	0.49	0.49	442.60	448.42
17	1457	24603	666	11819	0.49	0.49	429.43	447.36
18	1382	25985	715	12534	0.49	0.49	479.61	449.19
19	1465	27450	665	13199	0.49	0.49	430.73	448.26
20	1475	28925	711	13910	0.49	0.49	450.80	448.39
21	1467	30392	715	14625	0.49	0.49	453.50	448.64
22	1448	31840	715	15340	0.49	0.49	454.22	448.90
23	1471	33311	699	16039	0.49	0.49	446.92	448.77
24	1415	34726	682	16721	0.49	0.49	457.60	449.13
25	1367	36093	675	17396	0.49	0.49	463.30	449.68
26	1439	37532	703	18099	0.49	0.49	447.36	449.59
27	1476	39008	676	18775	0.49	0.49	432.37	448.97
28	1447	40455	706	19481	0.49	0.49	449.80	449.00
29	1448	41903	780	20261	0.49	0.49	492.51	450.29
30	1432	43335	701	20962	0.49	0.49	457.17	450.52
31	1407	44742	721	21683	0.49	0.49	473.69	451.29
32	1478	46220	708	22391	0.49	0.49	446.56	451.14
33	1400	47620	697	23088	0.49	0.49	459.76	451.37
34	1559	49179	714	23802	0.49	0.49	428.37	450.68
35	1431	50610	725	24527	0.49	0.49	463.54	451.06
36	1424	52034	697	25224	0.49	0.49	460.11	451.31
37	1432	53466	665	25889	0.49	0.49	436.13	450.92
38	1377	54843	705	26594	0.49	0.49	466.39	451.33
39	1480	56323	702	27296	0.49	0.49	428.78	450.75
40	1405	57728	718	28014	0.49	0.49	475.72	451.39
41	1446	59174	695	28709	0.49	0.49	451.80	451.40
42	1404	60578	697	29406	0.49	0.49	466.59	451.76
43	1379	61957	768	30174	0.49	0.49	492.23	452.79
44	1441	63398	702	30876	0.49	0.49	466.31	452.87
45	1398	64796	687	31563	0.49	0.49	457.48	452.97
46	1474	66270	737	32300	0.49	0.49	456.04	453.04
47	1456	67726	722	33022	0.49	0.49	454.41	453.07
48	1412	69138	760	33782	0.49	0.49	477.52	453.62
49	1435	70573	672	34454	0.49	0.49	446.42	453.46
50	1442	72015	754	35208	0.49	0.49	476.34	453.96
51	1421	73436	703	35911	0.49	0.49	460.08	454.07
52	1434	74870	(318)	35593	0.49	0.49	476.46	453.87
53	1440	76310	1737	37330	0.49	0.49	461.61	454.23
54	1478	77788	655	37985	0.49	0.49	414.80	453.56
55	1439	79227	659	38644	0.49	0.49	433.61	453.21
56	1413	80640	728	39372	0.49	0.49	473.22	453.58
57	1459	82099	739	40111	0.49	0.49	461.72	453.73
58	1479	83578	689	40800	0.49	0.49	434.19	453.40
59	1499	85077	722	41522	0.49	0.49	447.66	453.30
60	1483	86560	777	42299	0.49	0.49	478.89	453.77

Replication Number	Product C: Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Total Cycle Time
1	318	318	33	33	0.10	0.10	211.38	211.38
2	408	726	45	78	0.12	0.11	181.05	193.88
3	368	1094	36	114	0.11	0.11	183.11	190.48
4	372	1466	41	155	0.11	0.11	203.14	193.83
5	363	1829	46	201	0.11	0.11	199.86	195.21
6	353	2182	34	235	0.11	0.11	176.06	192.44
7	360	2542	35	270	0.11	0.11	189.30	192.04
8	360	2902	35	304	0.11	0.11	188.49	191.64
9	360	3262	35	339	0.11	0.11	187.69	191.23
10	360	3622	35	373	0.11	0.11	186.88	190.83
11	323	3945	29	402	0.11	0.11	191.38	190.87
12	353	4298	29	431	0.11	0.11	170.81	189.52
13	392	4690	36	467	0.11	0.11	179.01	188.71
14	333	5013	34	501	0.11	0.11	194.60	189.11
15	321	5334	35	536	0.11	0.11	203.35	190.04
16	379	5713	43	579	0.11	0.11	193.14	190.27
17	346	6059	34	613	0.11	0.11	195.50	190.56
18	350	6409	35	648	0.11	0.11	187.41	190.39
19	374	6783	29	677	0.11	0.11	176.15	189.78
20	337	7120	29	706	0.11	0.11	184.42	189.56
21	385	7505	37	743	0.11	0.11	184.94	189.33
22	389	7894	36	779	0.11	0.11	174.18	188.63
23	348	8242	38	817	0.11	0.11	198.09	189.07
24	356	8598	31	848	0.11	0.11	92.78	185.55
25	374	8972	35	883	0.11	0.11	270.07	188.90
26	344	9316	47	930	0.11	0.11	208.49	189.89
27	371	9687	43	973	0.11	0.11	195.09	190.12
28	329	10016	36	1009	0.11	0.11	203.85	190.61
29	344	10360	40	1049	0.11	0.11	204.77	191.15
30	394	10754	40	1089	0.11	0.11	182.98	190.85
31	371	11125	37	1126	0.11	0.11	169.55	190.15
32	405	11530	33	1159	0.11	0.11	167.67	189.51
33	333	11863	44	1203	0.11	0.11	210.29	190.27
34	364	12227	35	1238	0.11	0.11	187.79	190.20
35	402	12629	40	1278	0.11	0.11	177.74	189.81
36	367	12996	40	1318	0.11	0.11	190.80	189.84
37	352	13348	36	1354	0.11	0.11	203.38	190.20
38	368	13716	52	1406	0.11	0.11	211.29	190.98
39	355	14071	37	1443	0.11	0.11	189.03	190.93
40	360	14431	38	1481	0.11	0.11	187.03	190.83
41	395	14826	40	1521	0.11	0.11	189.31	190.79
42	339	15165	43	1564	0.11	0.11	213.70	191.42
43	390	15555	43	1607	0.11	0.11	191.79	191.43
44	325	15880	38	1645	0.11	0.11	208.31	191.82
45	385	16265	42	1687	0.11	0.11	182.18	191.58
46	344	16609	41	1728	0.11	0.11	210.12	192.02
47	360	16969	51	1779	0.11	0.11	220.97	192.86
48	349	17318	34	1813	0.11	0.11	198.18	192.95
49	386	17704	36	1849	0.11	0.11	172.41	192.55
50	336	18040	34	1883	0.11	0.11	194.21	192.58
51	366	18406	40	1923	0.11	0.11	205.56	192.86
52	332	18738	40	1963	0.11	0.11	194.81	192.89
53	357	19095	37	2000	0.11	0.11	206.94	193.15
54	365	19460	33	2033	0.11	0.11	166.04	192.71
55	355	19815	38	2071	0.11	0.11	198.70	192.82
56	381	20196	46	2117	0.11	0.11	201.10	193.00
57	367	20563	38	2155	0.11	0.11	192.43	192.99
58	391	20954	47	2202	0.11	0.11	198.14	193.10
59	359	21313	30	2232	0.11	0.11	173.01	192.83
60	322	21635	36	2268	0.11	0.11	211.73	193.13

MRP LOW LOW

Independent Variables / Dependent Variables — Product A

Replication Number	MAS	MOH	MIX	Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Total Cycle Time
1	2	1	1	1464	1464	1460	1460	1.00	1.00	311.75	311.75
2	2	1	1	1437	2901	1435	2895	1.00	1.00	299.22	305.52
3	2	1	1	1446	4347	1441	4326	1.00	1.00	325.06	312.03
4	2	1	1	1366	5713	1329	5655	1.00	1.00	248.16	297.02
5	2	1	1	1374	7087	1378	7033	1.00	1.00	233.22	284.52
6	2	1	1	1420	8507	1398	8431	1.00	1.00	319.80	290.37
7	2	1	1	1424	9931	1417	9848	1.00	1.00	226.91	281.24
8	2	1	1	1424	11356	1417	11265	1.00	1.00	256.12	278.08
9	2	1	1	1424	12780	1417	12681	1.00	1.00	249.80	274.92
10	2	1	1	1424	14204	1417	14098	1.00	1.00	302.88	277.73
11	2	1	1	1432	15636	1415	15513	1.00	1.00	251.97	275.38
12	2	1	1	1439	17075	1432	16945	1.00	1.00	237.51	272.18
13	2	1	1	1387	18462	1370	18315	1.00	1.00	209.75	267.51
14	2	1	1	1502	19964	1484	19799	1.00	1.00	332.22	272.36
15	2	1	1	1478	21442	1478	21277	1.00	1.00	290.50	273.62
16	2	1	1	1450	22892	1429	22706	1.00	1.00	297.77	275.14
17	2	1	1	1407	24299	1394	24100	1.00	1.00	257.33	274.11
18	2	1	1	1421	25720	1418	25518	1.00	1.00	306.14	275.89
19	2	1	1	1483	27203	1480	26998	1.00	1.00	340.28	279.42
20	2	1	1	1391	28594	1386	28384	1.00	1.00	224.33	276.73
21	2	1	1	1448	30042	1436	29820	1.00	1.00	293.34	277.53
22	2	1	1	1452	31494	1430	31250	1.00	1.00	323.42	279.63
23	2	1	1	1410	32904	1398	32648	1.00	1.00	303.66	280.66
24	2	1	1	1495	34399	1429	34077	1.00	1.00	253.00	279.50
25	2	1	1	1369	35768	1425	35502	1.00	1.00	366.20	282.98
26	2	1	1	1375	37143	1369	36871	1.00	1.00	308.57	283.93
27	2	1	1	1491	38634	1475	38346	1.00	1.00	400.66	288.42
28	2	1	1	1407	40041	1407	39753	1.00	1.00	281.07	288.16
29	2	1	1	1481	41522	1459	41212	1.00	1.00	290.98	288.26
30	2	1	1	1441	42963	1441	42653	1.00	1.00	357.98	290.95
31	2	1	1	1447	44410	1430	44083	1.00	1.00	269.68	290.26
32	2	1	1	1407	45817	1393	45476	1.00	1.00	313.11	290.96
33	2	1	1	1485	47302	1472	46948	1.00	1.00	295.11	291.09
34	2	1	1	1490	48792	1480	48428	1.00	1.00	329.70	292.27
35	2	1	1	1455	50247	1436	49864	1.00	1.00	298.17	292.44
36	2	1	1	1440	51687	1425	51289	1.00	1.00	315.48	293.08
37	2	1	1	1481	53168	1470	52759	1.00	1.00	318.56	293.79
38	2	1	1	1428	54596	1416	54175	1.00	1.00	278.10	293.38
39	2	1	1	1406	56002	1407	55582	1.00	1.00	298.91	293.52
40	2	1	1	1470	57472	1454	57036	1.00	1.00	270.38	292.93
41	2	1	1	1448	58920	1432	58468	1.00	1.00	329.68	293.83
42	2	1	1	1430	60350	1414	59882	1.00	1.00	357.36	295.33
43	2	1	1	1415	61765	1400	61282	1.00	1.00	252.40	294.36
44	2	1	1	1447	63212	1456	62738	1.00	1.00	365.46	296.00
45	2	1	1	1405	64617	1384	64122	1.00	1.00	249.21	294.99
46	2	1	1	1387	66004	1383	65505	1.00	1.00	266.10	294.38
47	2	1	1	1420	67424	1417	66922	1.00	1.00	427.56	297.20
48	2	1	1	1447	68871	1429	68351	1.00	1.00	300.56	297.27
49	2	1	1	1475	70346	1461	69812	1.00	1.00	377.07	298.94
50	2	1	1	1434	71780	1420	71232	1.00	1.00	275.36	298.47
51	2	1	1	1428	73208	1427	72659	1.00	1.00	276.58	298.04
52	2	1	1	1400	74608	1389	74048	1.00	1.00	288.98	297.87
53	2	1	1	1487	76095	1456	75504	1.00	1.00	391.21	299.67
54	2	1	1	1525	77620	1503	77007	1.00	1.00	357.06	300.79
55	2	1	1	1427	79047	1432	78439	1.00	1.00	329.82	301.32
56	2	1	1	1455	80502	1446	79885	1.00	1.00	319.00	301.64
57	2	1	1	1456	81958	1449	81334	1.00	1.00	345.42	302.42
58	2	1	1	1420	83378	1399	82733	1.00	1.00	277.58	302.00
59	2	1	1	1341	84719	1344	84077	1.00	1.00	309.51	302.12
60	2	1	1	1409	86128	1393	85470	1.00	1.00	319.91	302.41

Dependent Variables — Product B

Replication Number	Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Total Cycle Time
1	391	391	386	386	1.00	1.00	303.18	303.18
2	338	729	338	724	1.00	1.00	304.27	303.69
3	354	1083	343	1067	1.00	1.00	323.94	310.20
4	369	1452	360	1427	1.00	1.00	256.66	296.69
5	345	1797	343	1770	1.00	1.00	220.83	281.99
6	350	2147	336	2106	1.00	1.00	322.03	288.41
7	343	2490	338	2444	1.00	1.00	248.58	282.91
8	343	2833	337	2780	1.00	1.00	264.89	280.73
9	343	3176	337	3116	1.00	1.00	260.49	278.54
10	343	3518	336	3462	1.00	1.00	290.15	279.67
11	353	3871	348	3800	1.00	1.00	270.93	278.87
12	337	4208	329	4129	1.00	1.00	246.11	276.26
13	358	4566	352	4481	1.00	1.00	222.67	272.06
14	351	4917	346	4827	1.00	1.00	332.18	276.36
15	364	5281	355	5182	1.00	1.00	299.57	277.96
16	329	5610	321	5503	1.00	1.00	306.12	279.71
17	368	5978	367	5870	1.00	1.00	256.24	278.18
18	367	6345	362	6232	1.00	1.00	293.67	279.08
19	379	6724	376	6608	1.00	1.00	358.69	283.61
20	350	7074	343	6951	1.00	1.00	229.30	280.93
21	381	7455	375	7326	1.00	1.00	296.00	281.66
22	372	7827	357	7683	1.00	1.00	320.17	283.44
23	343	8170	346	8029	1.00	1.00	269.47	283.70
24	375	8545	368	8397	1.00	1.00	267.04	282.97
25	352	8897	344	8741	1.00	1.00	355.13	285.91
26	389	9286	379	9120	1.00	1.00	312.28	286.91
27	362	9648	354	9474	1.00	1.00	406.20	291.33
28	393	10041	384	9858	1.00	1.00	282.09	290.97
29	351	10392	347	10205	1.00	1.00	306.86	291.51
30	361	10753	363	10568	1.00	1.00	357.31	293.77
31	385	11138	379	10947	1.00	1.00	278.75	293.25
32	387	11525	376	11323	1.00	1.00	318.56	294.09
33	342	11867	336	11659	1.00	1.00	293.40	294.07
34	352	12219	350	12009	1.00	1.00	317.06	294.74
35	353	12572	345	12354	1.00	1.00	315.87	295.33
36	309	12881	306	12660	1.00	1.00	335.46	296.30
37	353	13234	342	13002	1.00	1.00	317.59	296.86
38	345	13579	336	13338	1.00	1.00	261.53	295.97
39	386	13965	385	13723	1.00	1.00	295.97	295.97
40	330	14295	326	14049	1.00	1.00	272.70	295.40
41	336	14631	329	14378	1.00	1.00	315.10	295.88
42	376	15007	370	14748	1.00	1.00	360.95	297.51
43	368	15375	363	15111	1.00	1.00	244.23	296.23
44	368	15743	361	15472	1.00	1.00	363.95	297.81
45	368	16111	362	15834	1.00	1.00	248.82	296.69
46	344	16455	340	16174	1.00	1.00	260.54	295.93
47	401	16856	401	16575	1.00	1.00	398.79	298.37
48	377	17233	372	16947	1.00	1.00	294.27	298.28
49	354	17587	347	17294	1.00	1.00	361.58	299.55
50	366	17953	363	17657	1.00	1.00	290.31	299.36
51	354	18307	349	18006	1.00	1.00	277.17	298.93
52	364	18671	359	18365	1.00	1.00	293.81	298.83
53	383	19054	379	18744	1.00	1.00	375.49	300.38
54	356	19410	350	19094	1.00	1.00	347.84	301.26
55	345	19755	338	19432	1.00	1.00	319.07	301.56
56	384	20139	381	19813	1.00	1.00	314.04	301.80
57	364	20503	357	20170	1.00	1.00	335.13	302.39
58	373	20876	367	20537	1.00	1.00	270.49	301.82
59	347	21223	346	20883	1.00	1.00	312.08	301.99
60	381	21604	372	21255	1.00	1.00	309.99	302.13

Dependent Variables — Product C

Replication Number	Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Total Cycle Time
1	81	81	77	77	0.97	0.97	360.87	360.87
2	89	170	80	157	0.95	0.96	430.13	396.16
3	101	271	93	250	0.93	0.95	393.01	394.99
4	97	368	95	345	0.95	0.95	350.83	382.83
5	69	436	66	411	0.95	0.95	349.64	377.60
6	97	533	86	497	0.95	0.95	424.77	385.66
7	85	618	80	577	0.95	0.95	379.29	384.79
8	85	704	80	658	1.00	0.96	376.60	383.79
9	85	789	80	738	0.96	0.96	374.60	382.79
10	85	874	80	818	0.96	0.96	371.48	381.66
11	87	961	82	900	0.96	0.96	345.46	378.38
12	84	1045	81	981	0.96	0.96	333.81	374.70
13	68	1113	63	1044	0.96	0.96	334.60	372.26
14	96	1209	84	1128	0.96	0.96	372.55	372.30
15	79	1288	79	1207	0.96	0.96	377.49	372.64
16	93	1381	85	1292	0.96	0.96	383.77	374.03
17	84	1465	77	1369	1.00	0.97	358.56	373.16
18	93	1558	89	1458	0.97	0.97	385.12	373.89
19	90	1648	81	1539	0.97	0.97	395.55	375.03
20	84	1732	82	1621	0.97	0.97	309.60	371.72
21	81	1813	79	1700	0.97	0.97	401.42	373.10
22	100	1913	82	1782	0.97	0.97	415.91	375.07
23	91	2004	84	1866	0.97	0.97	385.73	375.58
24	86	2090	78	1944	0.97	0.97	325.46	373.54
25	101	2191	89	2033	0.97	0.97	479.30	378.17
26	96	2287	89	2122	0.97	0.97	403.44	379.23
27	97	2384	78	2200	0.97	0.97	489.95	383.51
28	76	2460	70	2270	0.97	0.97	413.02	384.42
29	84	2544	72	2342	0.97	0.97	375.31	384.14
30	110	2654	95	2437	0.97	0.97	436.21	386.17
31	87	2741	85	2522	0.97	0.97	372.52	385.71
32	89	2830	82	2604	0.97	0.97	414.29	386.61
33	82	2912	72	2676	0.97	0.97	380.66	386.46
34	88	3000	78	2754	0.97	0.97	413.64	387.22
35	102	3102	96	2850	0.97	0.97	364.06	386.64
36	99	3201	89	2939	0.97	0.97	415.83	387.33
37	96	3297	90	3029	0.97	0.97	376.92	387.06
38	85	3382	82	3111	0.97	0.97	378.35	386.86
39	76	3458	72	3183	0.51	0.96	369.50	386.91
40	85	3543	83	3266	0.95	0.96	379.04	386.71
41	104	3647	100	3366	0.96	0.96	431.81	388.05
42	74447	78094	98	3464	0.96	0.96	421.63	389.00
43	(74259)	3835	75	3539	0.96	0.96	366.35	388.52
44	92	3927	81	3620	0.96	0.96	449.75	389.89
45	87	4014	79	3699	0.96	0.96	375.37	389.58
46	90	4104	83	3782	0.96	0.96	344.01	388.58
47	107	4211	85	3867	0.96	0.96	465.92	390.28
48	87	4298	81	3948	0.96	0.96	414.65	390.78
49	98	4396	86	4034	0.96	0.96	437.22	391.77
50	91	4487	87	4121	0.96	0.96	373.77	391.39
51	84	4571	76	4197	0.96	0.96	379.24	391.17
52	101	4672	95	4292	0.96	0.96	364.06	390.57
53	101	4773	93	4385	0.96	0.96	464.12	392.13
54	100	4873	83	4468	0.96	0.96	383.52	391.97
55	105	4978	90	4558	0.96	0.96	399.57	392.12
56	91	5069	90	4648	0.96	0.96	408.13	392.43
57	89	5158	79	4727	0.96	0.96	428.33	393.03
58	92	5250	83	4810	0.96	0.96	397.09	393.10
59	101	5351	95	4905	0.96	0.96	403.94	393.31
60	96	5447	85	4990	0.96	0.96	383.31	393.31

MRP LOW MED

Replication Number	Independent Variables: MAS	MOH	MIX	Product A: Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Total Cycle Time
1	2	1	2	1411	1411	1333	1333	0.97	0.97	803.14	803.14
2	2	1	2	1442	2853	1334	2667	0.96	0.96	788.69	795.91
3	2	1	2	1443	4296	1395	4062	0.96	0.96	784.41	791.98
4	2	1	2	1396	5692	1373	5435	0.96	0.96	788.24	791.02
5	2	1	2	1492	7184	1433	6868	0.96	0.96	808.03	794.57
6	2	1	2	1430	8614	1356	8224	0.96	0.96	800.63	795.57
7	2	1	2	1449	10063	1382	9606	0.96	0.96	801.88	796.48
8	2	1	2	1448	11511	1382	10988	0.96	0.96	803.69	797.39
9	2	1	2	1449	12960	1382	12369	0.96	0.96	806.51	798.29
10	2	1	2	1448	14408	1382	13751	0.96	0.96	807.32	799.20
11	2	1	2	1489	15897	1419	15170	0.96	0.96	817.37	800.90
12	2	1	2	1424	17321	1334	16504	0.96	0.96	823.42	802.72
13	2	1	2	1530	18851	1446	17950	0.96	0.96	810.42	803.34
14	2	1	2	1423	20274	1366	19316	0.96	0.96	779.02	801.62
15	2	1	2	1427	21701	1361	20677	0.96	0.96	802.23	801.66
16	2	1	2	1342	23043	1280	21957	0.96	0.96	806.29	801.93
17	2	1	2	1433	24476	1352	23309	0.96	0.96	801.93	801.93
18	2	1	2	1423	25899	1356	24665	0.96	0.96	760.64	799.66
19	2	1	2	1470	27369	1401	26066	0.96	0.96	832.41	801.42
20	2	1	2	1477	28846	1412	27478	0.96	0.96	818.56	802.30
21	2	1	2	1384	30230	1302	28780	0.96	0.96	794.78	801.96
22	2	1	2	1394	31624	1350	30130	0.96	0.96	789.46	801.40
23	2	1	2	1377	33001	1348	31478	0.96	0.96	760.30	799.64
24	2	1	2	1601	34602	1422	32900	0.96	0.96	768.17	798.28
25	2	1	2	1463	35965	1416	34316	0.96	0.96	801.92	798.43
26	2	1	2	1413	37378	1353	35669	0.96	0.96	795.00	798.30
27	2	1	2	1416	38794	1354	37023	0.96	0.96	818.53	799.04
28	2	1	2	1442	40236	1381	38404	0.96	0.96	811.03	799.50
29	2	1	2	1414	41650	1376	39780	0.96	0.96	748.33	797.73
30	2	1	2	1481	43131	1390	41170	0.96	0.96	832.98	798.92
31	2	1	2	1393	44524	1335	42505	0.96	0.96	789.06	798.61
32	2	1	2	1471	45995	1414	43919	0.96	0.96	788.67	798.29
33	2	1	2	1405	47400	1359	45278	0.96	0.96	792.29	798.11
34	2	1	2	1417	48817	1359	46637	0.96	0.96	775.12	797.44
35	2	1	2	1426	50243	1321	47958	0.96	0.96	730.64	795.60
36	2	1	2	1358	51601	1337	49295	0.96	0.96	680.20	792.47
37	2	1	2	1454	53055	1409	50704	0.96	0.96	809.74	792.96
38	2	1	2	1447	54502	1380	52084	0.96	0.96	828.43	793.89
39	2	1	2	1424	55926	1394	53478	0.96	0.96	767.80	793.21
40	2	1	2	1412	57338	1361	54839	0.96	0.96	809.33	793.61
41	2	1	2	1477	58815	1428	56267	0.96	0.96	795.97	793.67
42	2	1	2	1387	60202	1345	57612	0.96	0.96	821.94	794.33
43	2	1	2	1396	61598	1347	58959	0.96	0.96	771.57	793.81
44	2	1	2	1399	62997	1377	60336	0.96	0.96	799.51	793.94
45	2	1	2	1394	64391	1369	61705	0.96	0.96	806.21	794.19
46	2	1	2	1452	65843	1401	63106	0.96	0.96	830.66	795.00
47	2	1	2	1422	67265	1377	64483	0.96	0.96	764.26	794.13
48	2	1	2	1421	68686	1383	65866	0.96	0.96	794.60	793.93
49	2	1	2	1430	70116	1361	67227	0.96	0.96	796.40	793.98
50	2	1	2	1436	71552	1385	68612	0.96	0.96	818.25	794.47
51	2	1	2	1465	73017	1346	69958	0.96	0.96	810.58	794.78
52	2	1	2	1458	74475	1402	71360	0.96	0.96	770.35	794.30
53	2	1	2	1502	75977	1411	72771	0.96	0.96	777.80	793.98
54	2	1	2	1454	77431	1389	74160	0.96	0.96	827.62	794.61
55	2	1	2	1440	78871	1386	75546	0.96	0.96	815.32	794.99
56	2	1	2	1469	80340	1359	76905	0.96	0.96	811.97	795.29
57	2	1	2	1471	81811	1413	78318	0.96	0.96	831.87	795.95
58	2	1	2	1412	83223	1345	79663	0.96	0.96	781.74	795.71
59	2	1	2	1446	84669	1388	81051	0.96	0.96	786.96	795.56
60	2	1	2	1394	86063	1363	82414	0.96	0.96	816.72	795.91

Replication Number	Product B: Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Total Cycle Time
1	786	786	744	744	0.97	0.97	673.38	673.38
2	756	1542	731	1475	0.97	0.97	667.67	670.56
3	716	2258	689	2164	0.97	0.97	671.27	670.78
4	707	2965	676	2840	0.97	0.97	657.76	667.68
5	680	3645	669	3509	0.97	0.97	657.97	665.91
6	727	4372	700	4209	1.00	0.98	674.69	667.32
7	727	5099	703	4912	0.98	0.98	674.31	668.32
8	727	5826	703	5614	0.98	0.98	676.31	669.32
9	727	6553	703	6317	0.98	0.98	678.31	670.32
10	727	7280	703	7019	0.98	0.98	680.31	671.32
11	711	7991	700	7719	0.98	0.98	696.46	673.60
12	740	8731	710	8429	0.98	0.98	698.29	675.68
13	689	9420	662	9091	0.98	0.98	692.43	676.90
14	723	10143	707	9798	0.98	0.98	669.55	676.37
15	731	10874	697	10495	0.98	0.98	693.08	677.48
16	718	11592	701	11196	0.98	0.98	683.87	677.88
17	729	12321	714	11910	0.98	0.98	680.05	678.01
18	696	13017	672	12582	0.98	0.98	668.46	677.50
19	763	13780	731	13313	0.98	0.98	678.59	677.56
20	690	14470	667	13980	0.98	0.98	672.53	677.32
21	759	15229	747	14727	0.98	0.98	681.26	677.52
22	736	15965	703	15430	0.98	0.98	648.33	676.19
23	714	16679	695	16125	0.98	0.98	633.27	674.34
24	701	17380	675	16800	0.98	0.98	634.77	672.75
25	672	18052	651	17451	0.98	0.98	686.15	673.25
26	759	18811	721	18172	0.98	0.98	656.36	672.54
27	752	19563	732	18904	0.98	0.98	701.21	673.65
28	769	20332	724	19628	0.98	0.98	673.92	673.66
29	684	21016	670	20298	0.98	0.98	613.67	671.68
30	733	21749	697	20995	0.98	0.98	695.23	672.13
31	731	22480	715	21710	0.98	0.98	658.16	671.67
32	702	23182	664	22374	0.98	0.98	676.05	671.80
33	701	23883	690	23064	0.98	0.98	691.16	672.08
34	724	24607	694	23758	0.98	0.98	631.69	670.90
35	718	25325	698	24456	0.98	0.98	637.61	669.96
36	700	26025	688	25144	0.98	0.98	666.16	667.11
37	707	26732	688	25832	0.98	0.98	669.36	667.17
38	742	27474	694	26526	0.98	0.98	687.43	667.70
39	680	28154	661	27187	0.98	0.98	646.08	667.16
40	715	28869	704	27891	0.98	0.98	690.92	667.75
41	700	29569	679	28570	0.98	0.98	680.79	668.06
42	742	30311	714	29284	0.98	0.98	685.29	668.48
43	664	30975	647	29931	0.98	0.98	665.24	668.41
44	714	31689	697	30628	0.98	0.98	660.94	668.24
45	698	32387	685	31313	0.98	0.98	663.21	668.13
46	691	33078	669	31982	0.98	0.98	693.47	668.66
47	667	33745	666	32648	0.98	0.98	627.48	667.82
48	730	34475	706	33354	0.98	0.98	666.46	667.77
49	730	35205	711	34065	0.98	0.98	667.29	667.76
50	696	35901	674	34739	0.98	0.98	697.86	668.15
51	726	36627	706	35447	0.98	0.98	696.19	668.71
52	691	37318	688	36135	0.98	0.98	652.43	668.40
53	738	38056	712	36847	0.98	0.98	623.89	667.54
54	714	38770	693	37540	0.98	0.98	688.12	667.92
55	733	39503	714	38254	0.98	0.98	684.53	668.23
56	749	40252	714	38968	0.98	0.98	696.52	668.73
57	702	40954	670	39638	0.98	0.98	693.59	669.16
58	713	41667	707	40345	0.98	0.98	677.14	669.29
59	696	42363	670	41015	0.98	0.98	668.84	669.26
60	711	43064	697	41712	0.98	0.98	663.86	669.16

Replication Number	Product C: Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Total Cycle Time
1	192	192	51	51	0.37	0.37	332.46	332.46
2	214	406	57	108	0.29	0.33	349.82	341.62
3	146	552	49	157	0.29	0.32	409.81	362.59
4	182	734	56	213	0.32	0.32	404.01	373.46
5	167	901	47	260	0.27	0.31	417.69	381.47
6	173	1074	59	319	0.31	0.31	425.54	389.62
7	172	1246	49	368	0.31	0.31	403.70	391.50
8	172	1418	49	418	0.31	0.31	407.46	393.39
9	172	1589	49	467	0.31	0.31	411.23	395.27
10	172	1761	49	516	0.31	0.31	414.99	397.15
11	187	1948	46	562	0.31	0.31	360.97	393.37
12	174	2122	62	624	0.31	0.31	465.94	400.58
13	175	2297	43	667	0.31	0.31	384.81	399.57
14	181	2478	56	723	0.31	0.31	372.20	397.46
15	168	2646	52	775	0.31	0.31	440.97	400.37
16	194	2840	75	850	0.31	0.31	446.84	404.47
17	174	3014	57	907	0.31	0.31	414.97	405.13
18	157	3171	66	973	0.31	0.31	467.76	408.70
19	181	3352	41	1014	0.31	0.31	326.34	405.37
20	190	3542	56	1070	0.31	0.31	402.70	405.23
21	149	3691	60	1130	0.31	0.31	470.96	408.72
22	182	3873	58	1188	0.31	0.31	397.66	408.18
23	187	4060	60	1248	0.31	0.31	415.87	408.54
24	146	4206	48	1296	0.31	0.31	427.44	409.24
25	165	4371	54	1350	0.31	0.31	427.49	409.97
26	198	4569	51	1401	0.31	0.31	350.63	407.81
27	182	4751	51	1452	0.31	0.31	380.76	406.86
28	186	4937	41	1493	0.31	0.31	359.52	405.66
29	182	5119	60	1553	0.31	0.31	380.19	404.58
30	187	5306	51	1604	0.31	0.31	435.40	405.56
31	183	5489	59	1663	0.31	0.31	401.05	405.40
32	185	5674	51	1714	0.31	0.31	389.60	404.93
33	177	5851	62	1776	0.31	0.31	415.63	405.30
34	180	6031	56	1832	0.31	0.31	374.55	404.36
35	182	6213	60	1892	0.31	0.31	394.90	404.06
36	166	6379	60	1952	0.31	0.31	401.78	403.99
37	188	6567	49	2001	0.31	0.31	365.60	403.06
38	180	6747	49	2050	0.31	0.31	396.36	402.89
39	179	6926	61	2111	0.31	0.31	402.89	402.89
40	177	7103	55	2166	0.31	0.31	418.25	403.28
41	160	7263	46	2212	0.31	0.31	400.39	403.22
42	179	7442	50	2262	0.31	0.31	400.05	403.15
43	178	7620	77	2339	0.31	0.31	442.03	404.43
44	202	7822	53	2392	0.31	0.31	367.87	403.62
45	176	7998	59	2451	0.31	0.31	422.31	404.07
46	178	8176	55	2506	0.31	0.31	425.03	404.53
47	187	8363	64	2570	0.31	0.31	399.71	404.41
48	186	8549	47	2617	0.31	0.31	370.44	403.80
49	186	8735	50	2667	0.31	0.31	381.53	403.57
50	198	8933	58	2725	0.31	0.31	390.88	403.30
51	175	9108	59	2784	0.31	0.31	430.67	403.88
52	169	9277	49	2833	0.31	0.31	402.72	403.86
53	162	9439	42	2875	0.31	0.31	392.91	403.70
54	208	9647	52	2927	0.31	0.31	345.72	402.67
55	185	9832	48	2975	0.31	0.31	372.30	402.18
56	185	10017	53	3028	0.31	0.31	404.47	402.22
57	175	10192	52	3080	0.31	0.31	427.10	402.64
58	174	10366	57	3137	0.31	0.31	425.20	403.06
59	176	10542	59	3196	0.31	0.31	407.38	403.13
60	166	10708	56	3252	0.31	0.31	465.39	404.03

MRP LOW HIGH

Replication Number	MAS	MOH	MIX	Product A Period Demand	Product A Total Demand	Product A Period Shipped	Product A Total Shipped	Product A Period DFR	Product A Total DFR	Product A Period Cycle Time	Product A Total Cycle Time
1	2	1	3	1389	1389	1038	1038	0.76	0.75	801.28	801.28
2	2	1	3	1536	2925	1072	2110	0.73	0.74	750.20	775.32
3	2	1	3	1498	4423	1055	3165	0.74	0.74	753.42	769.02
4	2	1	3	1425	5848	1068	4233	0.74	0.74	775.91	770.01
5	2	1	3	1422	7270	1082	5315	0.74	0.74	779.06	771.85
6	2	1	3	1395	8665	994	6309	0.74	0.74	783.21	773.64
7	2	1	3	1416	10081	1052	7361	0.74	0.74	777.19	774.15
8	2	1	3	1416	11497	1052	8414	0.74	0.74	778.21	774.66
9	2	1	3	1416	12912	1052	9466	0.74	0.74	779.22	775.16
10	2	1	3	1416	14328	1052	10518	0.74	0.74	780.24	775.67
11	2	1	3	1449	15777	1065	11583	0.74	0.74	775.56	775.66
12	2	1	3	1429	17206	1061	12644	0.74	0.74	787.22	776.63
13	2	1	3	1383	18599	1038	13682	0.74	0.74	800.36	778.40
14	2	1	3	1443	20042	1056	14738	0.74	0.74	782.34	778.71
15	2	1	3	1477	21519	1065	15803	0.74	0.74	766.84	777.91
16	2	1	3	1516	23035	1101	16904	0.74	0.74	766.24	777.15
17	2	1	3	1399	24434	1032	17936	0.74	0.74	801.31	778.54
18	2	1	3	1413	25847	1030	18966	0.74	0.74	774.12	778.30
19	2	1	3	1419	27266	1040	20006	0.74	0.74	791.00	778.96
20	2	1	3	1423	28689	1070	21076	0.74	0.74	791.37	779.59
21	2	1	3	1405	30094	1083	22159	0.74	0.74	799.44	780.56
22	2	1	3	1425	31519	1074	23233	0.74	0.74	803.92	781.64
23	2	1	3	1385	32904	1061	24294	0.74	0.74	791.28	782.08
24	2	1	3	1459	34363	1004	25298	0.74	0.74	747.29	780.68
25	2	1	3	1440	35803	1055	26353	0.74	0.74	799.16	781.42
26	2	1	3	1420	37223	1046	27399	0.74	0.74	784.04	781.52
27	2	1	3	1476	38699	1087	28485	0.74	0.74	770.51	781.10
28	2	1	3	1432	40131	1023	29508	0.74	0.74	769.85	780.71
29	2	1	3	1412	41543	1052	30560	0.74	0.74	791.75	781.09
30	2	1	3	1401	42944	996	31556	0.74	0.74	798.20	781.63
31	2	1	3	1474	44418	1063	32619	0.74	0.74	764.75	781.08
32	2	1	3	1401	45819	1038	33657	0.74	0.74	779.79	781.04
33	2	1	3	1493	47312	1098	34755	0.74	0.74	767.43	780.61
34	2	1	3	1483	48795	1055	35810	0.74	0.74	774.84	780.44
35	2	1	3	1401	50196	1032	36842	0.74	0.74	787.22	780.63
36	2	1	3	1371	51567	1055	37897	0.74	0.74	794.64	781.02
37	2	1	3	1468	53035	1066	38963	0.74	0.74	763.11	780.63
38	2	1	3	1481	54516	1045	40008	0.74	0.74	756.79	779.91
39	2	1	3	1487	56003	1074	41082	0.74	0.74	770.36	779.66
40	2	1	3	1423	57426	1070	42152	0.74	0.74	800.15	780.18
41	2	1	3	1388	58814	1038	43190	0.74	0.74	777.68	780.12
42	2	1	3	1426	60240	1048	44238	0.74	0.74	788.56	780.32
43	2	1	3	1377	61617	1060	45298	0.74	0.74	797.84	780.73
44	2	1	3	1440	63057	1084	46382	0.74	0.74	792.71	781.01
45	2	1	3	1460	64517	980	47362	0.74	0.74	752.50	780.42
46	2	1	3	1447	65964	1055	48417	0.74	0.74	772.16	780.24
47	2	1	3	1391	67355	1083	49500	0.74	0.74	804.46	780.77
48	2	1	3	1443	68798	1070	50570	0.74	0.74	795.50	780.97
49	2	1	3	1477	70275	1098	51668	0.74	0.74	769.11	780.62
50	2	1	3	1450	71725	1089	52757	0.74	0.74	777.23	780.55
51	2	1	3	1460	73185	1126	53883	0.74	0.74	769.07	780.31
52	2	1	3	1439	74624	1109	54992	0.74	0.74	791.72	780.54
53	2	1	3	1455	76079	1022	56014	0.74	0.74	777.80	780.49
54	2	1	3	1452	77531	1092	57106	0.74	0.74	773.17	780.35
55	2	1	3	2453	79984	1064	58170	0.74	0.74	784.18	780.42
56	2	1	3	446	80430	1096	59266	0.74	0.74	763.12	780.10
57	2	1	3	1416	81846	1061	60327	0.74	0.74	798.86	780.43
58	2	1	3	1406	83252	1041	61368	0.74	0.74	785.74	780.52
59	2	1	3	1378	84630	1065	62433	0.74	0.74	794.59	780.76
60	2	1	3	1401	86031	1032	63465	0.74	0.74	802.28	781.11

Replication Number	Product B Period Demand	Product B Total Demand	Product B Period Shipped	Product B Total Shipped	Product B Period DFR	Product B Total DFR	Product B Period Cycle Time	Product B Total Cycle Time	Product C Period Demand	Product C Total Demand	Product C Period Shipped	Product C Total Shipped	Product C Period DFR	Product C Total DFR	Product C Period Cycle Time	Product C Total Cycle Time
1	1464	1464	1116	1116	0.78	0.79	570.92	570.92	356	356	19	19	0.05	0.06	166.42	166.42
2	1510	2964	1148	2264	0.79	0.78	558.95	564.95	385	741	5	24	0.05	0.06	38.50	139.77
3	1414	4378	1128	3392	0.78	0.79	560.58	570.08	386	1127	14	38	0.02	0.04	150.87	143.86
4	1368	5746	1098	4490	0.78	0.78	597.03	576.67	370	1497	20	58	0.04	0.04	146.56	145.48
5	1467	7213	1080	5570	0.79	0.79	546.98	570.72	351	1848	22	80	0.04	0.04	160.50	149.61
6	1465	8678	1160	6730	0.78	0.78	579.13	572.17	343	2191	21	101	0.04	0.04	159.46	151.46
7	1433	10111	1125	7855	0.78	0.78	573.95	572.43	374	2565	16	117	0.04	0.04	146.67	150.81
8	1433	11545	1125	8979	0.86	0.79	574.46	572.68	374	2940	16	133	0.12	0.06	145.38	150.16
9	1433	12978	1125	10104	0.79	0.79	574.07	572.94	374	3314	16	148	0.05	0.06	144.09	149.52
10	1433	14411	1125	11228	0.79	0.79	576.48	573.19	374	3688	16	164	0.05	0.06	142.80	148.87
11	1407	15818	1122	12350	0.79	0.79	579.68	573.78	351	4039	16	180	0.05	0.06	161.47	149.99
12	1456	17274	1119	13469	0.79	0.79	569.57	573.43	351	4390	18	198	0.05	0.06	167.25	150.66
13	1473	18747	1147	14616	0.79	0.79	567.06	572.93	357	4747	13	211	0.05	0.06	149.84	150.60
14	1417	20164	1123	15739	0.79	0.79	576.59	573.12	370	5117	17	228	0.05	0.06	147.25	150.35
15	1521	21685	1137	16876	0.79	0.79	549.67	571.54	363	5480	9	237	0.05	0.06	124.02	149.35
16	1427	23112	1115	17991	0.79	0.79	566.38	571.22	388	5868	10	247	0.05	0.06	113.29	147.89
17	1415	24527	1120	19111	0.79	0.79	588.62	572.24	373	6241	22	269	0.05	0.06	167.09	149.46
18	1441	25968	1146	20257	0.79	0.79	575.24	572.41	360	6601	17	286	0.05	0.06	150.30	149.51
19	1440	27408	1124	21381	0.79	0.79	582.68	572.96	355	6956	20	306	0.05	0.06	155.02	149.87
20	1474	28882	1101	22482	0.79	0.79	552.94	571.97	339	7295	17	323	0.05	0.06	149.68	149.86
21	1381	30263	1094	23576	0.79	0.79	581.67	572.42	391	7686	19	342	0.05	0.06	162.92	150.03
22	1444	31707	1123	24699	0.79	0.79	564.50	572.06	362	8048	11	353	0.05	0.06	119.85	149.09
23	1427	33134	1091	25790	0.79	0.79	563.56	571.70	358	8406	22	375	0.05	0.06	171.76	150.42
24	1477	34611	1148	26938	0.79	0.79	578.50	571.99	376	8782	20	395	0.05	0.06	158.64	150.73
25	1541	36152	1152	28090	0.79	0.79	550.04	571.09	358	9140	7	402	0.05	0.06	46.78	148.92
26	1425	37577	1129	29219	0.79	0.79	577.04	571.32	368	9508	18	420	0.05	0.06	177.82	150.15
27	1391	38968	1098	30317	0.79	0.79	574.08	571.42	339	9847	16	436	0.05	0.06	157.51	150.42
28	1414	40382	1123	31440	0.79	0.79	596.90	572.33	344	10191	22	458	0.05	0.06	155.83	150.66
29	1413	41795	1076	32516	0.79	0.79	572.33	572.33	330	10521	30	488	0.05	0.06	182.56	152.64
30	1492	43287	1160	33676	0.79	0.79	576.68	572.48	365	10886	20	508	0.05	0.06	156.70	152.80
31	1404	44691	1110	34786	0.79	0.79	573.11	572.50	370	11256	20	528	0.05	0.06	152.27	152.78
32	1362	46053	1127	35913	0.79	0.79	606.29	573.56	419	11675	22	550	0.05	0.06	141.53	152.33
33	1396	47449	1104	37017	0.79	0.79	578.26	573.73	341	12016	12	562	0.05	0.06	139.22	152.05
34	1479	48928	1140	38157	0.79	0.79	570.72	573.64	340	12356	11	573	0.05	0.06	151.53	152.04
35	1458	50386	1140	39297	0.79	0.79	576.40	573.72	380	12736	17	590	0.05	0.06	139.55	151.68
36	1458	51944	1119	40416	0.79	0.79	572.28	573.68	361	13097	18	608	0.05	0.06	151.68	151.68
37	1477	53321	1112	41528	0.79	0.79	550.16	573.06	350	13447	16	624	0.05	0.06	160.90	151.66
38	1434	54755	1111	42639	0.79	0.79	574.59	573.09	362	13809	22	646	0.05	0.06	163.11	152.06
39	1454	56209	1122	43761	0.79	0.79	567.63	572.96	360	14169	12	658	0.05	0.06	129.57	151.64
40	1335	57544	1111	44872	0.79	0.79	602.43	573.68	353	14522	18	676	0.05	0.06	159.90	151.86
41	1500	59044	1148	46020	0.79	0.79	561.25	573.37	327	14849	16	692	0.05	0.06	160.08	152.05
42	1395	60439	1115	47135	0.79	0.79	589.01	573.74	362	15211	19	711	0.05	0.06	144.57	151.86
43	1418	61857	1101	48236	0.79	0.79	573.74	573.74	347	15558	21	732	0.05	0.06	171.02	152.40
44	1404	63261	1104	49340	0.79	0.79	579.10	573.86	363	15921	14	746	0.05	0.06	134.26	152.06
45	1507	64768	1170	50510	0.79	0.79	570.41	573.78	349	16270	22	768	0.05	0.06	174.40	152.70
46	1432	66200	1130	51640	0.79	0.79	576.52	573.84	361	16631	18	786	0.05	0.06	161.00	152.89
47	1427	67627	1105	52745	0.79	0.79	569.54	573.75	350	16981	14	800	0.05	0.06	139.75	152.66
48	1384	69011	1107	53852	0.79	0.79	589.32	574.07	346	17327	16	816	0.05	0.06	160.31	152.81
49	1388	70399	1076	54928	0.79	0.79	564.88	573.89	330	17657	18	834	0.05	0.06	169.49	153.17
50	1462	71861	1110	56038	0.79	0.79	552.69	573.47	340	17997	11	845	0.05	0.06	140.88	153.01
51	1475	73336	1122	57160	0.79	0.79	556.15	573.13	365	18362	14	859	0.05	0.06	146.10	152.93
52	1384	74720	1067	58227	0.79	0.79	565.49	572.98	382	18744	24	883	0.05	0.06	149.62	152.94
53	1458	76178	1075	59302	0.79	0.79	549.72	572.56	372	19116	18	901	0.05	0.06	159.85	152.96
54	1391	77569	1063	60365	0.79	0.79	565.74	572.43	318	19434	19	920	0.05	0.06	174.27	153.40
55	1382	78951	1111	61476	0.79	0.79	585.71	572.67	331	19765	17	937	0.05	0.06	163.32	153.58
56	1425	80376	1075	62551	0.79	0.79	559.29	572.44	369	20134	19	956	0.05	0.06	167.10	153.65
57	1345	81721	1102	63653	0.79	0.79	594.39	572.82	388	20522	21	977	0.05	0.06	152.25	153.62
58	1462	83183	1141	64794	0.79	0.79	578.50	572.92	344	20866	16	993	0.05	0.06	166.10	153.66
59	1453	84636	1111	65905	0.79	0.79	557.50	572.66	381	21247	18	1011	0.05	0.06	149.17	153.58
60	1370	86006	1101	67006	0.79	0.79	590.92	572.96	355	21602	23	1034	0.05	0.06	164.82	153.83

MPS LOW LOW

Replication Number	Independent Variables: MAS	MOH	MIX	Dependent Variables: Product A: Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Total Cycle Time	Product B: Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Total Cycle Time	Product C: Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Total Cycle Time
1	1	1	1	1415	1415	1401	1401	0.99	0.99	295.04	295.04	343	343	339	339	1.00	1.00	289.71	289.71	91	91	85	85	1.00	1.00	430.02	430.02
2	1	1	1	1455	2870	1419	2820	0.99	0.99	295.83	295.44	366	709	358	697	1.00	1.00	297.01	293.46	88	179	82	167	1.00	1.00	385.03	407.93
3	1	1	1	1431	4301	1421	4241	0.99	0.99	524.60	372.19	373	1082	369	1066	1.00	1.00	447.99	346.95	103	282	103	270	1.00	1.00	515.90	449.12
4	1	1	1	1374	5675	1362	5603	0.99	0.99	290.49	352.33	354	1436	348	1414	1.00	1.00	304.25	336.44	96	378	94	364	1.00	1.00	382.40	431.89
5	1	1	1	1435	7110	1371	6974	0.99	0.99	307.16	343.45	344	1780	336	1750	1.00	1.00	309.46	331.26	87	465	86	450	1.00	1.00	422.94	430.18
6	1	1	1	1432	8542	1451	8425	0.99	0.99	290.96	334.41	389	2169	382	2132	1.00	1.00	282.31	322.49	76	541	75	525	1.00	1.00	352.76	419.12
7	1	1	1	1440	9982	1419	9844	0.99	0.99	357.83	337.79	373	2542	365	2497	1.00	1.00	331.16	323.76	89	630	84	609	1.00	1.00	424.79	419.90
8	1	1	1	1440	11423	1419	11262	0.99	0.99	364.58	341.18	373	2914	365	2862	1.00	1.00	333.70	325.03	89	719	84	693	1.00	1.00	426.36	420.69
9	1	1	1	1440	12863	1419	12681	0.99	0.99	371.33	344.54	373	3287	365	3227	1.00	1.00	336.23	326.29	89	808	84	777	1.00	1.00	427.82	421.47
10	1	1	1	1440	14303	1419	14099	0.99	0.99	378.08	347.91	373	3659	365	3592	1.00	1.00	338.77	327.56	89	897	84	861	1.00	1.00	429.49	422.25
11	1	1	1	1441	15744	1409	15508	0.99	0.99	437.17	358.02	347	4006	342	3934	1.00	1.00	396.35	333.54	110	1007	104	965	0.91	0.99	488.41	429.38
12	1	1	1	1418	17160	1407	16915	0.99	0.99	295.67	351.00	378	4384	372	4306	1.00	1.00	291.06	329.87	76	1083	74	1039	0.99	0.99	406.35	427.74
13	1	1	1	1430	18590	1431	18346	0.99	0.99	295.87	348.70	373	4757	366	4672	1.00	1.00	307.79	328.14	83	1166	79	1118	0.99	0.99	376.51	424.12
14	1	1	1	1486	20076	1431	19777	0.99	0.99	365.95	349.54	377	5134	362	5034	1.00	1.00	394.88	332.22	100	1266	92	1210	0.99	0.99	439.38	425.28
15	1	1	1	1402	21478	1407	21184	0.99	0.99	407.36	353.38	334	5468	335	5369	1.00	1.00	377.26	335.03	109	1375	105	1315	0.99	0.99	459.47	428.01
16	1	1	1	1467	22945	1456	22640	0.99	0.99	333.32	352.09	291	5759	283	5652	1.00	1.00	321.06	334.33	93	1468	88	1403	0.99	0.99	458.94	429.95
17	1	1	1	1446	24391	1387	24027	0.99	0.99	546.59	363.26	368	6127	361	6013	1.00	1.00	466.76	342.28	103	1571	101	1504	0.99	0.99	536.12	437.08
18	1	1	1	1364	25755	1362	25389	0.99	0.99	274.34	358.49	374	6501	375	6388	1.00	1.00	270.39	338.06	89	1660	85	1589	0.99	0.99	349.69	432.40
19	1	1	1	1391	27146	1383	26772	0.99	0.99	230.34	351.87	387	6888	380	6768	1.00	1.00	229.24	331.96	86	1746	84	1673	0.99	0.99	318.08	426.66
20	1	1	1	1412	28558	1399	28171	0.99	0.99	233.67	346.00	338	7226	336	7104	1.00	1.00	249.92	328.07	86	1832	79	1752	0.99	0.99	335.51	422.56
21	1	1	1	1429	29987	1412	29583	0.99	0.99	309.55	344.26	387	7613	383	7487	1.00	1.00	305.20	326.90	79	1911	78	1830	0.99	0.99	383.84	420.90
22	1	1	1	1425	31412	1405	30988	0.99	0.99	331.91	343.70	345	7958	341	7828	1.00	1.00	302.34	325.83	92	2003	86	1916	0.99	0.99	393.94	419.69
23	1	1	1	1443	32855	1428	32416	0.99	0.99	397.27	346.06	353	8311	348	8176	1.00	1.00	373.06	327.84	92	2095	87	2003	0.99	0.99	465.61	421.25
24	1	1	1	1435	34290	1429	33845	0.99	0.99	249.19	341.97	352	8663	350	8526	1.00	1.00	252.81	324.76	75	2170	73	2076	0.99	0.99	351.01	418.78
25	1	1	1	1379	35669	1363	35208	0.99	0.99	292.89	340.07	375	9038	371	8897	1.00	1.00	287.11	323.19	87	2257	82	2158	0.99	0.99	354.57	416.34
26	1	1	1	1438	37107	1357	36565	0.99	0.99	461.32	344.57	407	9445	393	9290	1.00	1.00	413.25	327.00	111	2368	108	2266	0.99	0.99	467.12	418.76
27	1	1	1	1495	38602	1507	38072	0.99	0.99	352.15	344.87	355	9800	350	9640	1.00	1.00	325.07	328.93	84	2452	80	2346	0.99	0.99	392.86	417.87
28	1	1	1	1432	40034	1428	39500	0.99	0.99	364.23	345.57	379	10179	374	10014	1.00	1.00	348.62	327.74	88	2540	82	2428	0.99	0.99	421.13	417.98
29	1	1	1	1448	41482	1446	40946	0.99	0.99	268.83	342.88	343	10522	342	10356	1.00	1.00	269.90	325.83	83	2623	80	2508	0.99	0.99	347.76	415.74
30	1	1	1	1356	42838	1342	42288	0.99	0.99	304.73	341.65	371	10893	367	10723	1.00	1.00	281.42	324.31	84	2707	83	2591	0.99	0.99	390.14	414.92
31	1	1	1	1437	44275	1421	43709	0.99	0.99	347.19	341.83	308	11201	303	11026	1.00	1.00	340.32	324.75	99	2806	97	2688	0.99	0.99	395.24	414.21
32	1	1	1	1421	45696	1404	45113	0.99	0.99	277.57	339.83	348	11549	339	11365	1.00	1.00	274.13	323.24	92	2898	87	2775	0.99	0.99	364.45	412.65
33	1	1	1	1475	47171	1455	46568	0.99	0.99	320.95	339.24	362	11911	355	11720	1.00	1.00	290.86	322.35	76	2974	72	2847	0.99	0.99	381.41	411.86
34	1	1	1	1421	48592	1405	47973	0.99	0.99	322.17	338.74	328	12239	322	12042	1.00	1.00	321.98	322.34	110	3084	106	2953	0.99	0.99	424.12	412.30
35	1	1	1	1413	50005	1374	49347	0.99	0.99	378.25	339.84	392	12631	383	12425	1.00	1.00	342.45	322.96	88	3172	83	3036	0.99	0.99	469.26	413.83
36	1	1	1	1411	51416	1399	50746	0.99	0.99	257.14	337.56	341	12972	332	12757	1.00	1.00	265.32	321.46	90	3262	84	3120	0.99	0.99	363.32	412.47
37	1	1	1	1359	52775	1356	52102	0.99	0.99	218.06	334.46	360	13332	361	13118	1.00	1.00	213.54	318.49	70	3332	69	3189	0.99	0.99	337.60	410.85
38	1	1	1	1385	54160	1369	53471	0.99	0.99	303.59	333.66	331	13663	326	13444	1.00	1.00	291.68	317.84	91	3423	87	3276	0.99	0.99	395.03	410.43
39	1	1	1	1404	55564	1380	54851	0.99	0.99	264.80	331.93	352	14015	347	13791	1.00	1.00	272.53	316.70	91	3514	87	3363	0.99	0.99	380.95	409.15
40	1	1	1	1407	56971	1415	56266	0.99	0.99	354.99	332.51	343	14358	334	14125	1.00	1.00	344.19	317.35	91	3605	83	3446	0.99	0.99	476.82	410.78
41	1	1	1	1424	58395	1393	57659	0.99	0.99	310.99	331.99	342	14700	339	14464	1.00	1.00	287.06	316.64	83	3688	78	3524	0.99	0.99	385.48	410.22
42	1	1	1	1388	59783	1355	59014	0.99	0.99	326.33	331.86	362	15062	360	14824	1.00	1.00	278.34	315.71	90	3778	83	3607	0.99	0.99	405.01	410.10
43	1	1	1	1433	61216	1421	60435	0.99	0.99	268.28	330.13	368	15430	364	15188	1.00	1.00	266.22	314.50	87	3865	86	3693	0.99	0.99	341.82	408.51
44	1	1	1	1431	62647	1432	61867	0.99	0.99	251.07	328.30	347	15777	340	15528	1.00	1.00	259.70	313.30	75	3940	69	3762	0.99	0.99	360.53	407.63
45	1	1	1	1499	64146	1457	63324	0.99	0.99	476.94	331.72	371	16148	363	15891	1.00	1.00	421.43	315.77	94	4034	87	3849	0.99	0.99	497.00	409.65
46	1	1	1	1371	65517	1364	64688	0.99	0.99	308.01	331.22	350	16498	339	16230	1.00	1.00	300.93	315.46	88	4122	86	3935	0.99	0.99	408.28	409.62
47	1	1	1	1486	67003	1452	66140	0.99	0.99	297.97	330.49	371	16869	368	16598	1.00	1.00	280.28	314.68	84	4206	73	4008	0.99	0.99	364.80	408.80
48	1	1	1	1368	68371	1354	67494	0.99	0.99	279.65	329.47	378	17247	367	16965	1.00	1.00	250.89	313.30	78	4284	76	4084	0.99	0.99	359.82	407.87
49	1	1	1	1453	69824	1434	68928	0.99	0.99	266.50	328.16	408	17655	402	17367	1.00	1.00	264.48	312.17	72	4356	69	4153	0.99	0.99	372.95	407.29
50	1	1	1	1416	71240	1391	70319	0.99	0.99	253.65	326.69	370	18025	355	17722	1.00	1.00	257.26	311.07	97	4453	90	4243	0.99	0.99	347.42	406.02
51	1	1	1	1394	72634	1388	71707	0.99	0.99	225.95	324.74	354	18379	350	18072	1.00	1.00	228.97	309.48	64	4517	65	4308	0.99	0.99	351.01	405.19
52	1	1	1	1451	74085	1440	73147	0.99	0.99	279.53	323.85	345	18724	344	18416	1.00	1.00	281.64	308.96	89	4606	88	4396	0.99	0.99	368.22	404.46
53	1	1	1	1472	75557	1443	74590	0.99	0.99	257.17	322.56	365	19089	356	18772	1.00	1.00	264.67	308.12	88	4694	81	4477	0.99	0.99	359.12	403.63
54	1	1	1	1426	76983	1403	75993	0.99	0.99	497.51	325.79	395	19484	386	19158	1.00	1.00	409.87	310.17	104	4798	101	4578	0.99	0.99	481.14	405.34
55	1	1	1	1427	78410	1411	77404	0.99	0.99	351.57	326.26	354	19838	351	19509	1.00	1.00	337.40	310.66	98	4896	87	4665	0.99	0.99	425.18	405.71
56	1	1	1	1447	79857	1451	78855	0.99	0.99	302.89	325.83	352	20190	344	19853	1.00	1.00	290.46	310.31	87	4983	81	4746	0.99	0.99	410.40	405.79
57	1	1	1	1438	81295	1375	80230	0.99	0.99	245.89	324.46	407	20597	400	20253	1.00	1.00	258.16	309.28	73	5056	67	4813	0.99	0.99	387.83	405.54
58	1	1	1	1529	82824	1514	81744	0.99	0.99	443.78	326.67	342	20939	339	20592	1.00	1.00	393.11	310.66	91	5147	86	4899	0.99	0.99	483.01	406.90
59	1	1	1	1473	84297	1470	83214	0.99	0.99	383.84	327.68	360	21299	358	20950	1.00	1.00	380.30	311.86	83	5230	78	4977	0.99	0.99	473.26	407.94
60	1	1	1	1446	85743	1395	84609	0.99	0.99	325.25	327.64	383	21682	379	21328	1.00	1.00	310.72	311.83	97	5327	93	5070	0.99	0.99	405.85	407.92

MPS LOW MED

Replication Number	Independent Variables			Dependent Variables: Product A								Product B								Product C							
	MAS	MOH	MIX	Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Total Cycle Time	Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Total Cycle Time	Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Total Cycle Time
1	1	1	2	1477	1477	826	826	0.60	0.60	754.99	754.99	695	695	671	671	0.98	0.98	651.90	651.90	185	185	162	162	0.84	0.84	669.35	669.35
2	1	1	2	1465	2942	811	1637	0.56	0.58	736.14	746.66	768	1463	737	1408	0.99	0.98	639.31	646.31	175	360	161	323	0.96	0.90	666.59	667.97
3	1	1	2	1367	4309	808	2445	0.58	0.58	768.10	759.68	730	2193	718	2126	0.98	0.98	653.63	648.12	175	535	155	478	0.93	0.91	664.09	666.71
4	1	1	2	1459	5768	773	3218	0.54	0.57	734.54	753.64	757	2950	741	2867	0.98	0.98	650.21	648.66	194	729	161	639	0.95	0.92	619.53	654.57
5	1	1	2	1387	7155	770	3988	0.57	0.57	764.93	756.92	720	3670	696	3563	1.00	0.99	656.85	650.26	186	915	170	809	0.92	0.92	676.56	659.19
6	1	1	2	1422	8577	842	4830	0.57	0.57	780.77	760.17	715	4385	704	4267	0.99	0.99	638.87	648.38	174	1089	161	970	0.92	0.92	647.14	657.19
7	1	1	2	1496	10073	843	5673	0.57	0.57	748.25	758.40	732	5117	711	4978	0.99	0.99	643.71	647.71	178	1267	156	1126	0.92	0.92	635.58	654.20
8	1	1	2	1495	11568	843	6516	0.57	0.57	744.71	756.63	732	5848	711	5689	0.99	0.99	642.37	647.05	178	1445	156	1282	0.92	0.92	629.60	651.21
9	1	1	2	1496	13064	843	7358	0.57	0.57	741.17	754.86	732	6580	711	6400	0.99	0.99	641.04	646.38	178	1623	156	1437	0.92	0.92	623.62	648.22
10	1	1	2	1496	14559	843	8200	0.57	0.57	737.63	753.09	732	7311	711	7111	0.99	0.99	639.70	645.71	178	1801	156	1593	0.92	0.92	617.64	646.23
11	1	1	2	1366	15925	749	8949	0.57	0.57	746.56	752.46	764	8075	737	7848	0.99	0.99	659.56	647.01	193	1994	168	1761	0.92	0.92	645.54	646.26
12	1	1	2	1529	17454	869	9818	0.57	0.57	746.13	751.90	702	8777	690	8538	0.99	0.99	642.18	646.62	166	2160	149	1910	0.92	0.92	677.31	647.76
13	1	1	2	1432	18886	770	10589	0.57	0.57	744.76	751.38	758	9535	729	9267	0.99	0.99	656.79	647.42	181	2341	163	2073	0.92	0.92	661.50	648.64
14	1	1	2	1470	20356	752	11340	0.57	0.57	724.69	749.61	716	10251	696	9963	0.99	0.99	657.44	648.12	194	2535	172	2245	0.92	0.92	661.50	649.81
15	1	1	2	1454	21810	963	12303	0.57	0.57	763.02	750.66	705	10956	689	10652	0.99	0.99	623.23	646.51	155	2690	139	2384	0.92	0.92	641.23	649.31
16	1	1	2	1400	23210	783	13086	0.57	0.57	763.36	751.42	764	11720	745	11397	0.99	0.99	647.12	646.55	178	2868	157	2541	0.92	0.92	650.28	649.37
17	1	1	2	1465	24675	940	14026	0.57	0.57	749.79	751.31	718	12438	690	12087	0.99	0.99	622.20	645.10	158	3026	135	2676	0.92	0.92	628.75	648.33
18	1	1	2	1396	26071	852	14878	0.57	0.57	734.72	750.36	729	13167	705	12792	0.99	0.99	631.37	644.40	164	3190	149	2825	0.92	0.92	686.34	649.28
19	1	1	2	1418	27489	859	15737	0.57	0.57	768.86	751.37	746	13913	716	13508	0.99	0.99	629.50	643.61	176	3366	148	2973	0.92	0.92	599.86	646.82
20	1	1	2	1426	28915	770	16507	0.57	0.57	742.58	750.96	724	14637	683	14191	0.99	0.99	662.52	644.52	201	3567	171	3144	0.92	0.92	681.02	648.68
21	1	1	2	1453	30368	800	17307	0.57	0.57	758.58	751.22	751	15388	727	14918	0.99	0.99	638.98	644.25	175	3742	160	3304	0.92	0.92	620.18	647.30
22	1	1	2	1456	31824	816	18123	0.57	0.57	746.46	750.96	725	16113	711	15629	0.99	0.99	645.79	644.32	190	3932	168	3472	0.92	0.92	633.46	646.63
23	1	1	2	1407	33231	755	18878	0.57	0.57	765.71	751.55	716	16829	689	16318	0.99	0.99	662.79	645.10	196	4128	170	3642	0.92	0.92	642.56	646.44
24	1	1	2	1431	34662	806	19684	0.57	0.57	758.96	751.73	707	17536	679	16997	0.99	0.99	654.38	645.47	199	4327	163	3805	0.92	0.92	611.89	644.96
25	1	1	2	1448	36110	880	20564	0.57	0.57	756.00	751.87	689	18225	677	17674	0.99	0.99	642.08	645.34	171	4498	147	3952	0.92	0.92	633.67	644.54
26	1	1	2	1472	37582	888	21452	0.57	0.57	769.26	752.59	717	18942	697	18371	0.99	0.99	642.70	645.24	169	4667	153	4105	0.92	0.92	612.88	643.36
27	1	1	2	1421	39003	808	22260	0.57	0.57	739.37	752.11	716	19658	688	19059	0.99	0.99	650.23	645.42	197	4864	162	4267	0.92	0.92	657.85	643.91
28	1	1	2	1413	40416	839	23099	0.57	0.57	772.76	752.86	746	20404	717	19776	0.99	0.99	635.21	645.05	177	5041	153	4420	0.92	0.92	620.02	643.36
29	1	1	2	1412	41828	764	23863	0.57	0.57	736.62	752.34	748	21152	718	20494	0.99	0.99	658.18	645.51	183	5224	166	4586	0.92	0.92	688.84	646.01
30	1	1	2	1515	43343	762	24625	0.57	0.57	724.66	751.48	724	21876	719	21213	0.99	0.99	661.74	646.06	188	5412	169	4755	0.92	0.92	652.89	646.29
31	1	1	2	1441	44784	756	25381	0.57	0.57	749.60	751.43	705	22581	682	21895	0.99	0.99	669.50	646.79	198	5610	172	4927	0.92	0.92	663.62	646.93
32	1	1	2	1419	46203	840	26221	0.57	0.57	770.79	752.06	736	23317	713	22608	0.99	0.99	635.38	646.43	174	5784	158	5085	0.92	0.92	650.44	646.07
33	1	1	2	1375	47578	819	27040	0.57	0.57	757.66	752.22	753	24070	733	23341	0.99	0.99	645.79	646.41	184	5968	148	5233	0.92	0.92	630.16	645.62
34	1	1	2	1442	49020	749	27789	0.57	0.57	727.36	751.56	736	24806	711	24052	0.99	0.99	676.84	647.28	193	6161	165	5398	0.92	0.92	683.57	646.78
35	1	1	2	1510	50530	830	28619	0.57	0.57	743.96	751.33	738	25544	719	24771	0.99	0.99	641.77	647.12	180	6341	164	5562	0.92	0.92	640.00	646.59
36	1	1	2	1379	51909	830	29449	0.57	0.57	784.33	752.26	726	26270	698	25469	0.99	0.99	648.94	647.17	181	6522	162	5724	0.92	0.92	629.97	646.11
37	1	1	2	1483	53392	847	30296	0.57	0.57	744.03	752.03	768	27038	746	26215	0.99	0.99	630.30	646.69	168	6690	149	5873	0.92	0.92	632.31	645.76
38	1	1	2	1536	54928	945	31241	0.57	0.57	739.80	751.66	739	27777	715	26930	0.99	0.99	607.52	645.65	148	6838	132	6005	0.92	0.92	624.38	645.29
39	1	1	2	1429	56357	776	32017	0.57	0.57	754.14	751.72	739	28516	723	27653	0.99	0.99	643.36	645.59	189	7027	164	6169	0.92	0.92	644.91	645.28
40	1	1	2	1439	57796	737	32754	0.57	0.57	746.94	751.59	693	29209	672	28325	0.99	0.99	678.89	646.38	204	7231	183	6352	0.92	0.92	663.33	645.80
41	1	1	2	1410	59206	863	33617	0.57	0.57	780.42	752.33	724	29933	702	29027	0.99	0.99	629.84	645.98	174	7405	152	6504	0.92	0.92	626.97	645.36
42	1	1	2	1500	60706	881	34498	0.57	0.57	729.62	751.75	724	30657	711	29738	0.99	0.99	633.01	645.67	170	7575	148	6652	0.92	0.92	649.41	645.46
43	1	1	2	1398	62104	797	35295	0.57	0.57	780.09	752.39	748	31405	729	30467	0.99	0.99	642.74	645.60	182	7757	162	6814	0.92	0.92	653.44	645.64
44	1	1	2	1483	63587	877	36172	0.57	0.57	739.60	752.08	722	32127	704	31171	0.99	0.99	631.43	645.28	172	7929	152	6966	0.92	0.92	627.77	645.25
45	1	1	2	1453	65040	936	37108	0.57	0.57	758.42	752.24	695	32822	673	31844	0.99	0.99	627.30	644.90	166	8095	146	7112	0.92	0.92	611.84	644.56
46	1	1	2	1395	66435	749	37857	0.57	0.57	754.26	752.28	747	33569	718	32562	0.99	0.99	661.23	645.26	189	8284	172	7284	0.92	0.92	681.40	645.43
47	1	1	2	612221	678656	759	38616	0.57	0.57	749.21	752.20	769	34338	740	33302	0.99	0.99	650.66	645.38	187	8471	162	7446	0.92	0.92	652.32	645.58
48	1	1	2	(609285)	69371	874	39490	0.57	0.57	744.52	752.03	699	35037	690	33992	0.99	0.99	639.47	645.26	174	8645	154	7600	0.92	0.92	635.22	645.37
49	1	1	2	1392	70763	885	40375	0.57	0.57	756.59	752.13	674	35711	636	34628	0.99	0.99	633.83	645.05	174	8819	153	7753	0.92	0.92	667.67	645.81
50	1	1	2	1443	72206	869	41244	0.57	0.57	753.08	752.15	732	36443	705	35333	0.99	0.99	624.50	644.64	169	8988	150	7903	0.92	0.92	627.90	645.47
51	1	1	2	1301	73507	865	42109	0.57	0.57	794.29	752.91	751	37194	748	36081	0.99	0.99	632.58	644.39	166	9155	146	8049	0.92	0.92	628.38	645.16
52	1	1	2	1509	75016	936	43045	0.57	0.57	736.33	752.43	707	37901	685	36766	0.99	0.99	613.80	643.82	156	9312	142	8191	0.92	0.92	663.62	645.48
53	1	1	2	1389	76405	835	43880	0.57	0.57	781.33	752.98	664	38565	653	37419	0.99	0.99	660.44	644.11	188	9500	168	8359	0.92	0.92	673.34	646.04
54	1	1	2	1421	77826	849	44729	0.57	0.57	780.38	753.50	700	39265	695	38114	0.99	0.99	643.01	644.09	177	9677	156	8515	0.92	0.92	636.76	645.87
55	1	1	2	1352	79178	770	45499	0.57	0.57	804.91	754.37	719	39984	706	38820	0.99	0.99	658.39	644.35	193	9870	159	8674	0.92	0.92	634.41	645.66
56	1	1	2	1473	80651	732	46231	0.57	0.57	718.37	753.80	698	40682	681	39501	0.99	0.99	681.47	644.98	208	10078	184	8858	0.92	0.92	660.10	645.96
57	1	1	2	1448	82099	771	47002	0.57	0.57	753.80	753.80	696	41378	684	40185	0.99	0.99	658.50	645.22	188	10266	170	9028	0.92	0.92	677.82	646.56
58	1	1	2	1427	83526	800	47802	0.57	0.57	760.97	753.92	709	42087	688	40873	0.99	0.99	657.70	645.43	187	10453	164	9192	0.92	0.92	664.50	646.88
59	1	1	2	1474	85000	872	48674	0.57	0.57	744.43	753.75	715	42802	688	41561	0.99	0.99	641.81	645.37	175	10628	150	9342	0.92	0.92	653.73	646.99
60	1	1	2	1494	86494	875	49549	0.57	0.57	753.75	753.75	716	43518	704	42265	0.99	0.99	628.56	645.09	175	10803	150	9492	0.92	0.92	598.90	646.23

MPS LOW HIGH

Replication Number	Independent Variables			Dependent Variables: Product A								Product B								Product C							
	MAS	MOH	MIX	Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Total Cycle Time	Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Total Cycle Time	Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Total Cycle Time
1	1	1	3	1423	1423	36	36	0.04	0.04	292.06	292.06	1424	1424	848	848	0.61	0.61	588.00	588.00	350	350	274	274	0.77	0.77	730.25	730.25
2	1	1	3	1474	2897	49	85	0.02	0.03	513.79	477.53	1466	2890	927	1775	0.63	0.62	586.35	587.14	363	713	268	542	0.79	0.78	671.10	701.00
3	1	1	3	1391	4288	38	123	0.03	0.03	467.92	474.56	1390	4270	830	2605	0.62	0.62	596.93	590.28	379	1092	281	823	0.81	0.79	709.41	703.53
4	1	1	3	1439	5727	41	164	0.03	0.03	516.20	484.72	1383	5653	868	3473	0.62	0.62	610.27	595.28	347	1439	284	1107	0.79	0.79	747.15	714.72
5	1	1	3	1446	7173	45	209	0.03	0.03	498.51	487.69	1420	7073	861	4334	0.62	0.62	596.37	595.49	373	1812	272	1379	0.79	0.79	691.75	710.19
6	1	1	3	1468	8641	34	243	0.03	0.03	488.19	487.76	1434	8507	839	5173	0.62	0.62	581.42	593.20	368	2180	279	1658	0.79	0.79	719.27	711.56
7	1	1	3	1457	10098	30	273	0.03	0.03	479.76	486.89	1421	9928	849	6022	0.62	0.62	597.56	593.81	375	2555	279	1937	0.79	0.79	700.05	710
8	1	1	3	1457	11554	30	303	0.03	0.03	478.02	486.02	1421	11349	849	6871	0.62	0.62	598.77	594.43	375	2930	279	2216	0.79	0.79	695.74	709
9	1	1	3	1457	13011	30	332	0.03	0.03	476.27	485.14	1421	12769	849	7719	0.62	0.62	600.00	595.04	375	3304	279	2494	0.79	0.79	693.43	707
10	1	1	3	1457	14467	30	362	0.03	0.03	474.53	484.27	1421	14189	849	8568	0.62	0.62	601.22	595.66	376	3679	279	2773	0.79	0.79	690.12	704.93
11	1	1	3	1422	15889	41	403	0.03	0.03	546.49	490.60	1432	15621	781	9349	0.62	0.62	557.70	592.48	401	4080	296	3069	0.79	0.79	724.42	706.81
12	1	1	3	1499	17388	31	434	0.03	0.03	541.28	494.22	1473	17094	886	10235	0.62	0.62	587.63	592.06	364	4444	281	3350	0.79	0.79	695.98	705.90
13	1	1	3	1468	18856	55	489	0.03	0.03	442.12	488.36	1408	18502	883	11118	0.62	0.62	596.34	592.40	376	4819	273	3623	0.79	0.79	666.75	702.96
14	1	1	3	1454	20310	58	547	0.03	0.03	491.00	488.64	1555	20057	924	12042	0.62	0.62	554.08	589.46	340	5159	273	3896	0.79	0.79	708.52	703.34
15	1	1	3	1419	21729	33	580	0.03	0.03	425.89	485.07	1399	21456	891	12933	0.62	0.62	611.52	590.98	361	5520	271	4167	0.79	0.79	708.57	703.68
16	1	1	3	1494	23222	42	622	0.03	0.03	567.71	490.66	1450	22906	784	13717	0.62	0.62	555.64	588.96	382	5902	283	4450	0.79	0.79	743.78	706.23
17	1	1	3	1468	24690	86	708	0.03	0.03	516.92	493.72	1384	24290	879	14596	0.62	0.62	596.43	589.41	345	6247	255	4705	0.79	0.79	689.07	705.30
18	1	1	3	1410	26100	64	772	0.03	0.03	522.67	496.12	1427	25717	838	15434	0.62	0.62	583.15	589.07	357	6604	282	4987	0.79	0.79	738.02	707.15
19	1	1	3	1397	27497	53	825	0.03	0.03	475.26	494.78	1457	27174	961	16395	0.62	0.62	597.77	589.58	332	6936	262	5249	0.79	0.79	675.60	705.57
20	1	1	3	1441	28938	51	876	0.03	0.03	509.04	495.61	1442	28616	890	17285	0.62	0.62	591.52	589.68	348	7284	265	5514	0.79	0.79	694.75	705.06
21	1	1	3	1466	30404	73	949	0.03	0.03	512.38	496.90	1404	30020	988	18273	0.62	0.62	617.79	591.20	331	7615	245	5759	0.79	0.79	642.76	702.40
22	1	1	3	1459	31863	69	1018	0.03	0.03	505.31	497.47	1481	31501	983	19256	0.62	0.62	592.57	591.27	329	7944	246	6005	0.79	0.79	640.18	700.22
23	1	1	3	1447	33310	48	1066	0.03	0.03	406.08	493.31	1460	32961	838	20094	0.62	0.62	587.06	590.28	363	8307	284	6289	0.79	0.79	722.36	701.22
24	1	1	3	1446	34756	49	1115	0.03	0.03	499.68	493.59	1386	34347	882	20976	0.62	0.62	606.72	590.91	356	8663	272	6561	0.79	0.79	714.25	701.76
25	1	1	3	1414	36170	43	1158	0.03	0.03	509.75	494.19	1368	35715	820	21796	0.62	0.62	602.34	591.34	373	9036	286	6847	0.79	0.79	712.29	702.20
26	1	1	3	1449	37619	20	1178	0.03	0.03	471.81	493.81	1379	37094	813	22609	0.62	0.62	610.26	592.02	373	9409	293	7140	0.79	0.79	732.66	703.46
27	1	1	3	1367	38986	91	1269	0.03	0.03	595.69	501.13	1412	38506	938	23547	0.62	0.62	597.54	592.24	330	9739	248	7388	0.79	0.79	677.53	702.58
28	1	1	3	1467	40453	61	1330	0.03	0.03	464.06	499.40	1460	39966	914	24461	0.62	0.62	588.49	592.10	347	10086	261	7649	0.79	0.79	670.05	701.47
29	1	1	3	1441	41894	68	1398	0.03	0.03	491.62	499.05	1441	41407	957	25418	0.62	0.62	600.33	592.41	343	10429	249	7898	0.79	0.79	638.35	699.46
30	1	1	3	1466	43360	31	1429	0.03	0.03	412.39	497.17	1448	42855	903	26321	0.62	0.62	594.16	592.47	370	10799	271	8169	0.79	0.79	671.75	698.56
31	1	1	3	1459	44809	43	1472	0.03	0.03	567.06	498.92	1451	44306	868	27189	0.62	0.62	596.21	592.27	356	11154	277	8446	0.79	0.79	731.49	699.64
32	1	1	3	1454	46263	84	1556	0.03	0.03	517.63	499.93	1463	45769	930	28119	0.62	0.62	595.32	592.04	339	11493	263	8709	0.79	0.79	677.78	698.98
33	1	1	3	1485	47747	45	1601	0.03	0.03	433.40	498.06	1404	47163	940	29059	0.62	0.62	611.82	592.68	337	11830	259	8968	0.79	0.79	697.25	698.93
34	1	1	3	1447	49194	51	1652	0.03	0.03	470.20	497.20	1486	48649	837	29896	0.62	0.62	597.88	592.53	332	12162	261	9229	0.79	0.79	695.04	698.82
35	1	1	3	1450	50644	35	1687	0.03	0.03	558.41	498.47	1524	50173	858	30854	0.62	0.62	550.46	591.36	388	12550	274	9503	0.79	0.79	675.24	698.14
36	1	1	3	1477	52121	49	1736	0.03	0.03	480.76	497.97	1493	51666	920	31774	0.62	0.62	580.65	591.06	334	12884	265	9768	0.79	0.79	713.62	698.56
37	1	1	3	1349	53470	69	1805	0.03	0.03	530.93	499.23	1429	53095	913	32687	0.62	0.62	589.98	591.02	351	13235	261	10029	0.79	0.79	685.60	698.22
38	1	1	3	1413	54883	54	1859	0.03	0.03	536.75	500.32	1418	54513	877	33564	0.62	0.62	596.76	591.17	368	13603	271	10300	0.79	0.79	712.29	698.59
39	1	1	3	1400	56283	40	1899	0.03	0.03	407.27	498.36	1479	55992	904	34468	0.62	0.62	579.36	590.88	366	13969	275	10575	0.79	0.79	650.91	697.35
40	1	1	3	1408	57691	35	1934	0.03	0.03	408.29	496.73	1425	57417	901	35369	0.62	0.62	608.13	591.30	363	14332	265	10840	0.79	0.79	691.62	697.21
41	1	1	3	1400	59091	34	1968	0.03	0.03	629.28	499.02	1435	58852	864	36233	0.62	0.62	590.88	591.29	373	14705	275	11115	0.79	0.79	689.93	697.03
42	1	1	3	1347	60438	61	2029	0.03	0.03	577.52	501.38	1480	60332	930	37163	0.62	0.62	576.31	590.89	357	15062	265	11380	0.79	0.79	648.50	695.90
43	1	1	3	1450	61888	37	2066	0.03	0.03	398.08	499.53	1436	61768	829	37992	0.62	0.62	574.86	590.54	381	15443	280	11660	0.79	0.79	704.23	696.10
44	1	1	3	1458	63346	74	2140	0.03	0.03	557.37	501.53	1437	63205	952	38944	0.62	0.62	599.54	590.76	333	15776	256	11916	0.79	0.79	652.81	695.17
45	1	1	3	1462	64808	26	2166	0.03	0.03	139.14	497.18	1498	64703	829	39773	0.62	0.62	558.14	590.06	399	16175	285	12201	0.79	0.79	696.88	695.21
46	1	1	3	1404	66212	85	2251	0.03	0.03	652.10	503.03	1441	66144	886	40659	0.62	0.62	578.61	589.83	346	16521	262	12463	0.79	0.79	695.21	695.21
47	1	1	3	1403	67615	68	2319	0.03	0.03	492.46	502.72	1419	67563	850	41509	0.62	0.62	560.53	589.23	354	16875	279	12742	0.79	0.79	733.12	696.04
48	1	1	3	1406	69021	28	2347	0.03	0.03	336.75	500.74	1481	69044	830	42339	0.62	0.62	589.23	589.23	376	17251	291	13033	0.79	0.79	730.53	696.81
49	1	1	3	1404	70425	77	2424	0.03	0.03	529.07	501.64	1393	70437	911	43250	0.62	0.62	589.23	589.23	364	17615	257	13290	0.79	0.79	641.48	695.74
50	1	1	3	1414	71839	26	2450	0.03	0.03	501.52	502.70	1519	71956	900	44150	0.62	0.62	588.74	589.22	363	17978	273	13563	0.79	0.79	693.75	695.70
51	1	1	3	1426	73265	56	2506	0.03	0.03	548.25	503.70	1532	73487	869	45019	0.62	0.62	542.60	588.32	369	18347	272	13835	0.79	0.79	702.31	695.83
52	1	1	3	1396	74661	35	2541	0.03	0.03	288.42	500.65	1478	74965	867	45886	0.62	0.62	576.68	588.10	376	18723	272	14107	0.79	0.79	675.60	695.44
53	1	1	3	1408	76069	17	2558	0.03	0.03	329.11	499.51	1455	76420	855	46741	0.62	0.62	592.47	588.18	366	19089	275	14382	0.79	0.79	731.00	696.12
54	1	1	3	1445	77514	49	2607	0.03	0.03	668.38	503.06	1454	77874	924	47665	0.62	0.62	590.24	588.22	355	19444	265	14647	0.79	0.79	671.80	695.68
55	1	1	3	1506	79020	44	2651	0.03	0.03	451.26	502.20	1436	79310	915	48580	0.62	0.62	598.31	588.41	366	19810	270	14917	0.79	0.79	666.45	694.97
56	1	1	3	1469	80489	61	2712	0.03	0.03	531.99	502.87	1501	80811	966	49546	0.62	0.62	586.84	588.36	349	20159	252	15169	0.79	0.79	665.24	694.31
57	1	1	3	1439	81928	57	2769	0.03	0.03	502.87	502.87	1500	82311	908	50453	0.62	0.62	587.25	587.98	352	20511	264	15433	0.79	0.79	677.94	694.03
58	1	1	3	1453	83381	39	2808	0.03	0.03	433.76	501.91	1434	83745	885	51338	0.62	0.62	597.26	588.14	357	20868	272	15705	0.79	0.79	707.89	694.27
59	1	1	3	1422	84803	58	2866	0.03	0.03	549.84	502.88	1429	85174	936	52274	0.62	0.62	602.66	588.40	341	21209	260	15965	0.79	0.79	680.15	694.04
60	1	1	3	1453	86256	55	2921	0.03	0.03	508.72	502.98	1409	86583	886	53160	0.62	0.62	596.80	588.54	369	21578	270	16235	0.79	0.79	693.44	694.03

JIT LOW LOW

Replication Number	Independent Variables MAS	MOH	MIX	All Products Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	MOH LOW Period Cycle Time	Cycle Time	Period NOI	Cumulative NOI	MED Period NOI	Cumulative NOI	HIGH Period NOI	Cumulative NOI
1	3	1	1	1867	1867	1853	1853	0.999	0.999	270.37	270.37	85,464.41	85,464.41	77,333.49	77,333.49	53,111.63	53,111.63
2	3	1	1	1858	3725	1817	3670	0.999	0.999	291.38	280.77	82,898.22	168,362.63	74,482.29	151,815.77	50,260.44	103,372.07
3	3	1	1	1994	5719	1952	5622	0.996	0.999	325.84	296.80	89,451.21	257,813.83	81,865.28	233,681.05	57,643.43	161,015.49
4	3	1	1	1874	7593	1852	7474	0.999	0.999	288.58	297.24	85,097.21	342,911.05	76,936.29	310,617.34	52,714.43	213,729.93
5	3	1	1	1931	9524	1874	9348	0.998	0.996	329.44	303.49	88,074.61	430,985.66	80,058.68	390,676.02	55,836.83	269,566.76
6	3	1	1	1932	11456	1916	11264	0.996	0.996	327.90	307.66	86,529.01	517,514.67	78,498.08	469,174.11	54,276.22	323,842.98
7	3	1	1	1894	13350	1868	13132	0.996	0.996	339.62	312.16	86,387.06	603,901.73	78,327.38	547,501.49	54,105.53	377,948.52
8	3	1	1	1894	15244	1868	14999	0.996	0.996	301.23	310.82	86,387.06	690,288.79	78,327.38	625,828.88	54,105.53	432,054.05
9	3	1	1	1894	17138	1868	16867	0.996	0.996	304.70	310.14	86,387.06	776,675.85	78,327.38	704,156.26	54,105.53	486,159.58
10	3	1	1	1894	19032	1868	18734	0.996	0.996	303.32	309.46	86,387.06	863,062.91	78,327.38	782,483.65	54,105.53	540,265.11
11	3	1	1	1949	20981	1908	20642	0.995	0.996	370.89	315.14	89,437.41	952,500.32	81,596.48	864,080.13	57,374.63	597,639.74
12	3	1	1	1848	22829	1817	22459	0.996	0.996	281.13	312.39	82,615.22	1,035,115.54	74,179.29	938,259.42	49,957.44	647,597.17
13	3	1	1	1886	24715	1869	24328	0.996	0.996	324.64	313.32	85,598.61	1,120,714.15	77,457.88	1,015,717.10	53,235.83	700,833.01
14	3	1	1	1882	26597	1850	26178	0.996	0.996	248.89	308.77	80,966.81	1,201,680.96	72,505.89	1,088,222.99	48,284.03	749,117.04
15	3	1	1	1853	28450	1834	28012	0.995	0.996	312.37	309.00	87,349.61	1,289,030.58	79,308.69	1,167,531.67	55,086.83	804,203.87
16	3	1	1	1899	30349	1880	29892	0.996	0.996	280.42	307.21	85,547.81	1,374,578.39	77,461.88	1,244,993.56	53,240.03	857,443.90
17	3	1	1	1868	32217	1825	31717	0.996	0.996	299.14	306.74	83,912.81	1,458,491.20	75,631.89	1,320,625.45	51,410.03	908,853.94
18	3	1	1	1828	34046	1826	33543	0.996	0.996	279.84	305.28	86,548.01	1,546,039.22	78,432.09	1,399,057.53	54,210.23	963,064.17
19	3	1	1	1895	35940	1861	35404	0.996	0.996	334.50	306.81	87,096.01	1,632,135.23	79,020.09	1,478,077.62	54,798.23	1,017,862.40
20	3	1	1	1827	37767	1803	37207	0.996	0.996	218.59	302.64	80,191.42	1,712,326.64	71,645.49	1,549,723.11	47,423.64	1,065,286.04
21	3	1	1	1857	39624	1845	39052	0.996	0.996	253.25	300.21	87,248.81	1,799,575.46	79,177.89	1,628,901.00	54,956.03	1,120,242.07
22	3	1	1	1911	41535	1873	40925	0.995	0.996	354.06	302.67	90,168.41	1,889,743.87	82,442.46	1,711,343.46	58,220.63	1,178,462.70
23	3	1	1	1886	43421	1866	42791	0.996	0.996	209.92	298.63	81,608.01	1,971,351.88	73,347.09	1,784,690.57	49,125.23	1,227,587.94
24	3	1	1	1831	45252	1800	44591	0.996	0.996	295.67	298.55	82,497.82	2,053,849.70	74,026.89	1,858,717.46	49,805.04	1,277,392.97
25	3	1	1	1860	47112	1823	46414	0.996	0.996	294.35	298.38	82,682.41	2,136,532.11	74,261.49	1,932,978.94	50,039.63	1,327,432.61
26	3	1	1	1847	48959	1841	48255	0.996	0.996	246.40	296.47	81,868.01	2,218,400.13	73,482.09	2,006,461.03	49,260.23	1,376,692.84
27	3	1	1	1915	50874	1878	50133	0.995	0.996	362.61	298.58	90,415.41	2,308,815.54	82,634.48	2,089,095.52	58,412.63	1,435,105.47
28	3	1	1	1845	52719	1825	51958	0.996	0.996	262.07	296.94	81,939.81	2,390,755.35	73,468.89	2,162,564.40	49,247.03	1,484,352.51
29	3	1	1	1913	54632	1877	53835	0.995	0.996	321.97	297.82	87,993.21	2,478,748.56	80,107.28	2,242,671.69	55,885.43	1,540,237.94
30	3	1	1	1882	56514	1846	55681	0.996	0.996	306.33	298.10	86,286.01	2,565,034.58	78,210.09	2,320,881.77	53,988.23	1,594,226.17
31	3	1	1	1931	58445	1885	57566	0.995	0.996	384.82	300.94	89,248.81	2,654,283.39	81,382.88	2,402,264.66	57,161.03	1,651,387.20
32	3	1	1	1882	60327	1858	59424	0.996	0.996	326.08	301.72	86,924.41	2,741,207.80	78,908.49	2,481,173.14	54,686.63	1,706,073.83
33	3	1	1	1930	62257	1911	61335	0.996	0.996	372.07	303.92	89,589.01	2,830,796.81	81,813.08	2,562,986.23	57,591.23	1,763,665.06
34	3	1	1	1947	64204	1934	63269	0.996	0.996	349.93	305.32	90,882.61	2,921,679.41	83,181.68	2,646,167.91	58,959.83	1,822,624.89
35	3	1	1	1880	66084	1860	65129	0.996	0.996	304.20	305.29	84,386.81	3,006,066.23	76,210.89	2,722,378.79	51,989.03	1,874,613.92
36	3	1	1	1828	67912	1807	66936	0.996	0.996	249.02	303.77	80,404.22	3,086,470.44	71,878.29	2,794,257.08	47,656.44	1,922,270.36
37	3	1	1	1950	69862	1898	68834	0.996	0.996	300.46	303.68	86,621.41	3,173,091.85	78,695.48	2,872,952.56	54,473.63	1,976,743.99
38	3	1	1	1844	71706	1832	70666	0.996	0.996	346.52	304.79	85,289.21	3,258,381.07	77,128.29	2,950,080.85	52,906.43	2,029,650.42
39	3	1	1	1868	73574	1845	72511	0.996	0.996	240.53	303.16	81,037.81	3,339,418.88	72,631.89	3,022,712.74	48,410.03	2,078,060.45
40	3	1	1	1888	75462	1849	74360	0.995	0.995	367.98	304.52	87,054.61	3,426,473.49	78,963.69	3,101,676.42	54,741.83	2,132,802.29
41	3	1	1	1903	77365	1866	76226	0.995	0.996	337.62	305.33	89,486.01	3,515,959.50	81,675.09	3,183,351.51	57,463.23	2,190,256.52
42	3	1	1	1833	79198	1789	78015	0.995	0.996	289.67	304.97	82,920.62	3,598,880.12	74,464.69	3,257,806.20	50,232.84	2,240,488.35
43	3	1	1	1848	81046	1835	79850	0.995	0.996	281.30	304.42	83,273.81	3,682,153.94	75,007.99	3,332,814.09	50,786.03	2,291,274.39
44	3	1	1	1854	82900	1825	81675	0.996	0.996	244.85	303.09	84,947.81	3,767,101.75	76,756.99	3,409,570.97	52,535.03	2,343,809.42
45	3	1	1	1938	84838	1908	83583	0.995	0.996	366.14	304.53	91,561.41	3,858,663.16	83,960.46	3,493,531.46	59,738.63	2,403,548.05
46	3	1	1	1897	86735	1870	85453	0.996	0.996	330.00	305.09	84,100.81	3,942,763.97	75,919.88	3,569,451.34	51,698.03	2,455,246.08
47	3	1	1	1934	88669	1890	87343	0.995	0.996	371.81	306.53	88,223.81	4,030,987.78	80,302.88	3,649,754.22	56,081.03	2,511,327.11
48	3	1	1	1828	90497	1793	89136	0.996	0.996	264.94	305.70	79,566.42	4,110,554.20	70,955.49	3,720,709.71	46,733.64	2,558,060.75
49	3	1	1	1906	92403	1884	91020	0.996	0.996	307.34	305.73	88,051.61	4,198,605.81	80,176.68	3,800,886.40	55,953.83	2,614,014.58
50	3	1	1	1858	94261	1835	92855	0.996	0.996	291.78	305.46	84,777.81	4,283,383.62	76,651.89	3,877,537.29	52,430.03	2,666,444.61
51	3	1	1	1889	96150	1857	94712	0.996	0.996	326.43	305.87	84,491.21	4,367,874.83	76,240.29	3,953,777.57	52,018.43	2,718,463.05
52	3	1	1	1944	98094	1905	96617	0.996	0.996	319.83	306.14	87,691.81	4,455,566.64	79,810.88	4,033,588.45	55,589.03	2,774,052.07
53	3	1	1	1857	99951	1815	98432	0.995	0.996	301.56	306.06	87,691.82	4,543,258.46	79,645.89	4,113,234.34	55,424.04	2,829,476.11
54	3	1	1	1911	101862	1880	100312	0.996	0.996	358.41	307.04	88,218.81	4,631,477.27	80,332.88	4,193,567.23	56,111.03	2,885,587.14
55	3	1	1	1836	103698	1816	102128	0.996	0.996	295.12	306.82	85,392.02	4,716,869.29	77,151.09	4,270,718.32	52,929.24	2,938,516.38
56	3	1	1	1884	105582	1868	103996	0.996	0.996	312.83	306.93	86,169.41	4,803,038.70	78,098.48	4,348,816.80	53,876.63	2,992,393.01
57	3	1	1	1855	107437	1818	105814	0.996	0.996	237.12	305.73	81,695.42	4,884,734.11	73,184.49	4,422,001.29	48,962.64	3,041,355.64
58	3	1	1	1827	109264	1812	107626	0.996	0.996	261.91	304.99	81,395.22	4,966,129.33	72,934.29	4,494,935.58	48,712.44	3,090,068.08
59	3	1	1	1835	111099	1817	109443	0.996	0.996	272.86	304.46	82,510.22	5,048,639.54	74,134.29	4,569,069.87	49,912.44	3,139,980.51
60	3	1	1	1912	113011	1896	111339	0.996	0.996	359.65	305.40	87,550.01	5,136,189.55	79,704.08	4,648,773.95	55,482.23	3,195,462.74

JIT LOW MED

Replication Number	Independent Variables: MAS	MOH	MIX	All Products: Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	MOH LOW: Period Cycle Time	Cycle Time	Period NOI	Cumulative NOI	MED: Period NOI	Cumulative NOI	HIGH: Period NOI	Cumulative NOI
1	3	1	2	2323	2323	2033	2033	0.890	0.890	544.50	544.50	99,741.46	99,741.46	93,407.93	93,407.93	69,440.90	69,440.90
2	3	1	2	2296	4619	2065	4098	0.896	0.893	565.84	550.72	102,603.46	202,344.91	96,614.94	190,022.87	72,647.91	142,088.81
3	3	1	2	2316	6935	2026	6124	0.900	0.896	526.83	542.61	100,413.29	302,758.19	94,059.77	284,082.65	70,092.74	212,181.56
4	3	1	2	2388	9323	2101	8225	0.883	0.893	549.69	544.57	102,799.85	405,558.04	96,891.33	380,973.98	72,924.30	285,105.96
5	3	1	2	2323	11646	2067	10292	0.900	0.894	560.25	546.71	101,485.65	507,043.69	95,412.13	476,386.11	71,446.10	356,550.96
6	3	1	2	2424	14070	2092	12384	0.895	0.894	565.36	547.34	99,580.50	606,624.19	93,441.99	569,828.10	69,474.95	425,025.91
7	3	1	2	2386	16456	2082	14466	0.894	0.894	565.97	548.73	100,954.26	707,578.46	94,883.25	664,711.34	70,916.22	496,942.13
8	3	1	2	2386	18843	2082	16547	0.894	0.894	569.61	550.10	100,954.26	808,532.71	94,883.25	759,594.59	70,916.22	567,858.35
9	3	1	2	2386	21229	2082	18629	0.867	0.891	562.24	551.46	100,954.26	909,486.98	94,883.25	854,477.84	70,916.22	638,774.56
10	3	1	2	2386	23615	2082	20710	0.891	0.891	564.87	552.80	100,954.26	1,010,441.24	94,883.25	949,361.08	70,916.22	709,690.78
11	3	1	2	2263	25878	2019	22729	0.889	0.891	533.83	551.12	100,557.13	1,110,998.37	94,303.61	1,043,664.70	70,336.58	780,027.36
12	3	1	2	2316	28194	2074	24803	0.895	0.891	561.63	552.00	102,480.81	1,213,479.17	96,542.29	1,140,206.99	72,575.26	852,602.62
13	3	1	2	2368	30562	2076	26879	0.888	0.891	567.14	553.17	101,118.99	1,314,598.17	95,030.48	1,235,237.47	71,063.46	923,666.07
14	3	1	2	2325	32887	2037	28916	0.887	0.891	543.07	552.46	101,304.82	1,415,902.99	95,106.31	1,330,343.78	71,139.29	994,805.35
15	3	1	2	2299	35186	2024	30940	0.897	0.890	534.44	551.28	100,189.10	1,516,092.09	93,960.59	1,424,304.36	69,993.55	1,064,798.90
16	3	1	2	2329	37515	2066	33006	0.895	0.891	538.42	550.47	100,618.05	1,616,710.14	94,459.54	1,518,763.90	70,492.51	1,135,291.41
17	3	1	2	2295	39810	2014	35020	0.886	0.890	536.60	549.67	100,634.16	1,717,344.30	94,385.64	1,613,149.54	70,418.61	1,205,710.02
18	3	1	2	2333	42143	2064	37084	0.888	0.890	545.57	549.44	102,421.86	1,819,766.16	96,433.35	1,709,582.89	72,466.32	1,278,176.34
19	3	1	2	2334	44477	2048	39132	0.886	0.890	534.24	548.66	102,568.36	1,922,334.52	96,584.84	1,806,167.73	72,617.81	1,350,794.15
20	3	1	2	2268	46745	1998	41130	0.888	0.890	533.68	547.92	99,648.65	2,021,983.17	93,325.14	1,899,492.87	69,358.11	1,420,152.26
21	3	1	2	2309	49054	2063	43193	0.892	0.890	549.30	547.99	102,345.27	2,124,328.46	96,296.76	1,995,789.63	72,329.72	1,492,481.98
22	3	1	2	2256	51309	2029	45222	0.886	0.890	546.86	547.89	103,585.07	2,227,913.52	97,706.55	2,093,496.18	73,739.52	1,566,221.51
23	3	1	2	2374	53683	2024	47246	0.889	0.890	520.28	546.71	99,469.10	2,327,382.61	92,970.58	2,186,466.76	69,003.55	1,635,225.06
24	3	1	2	2338	56021	2049	49295	0.886	0.890	533.46	546.16	101,001.96	2,428,384.57	94,813.44	2,281,280.20	70,846.41	1,706,071.47
25	3	1	2	2355	58376	2064	51359	0.893	0.890	533.68	546.66	100,638.86	2,529,023.43	94,465.35	2,375,746.56	70,498.32	1,776,569.79
26	3	1	2	2427	60803	2092	53461	0.887	0.890	538.74	549.30	101,067.50	2,630,080.93	95,028.99	2,470,774.54	71,061.95	1,847,631.74
27	3	1	2	2241	63044	2049	55500	0.887	0.890	534.04	548.74	100,753.95	2,730,834.89	94,525.44	2,565,299.97	70,558.41	1,918,190.15
28	3	1	2	2468	65502	2077	57577	0.896	0.890	564.71	548.96	101,122.58	2,831,957.47	94,954.07	2,660,254.05	70,987.04	1,989,177.19
29	3	1	2	2424	67926	2105	59682	0.891	0.890	572.20	549.77	102,374.22	2,934,331.70	96,510.71	2,756,764.76	72,543.69	2,061,720.87
30	3	1	2	2413	70339	2097	61779	0.891	0.890	547.03	549.68	102,306.47	3,036,638.17	96,332.96	2,853,097.71	72,365.93	2,134,086.80
31	3	1	2	2223	72562	2016	63795	0.889	0.890	564.62	550.16	103,237.35	3,139,875.52	97,299.83	2,950,396.54	73,331.80	2,207,418.60
32	3	1	2	2325	74887	2073	65868	0.892	0.890	574.85	550.93	100,939.21	3,240,814.73	94,755.70	3,045,152.24	70,788.67	2,278,207.26
33	3	1	2	2270	77157	2028	67896	0.890	0.890	536.11	550.49	100,992.48	3,341,807.20	94,879.96	3,140,031.20	70,911.93	2,349,119.19
34	3	1	2	2327	79484	2078	69974	0.894	0.890	535.32	550.04	100,916.18	3,442,723.39	94,787.67	3,234,818.87	70,820.64	2,419,939.83
35	3	1	2	2379	81863	2043	72017	0.889	0.890	541.39	549.79	99,878.39	3,542,601.77	93,504.87	3,328,323.74	69,537.84	2,489,477.67
36	3	1	2	2283	84146	2027	74044	0.891	0.890	526.00	549.14	100,551.88	3,643,153.65	94,268.37	3,422,592.11	70,301.34	2,559,779.01
37	3	1	2	2361	86507	2087	76131	0.888	0.890	545.89	549.06	102,665.53	3,745,819.19	96,812.01	3,519,404.12	72,844.98	2,632,623.99
38	3	1	2	2376	88883	2075	78206	0.891	0.890	566.95	549.52	101,941.40	3,847,760.59	95,937.89	3,615,342.01	71,970.85	2,704,594.85
39	3	1	2	2358	91241	2093	80299	0.890	0.890	561.64	549.84	102,541.09	3,950,301.68	96,722.58	3,712,064.59	72,755.55	2,777,350.40
40	3	1	2	2348	93589	2062	82361	0.917	0.891	589.85	550.84	101,457.68	4,051,759.36	95,449.16	3,807,513.75	71,482.13	2,848,832.53
41	3	1	2	2414	96003	2091	84452	0.888	0.891	581.73	551.61	100,578.91	4,152,338.26	94,628.39	3,902,142.14	70,661.36	2,919,493.89
42	3	1	2	2266	98269	2013	86465	0.887	0.891	548.93	551.54	100,948.58	4,253,284.83	94,780.05	3,996,922.19	70,813.02	2,990,306.91
43	3	1	2	2233	100502	2032	88497	0.895	0.891	543.12	551.36	101,128.85	4,354,413.68	95,125.34	4,092,047.52	71,158.31	3,061,465.21
44	3	1	2	2256	102758	2019	90516	0.890	0.891	525.77	550.78	101,018.13	4,455,431.81	94,864.61	4,186,912.14	70,897.58	3,132,362.79
45	3	1	2	2278	105036	2010	92526	0.889	0.891	529.02	550.31	101,404.78	4,556,836.59	95,141.27	4,282,053.40	71,174.24	3,203,537.03
46	3	1	2	2342	107378	2082	94608	0.894	0.891	565.58	550.44	100,556.58	4,657,393.16	94,458.04	4,376,511.45	70,491.01	3,274,028.04
47	3	1	2	2374	109752	2102	96710	0.893	0.891	584.91	551.19	102,810.44	4,760,203.59	96,976.93	4,473,488.37	73,009.90	3,347,037.94
48	3	1	2	2278	112030	2050	98760	0.891	0.891	520.64	550.56	103,341.55	4,863,545.14	97,578.03	4,571,066.41	73,611.00	3,420,648.94
49	3	1	2	2318	114348	2059	100819	0.895	0.891	562.21	550.80	101,131.30	4,964,676.44	95,007.78	4,666,074.19	71,040.75	3,491,689.70
50	3	1	2	2442	116790	2073	102891	0.889	0.891	534.79	550.47	99,431.21	5,064,107.65	93,132.70	4,759,206.89	69,165.67	3,560,855.36
51	3	1	2	2396	119186	2067	104959	0.889	0.891	580.83	551.07	102,574.65	5,166,682.30	96,651.13	4,855,858.02	72,684.10	3,633,539.46
52	3	1	2	2354	121540	2077	107036	0.889	0.891	567.66	551.38	103,393.59	5,270,075.89	97,540.07	4,953,398.09	73,573.04	3,707,112.51
53	3	1	2	2409	123949	2093	109128	0.888	0.891	534.41	552.99	102,247.09	5,372,322.98	96,278.59	5,049,676.67	72,311.55	3,779,424.06
54	3	1	2	2396	126345	2107	111235	0.897	0.891	554.94	553.02	100,237.41	5,472,560.39	94,098.90	5,143,775.57	70,131.87	3,849,555.92
55	3	1	2	2330	128675	2033	113268	0.884	0.891	541.98	552.83	102,706.45	5,575,266.84	96,722.93	5,240,498.50	72,755.90	3,922,311.82
56	3	1	2	2346	131021	2063	115321	0.884	0.891	540.27	552.60	102,956.33	5,678,223.17	97,042.81	5,337,541.31	73,075.78	3,995,387.61
57	3	1	2	2288	133309	2015	117336	0.890	0.891	520.43	552.06	101,443.75	5,779,666.92	96,245.24	5,432,786.55	71,278.21	4,066,665.81
58	3	1	2	2276	135585	2048	119384	0.892	0.891	541.36	551.87	102,157.36	5,881,824.28	96,158.84	5,528,945.39	72,191.81	4,138,857.62
59	3	1	2	2286	137871	2042	121426	0.890	0.891	539.81	551.66	101,831.79	5,983,656.07	95,828.28	5,624,773.67	71,861.25	4,210,718.87
60	3	1	2	2322	140193	2046	123472	0.894	0.891	528.83	551.28	100,624.17	6,084,280.24	94,385.66	5,719,159.33	70,418.62	4,281,137.50

JIT LOW HIGH

Replication Number	Independent Variables: MAS	MOH	MIX	All Products: Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Cycle Time	MOH LOW: Period NOI	LOW: Cumulative NOI	MED: Period NOI	MED: Cumulative NOI	HIGH: Period NOI	HIGH: Cumulative NOI
1	3	1	3	3215	3215	2191	2191	0.668	0.668	614.51	614.51	102,781.92	102,781.92	97,559.64	97,559.64	73,846.09	73,846.09
2	3	1	3	3296	6511	2164	4355	0.673	0.671	620.71	617.59	104,217.57	206,999.49	99,020.30	196,579.94	75,305.75	149,150.94
3	3	1	3	3241	9752	2172	6527	0.679	0.674	621.50	618.89	101,143.45	308,142.94	95,651.18	292,231.12	71,936.63	221,087.47
4	3	1	3	3215	12967	2169	8696	0.670	0.673	629.09	621.44	104,441.75	412,584.69	99,364.47	391,595.59	75,649.82	296,737.39
5	3	1	3	3283	16250	2172	10868	0.691	0.676	585.24	614.20	104,686.45	517,271.14	99,509.18	491,104.77	75,794.63	372,532.02
6	3	1	3	3260	19510	2195	13063	0.679	0.677	612.45	613.91	103,715.86	620,987.00	98,603.58	589,708.35	74,889.03	447,421.05
7	3	1	3	3266	22776	2188	15251	0.678	0.677	617.36	614.40	103,342.09	724,329.09	98,184.82	687,893.17	74,470.27	521,891.33
8	3	1	3	3266	26042	2188	17438	0.678	0.677	618.42	614.91	103,342.09	827,671.19	98,184.82	786,077.99	74,470.27	596,361.60
9	3	1	3	3266	29307	2188	19626	0.678	0.677	619.48	615.42	103,342.09	931,013.28	98,184.82	884,262.81	74,470.27	670,831.87
10	3	1	3	3266	32573	2188	21813	0.678	0.677	620.55	615.93	103,342.09	1,034,355.38	98,184.82	982,447.63	74,470.27	745,302.14
11	3	1	3	3296	35869	2208	24021	0.690	0.678	620.72	616.37	101,176.91	1,135,532.29	95,734.64	1,078,182.27	72,020.09	817,322.23
12	3	1	3	3347	39216	2210	26231	0.677	0.678	627.60	617.32	102,835.38	1,238,367.67	97,653.11	1,175,835.38	73,938.56	891,260.78
13	3	1	3	4061	43277	2168	28399	0.733	0.683	616.30	617.24	103,685.51	1,342,053.18	98,618.24	1,274,453.61	74,903.69	966,164.47
14	3	1	3	2482	45759	2199	30598	0.573	0.677	616.22	617.17	104,056.80	1,446,109.98	98,984.52	1,373,438.14	75,269.97	1,041,434.45
15	3	1	3	3255	49014	2195	32739	0.696	0.678	623.29	618.60	103,254.86	1,549,364.84	98,042.58	1,471,480.72	74,328.03	1,115,762.48
16	3	1	3	3307	52321	2162	34965	0.665	0.677	613.94	617.35	105,031.10	1,654,395.94	100,023.83	1,571,504.55	76,309.28	1,192,071.76
17	3	1	3	3309	55630	2185	37140	0.682	0.678	613.51	617.13	101,902.51	1,756,298.45	96,535.23	1,668,039.78	72,820.68	1,264,892.44
18	3	1	3	3174	58804	2187	39327	0.680	0.678	629.67	617.82	103,781.98	1,860,080.43	98,684.70	1,766,724.48	74,970.15	1,339,862.59
19	3	1	3	3391	62195	2203	41530	0.682	0.678	615.28	617.69	101,587.74	1,961,668.16	96,230.46	1,862,954.94	72,615.91	1,412,378.51
20	3	1	3	3281	65476	2189	43719	0.679	0.678	613.02	617.46	102,254.45	2,063,922.61	97,057.17	1,960,012.12	73,342.62	1,485,721.13
21	3	1	3	3295	68771	2178	45897	0.669	0.677	620.05	617.58	103,797.86	2,167,720.47	98,685.59	2,058,697.70	74,971.04	1,560,692.17
22	3	1	3	3273	72044	2182	48079	0.669	0.677	622.36	617.79	103,762.80	2,271,483.27	98,655.53	2,157,353.23	74,940.98	1,635,633.15
23	3	1	3	3302	75346	2170	50249	0.679	0.677	615.06	617.68	103,119.98	2,374,603.26	97,902.71	2,255,256.94	74,188.16	1,709,821.30
24	3	1	3	3280	78626	2216	52465	0.683	0.677	621.79	617.85	103,323.79	2,477,927.05	98,146.52	2,353,402.46	74,431.97	1,784,253.27
25	3	1	3	3213	81839	2168	54633	0.679	0.678	627.58	618.24	101,511.51	2,579,438.56	96,119.24	2,449,521.69	72,404.69	1,856,657.96
26	3	1	3	3206	85045	2163	56796	0.676	0.677	612.25	618.01	105,132.34	2,684,570.90	100,035.08	2,549,556.76	76,320.51	1,932,978.47
27	3	1	3	3297	88342	2162	58958	0.672	0.677	614.82	617.89	103,233.10	2,787,804.00	97,935.83	2,647,492.58	74,221.28	2,007,199.75
28	3	1	3	3231	91573	2183	61141	0.691	0.677	616.17	617.83	103,538.04	2,891,342.04	98,390.76	2,745,883.35	74,676.21	2,081,875.97
29	3	1	3	3144	94717	2147	63288	0.668	0.677	623.79	618.03	104,887.58	2,996,229.61	99,990.30	2,845,873.65	76,275.75	2,158,151.72
30	3	1	3	3264	97981	2175	65463	0.669	0.677	622.59	618.18	103,967.16	3,100,196.77	98,804.88	2,944,678.53	75,090.33	2,233,242.05
31	3	1	3	3216	101197	2174	67637	0.674	0.677	623.67	618.36	103,766.92	3,203,963.69	98,664.65	3,043,343.19	74,950.10	2,308,192.15
32	3	1	3	3347	104544	2186	69823	0.667	0.676	614.95	618.25	103,006.74	3,306,960.44	97,839.47	3,141,182.66	74,124.92	2,382,317.07
33	3	1	3	3169	107712	2160	71983	0.681	0.677	615.55	618.17	104,027.63	3,410,988.07	98,840.36	3,240,023.00	75,125.81	2,457,442.88
34	3	1	3	3376	111088	2189	74172	0.669	0.676	614.31	618.06	103,859.46	3,514,847.52	98,767.17	3,338,790.18	75,052.62	2,532,495.50
35	3	1	3	3244	114332	2172	76344	0.666	0.676	615.78	617.98	104,538.46	3,619,385.97	99,491.18	3,438,281.35	75,776.63	2,608,272.13
36	3	1	3	3244	117576	2168	78512	0.676	0.676	624.62	618.17	103,463.51	3,722,839.48	98,246.24	3,536,527.59	74,531.69	2,682,803.82
37	3	1	3	3301	120877	2196	80708	0.694	0.676	620.96	618.26	102,972.09	3,825,811.57	97,684.82	3,634,212.41	73,970.27	2,756,774.08
38	3	1	3	3121	123998	2125	82833	0.670	0.676	619.11	618.27	104,393.41	3,930,204.98	99,191.13	3,733,403.54	75,476.68	2,832,250.67
39	3	1	3	3313	127311	2184	85017	0.677	0.676	607.81	618.00	103,720.27	4,033,925.25	98,573.00	3,831,976.54	74,858.45	2,907,109.12
40	3	1	3	3182	130493	2173	87190	0.674	0.676	622.96	618.12	103,871.69	4,137,796.94	98,764.41	3,930,740.95	75,049.86	2,982,158.98
41	3	1	3	3276	133769	2154	89344	0.668	0.676	624.46	618.28	102,632.22	4,240,429.16	97,344.95	4,028,085.90	73,630.40	3,055,789.38
42	3	1	3	3165	136934	2152	91496	0.678	0.676	635.80	618.69	103,341.75	4,343,770.91	98,099.48	4,126,185.38	74,384.93	3,130,174.31
43	3	1	3	3131	140065	2156	93652	0.665	0.676	624.90	618.83	105,759.69	4,449,530.61	100,892.42	4,227,077.80	77,177.87	3,207,352.17
44	3	1	3	3201	143266	2174	95826	0.680	0.676	624.86	618.97	103,429.92	4,552,960.53	98,247.65	4,325,325.44	74,533.10	3,281,885.27
45	3	1	3	3232	146498	1167	97993	0.673	0.676	536.74	611.67	49,358.28	4,602,318.81	39,126.01	4,364,451.45	15,411.46	3,297,296.73
46	3	1	3	3201	149699	3147	100140	0.670	0.675	644.11	618.80	158,041.57	4,760,360.38	157,944.30	4,522,395.75	134,229.75	3,431,526.48
47	3	1	3	3173	152872	2119	102259	0.666	0.675	611.74	618.65	104,343.00	4,864,703.38	99,180.72	4,621,576.47	75,466.17	3,506,992.65
48	3	1	3	3158	156030	2167	104426	0.674	0.675	620.39	618.69	103,840.28	4,968,543.66	98,853.00	4,720,429.47	75,138.45	3,582,131.11
49	3	1	3	3311	159341	2190	106616	0.675	0.675	626.06	618.84	102,863.68	5,071,407.34	97,581.41	4,818,010.88	73,866.85	3,655,997.96
50	3	1	3	3211	162552	2190	108806	0.676	0.675	622.24	618.91	104,901.68	5,176,309.02	99,999.41	4,918,010.29	76,284.86	3,732,282.82
51	3	1	3	3201	165753	2159	110965	0.672	0.675	620.33	618.94	103,151.40	5,279,460.42	97,829.12	5,015,839.41	74,214.57	3,806,497.40
52	3	1	3	3249	169002	1183	113148	0.694	0.675	765.18	615.01	18,567.04	5,298,027.46	3,359.77	5,019,299.18	(20,354.78)	3,786,142.61
53	3	1	3	3201	172203	3163	115311	0.671	0.675	569.94	619.10	188,901.33	5,486,928.79	192,824.06	5,213,123.24	170,109.51	3,956,252.12
54	3	1	3	3380	175583	2210	117521	0.681	0.675	615.29	619.03	102,665.38	5,589,594.18	97,353.11	5,310,476.34	73,638.56	4,029,890.68
55	3	1	3	3302	178885	2176	119697	0.682	0.676	618.89	619.03	102,205.39	5,691,799.57	96,818.12	5,407,294.46	73,103.57	4,102,994.25
56	3	1	3	3163	182048	2166	121863	0.666	0.675	621.54	619.08	105,275.69	5,797,075.26	100,253.42	5,507,547.88	76,538.87	4,179,533.12
57	3	1	3	3251	185299	2172	124025	0.671	0.675	616.98	619.04	104,468.45	5,901,543.71	99,461.18	5,607,009.06	75,746.63	4,255,279.76
58	3	1	3	3300	188599	2161	126176	0.666	0.675	611.76	618.92	104,047.52	6,005,591.23	98,820.24	5,705,829.30	75,105.69	4,330,385.44
59	3	1	3	3324	191923	2203	128379	0.674	0.675	621.07	618.96	103,606.74	6,109,197.97	98,549.46	5,804,378.76	74,834.91	4,405,220.35
60	3	1	3	6178	198101	2175	130554	0.831	0.680	620.90	618.98	105,305.16	6,214,503.13	100,472.88	5,904,851.65	76,758.33	4,481,978.69

MRP LOW LOW

Replication Number	Independent Variables: MAS	Independent Variables: MOH	Independent Variables: MIX	All Products: Period Demand	All Products: Total Demand	All Products: Period Shipped	All Products: Total Shipped	All Products: Period DFR	Total DFR	Period Cycle Time	Cycle Time	MOH LOW: Period NOI	MOH LOW: Cumulative NOI	MOH MED: Period NOI	MOH MED: Cumulative NOI	MOH HIGH: Period NOI	MOH HIGH: Cumulative NOI
1	2	1	1	1936	1936	1913	1913	0.999	0.999	312.00	312.00	88,166.29	88,166.29	80,375.30	80,375.30	56,046.33	56,046.33
2	2	1	1	1864	3800	1853	3766	0.998	0.999	305.80	308.96	84,243.28	172,409.57	75,958.29	156,333.59	51,628.32	107,673.65
3	2	1	1	1901	5701	1877	5643	0.996	0.999	329.23	315.36	88,950.28	261,359.85	81,005.30	237,339.89	56,675.33	164,348.98
4	2	1	1	1832	7533	1784	7427	0.997	0.998	265.34	300.94	85,036.77	346,395.62	76,741.79	314,080.88	52,411.82	216,760.80
5	2	1	1	1787	9320	1787	9214	0.998	0.998	235.14	298.19	77,361.27	423,756.89	68,561.29	382,641.97	44,231.32	260,992.11
6	2	1	1	1867	11187	1822	11036	0.997	0.998	325.17	294.29	84,107.11	507,864.00	75,757.12	458,399.09	51,427.15	312,419.27
7	2	1	1	1852	13039	1835	12869	0.998	0.998	237.66	286.20	83,307.19	591,171.20	74,930.96	533,330.05	50,600.99	363,020.26
8	2	1	1	1852	14892	1834	14702	1.000	0.998	263.00	283.31	83,265.11	674,436.31	74,883.88	608,213.93	50,553.91	413,574.16
9	2	1	1	1852	16744	1834	16535	0.998	0.998	267.22	280.42	83,223.03	757,659.34	74,836.79	683,050.72	50,506.82	464,080.98
10	2	1	1	1852	18596	1833	18368	0.998	0.998	303.65	282.72	83,180.94	840,840.28	74,789.71	757,840.43	50,459.74	514,540.72
11	2	1	1	1872	20468	1846	20213	0.998	0.998	269.70	280.62	84,631.95	925,472.23	76,386.96	834,227.39	52,056.99	566,597.71
12	2	1	1	1860	22328	1842	22055	0.998	0.998	243.28	277.60	83,631.46	1,009,103.67	75,261.46	909,488.85	50,931.49	617,529.20
13	2	1	1	1813	24141	1785	23840	0.998	0.998	216.70	272.96	76,777.94	1,085,881.61	67,967.95	977,456.80	43,637.98	661,167.18
14	2	1	1	1949	26090	1914	25754	0.998	0.998	333.98	277.49	88,742.45	1,174,624.06	80,862.47	1,058,319.27	56,532.50	717,699.68
15	2	1	1	1921	28011	1912	27666	0.998	0.998	295.78	278.75	87,655.12	1,262,279.18	79,735.13	1,138,054.40	55,405.16	773,104.84
16	2	1	1	1872	29883	1835	29501	0.998	0.998	304.03	280.32	84,019.28	1,346,298.46	75,634.29	1,213,688.69	51,304.32	824,409.17
17	2	1	1	1859	31742	1838	31399	1.000	0.999	261.16	278.67	83,588.78	1,429,887.24	75,328.79	1,289,017.49	50,998.82	875,407.99
18	2	1	1	1881	33623	1869	33208	0.999	0.999	307.49	280.79	88,105.95	1,517,993.18	80,155.96	1,369,173.46	55,825.99	931,233.98
19	2	1	1	1952	35575	1937	35145	0.999	0.999	346.17	284.39	90,139.29	1,608,132.47	82,479.30	1,451,652.76	58,149.33	989,383.31
20	2	1	1	1825	37400	1811	36956	0.999	0.999	229.13	281.69	82,669.28	1,690,801.75	74,229.29	1,525,882.04	49,899.32	1,039,282.63
21	2	1	1	1910	39310	1890	38846	0.999	0.999	298.19	282.49	87,105.46	1,777,907.20	79,175.46	1,605,057.51	54,845.49	1,094,128.13
22	2	1	1	1924	41234	1869	40715	0.998	0.999	326.86	284.53	86,186.95	1,864,094.15	78,106.96	1,683,164.47	53,776.99	1,147,905.12
23	2	1	1	1844	43078	1828	42543	0.999	0.999	304.76	285.40	84,170.11	1,948,264.26	75,880.13	1,759,024.59	51,530.15	1,199,435.27
24	2	1	1	1956	45034	1875	44418	0.999	0.999	268.77	284.27	85,838.95	2,034,103.20	77,783.96	1,836,808.56	53,463.99	1,252,899.27
25	2	1	1	1822	46856	1868	46276	0.998	0.999	369.57	287.70	86,983.11	2,121,086.32	78,869.13	1,915,676.69	54,538.16	1,307,427.42
26	2	1	1	1860	48716	1837	48113	0.998	0.999	313.93	288.70	86,931.61	2,207,997.93	78,906.63	1,994,583.31	54,576.66	1,362,004.08
27	2	1	1	1950	50666	1907	50020	0.999	0.999	405.56	293.15	87,106.28	2,295,104.21	79,141.30	2,073,724.61	54,811.33	1,416,815.41
28	2	1	1	1876	52542	1861	51881	0.999	0.999	285.25	292.91	83,574.61	2,378,678.83	75,409.63	2,149,134.24	51,079.66	1,467,895.07
29	2	1	1	1916	54458	1878	53759	0.999	0.999	297.15	293.06	83,835.46	2,462,514.28	75,600.46	2,224,734.70	51,270.49	1,519,165.56
30	2	1	1	1912	56370	1899	55659	0.998	0.999	369.28	295.66	91,243.95	2,553,759.23	83,538.97	2,308,273.67	59,208.99	1,578,374.55
31	2	1	1	1919	58289	1894	57552	0.999	0.999	276.11	295.01	88,954.12	2,642,712.34	81,154.13	2,389,427.80	56,824.16	1,635,198.71
32	2	1	1	1883	60172	1851	59403	0.999	0.999	318.70	295.76	85,818.95	2,728,531.29	77,740.96	2,467,171.76	53,413.99	1,688,612.70
33	2	1	1	1909	62081	1880	61283	0.999	0.999	298.09	296.82	83,600.78	2,812,132.07	75,320.80	2,542,492.56	50,990.83	1,739,603.53
34	2	1	1	1930	64011	1908	63191	0.999	0.999	330.81	296.88	87,035.45	2,899,167.52	79,055.47	2,621,548.02	54,725.50	1,794,329.03
35	2	1	1	1910	65921	1877	65068	0.998	0.999	304.80	297.11	89,768.28	2,988,935.81	81,878.30	2,703,426.32	57,548.33	1,851,877.35
36	2	1	1	1848	67769	1820	66888	0.998	0.999	323.74	297.83	83,764.78	3,072,700.58	75,289.79	2,778,716.11	50,959.82	1,902,837.17
37	2	1	1	1930	69699	1902	68790	0.999	0.999	321.24	298.46	89,492.45	3,162,193.03	81,622.47	2,860,338.58	57,292.50	1,960,129.67
38	2	1	1	1858	71557	1834	70624	0.999	0.999	279.65	297.99	83,675.11	3,245,868.14	75,315.13	2,935,653.70	50,985.16	2,011,114.82
39	2	1	1	1868	73425	1864	72488	0.980	0.998	301.80	298.08	84,269.11	3,330,137.26	76,154.13	3,011,807.83	51,824.16	2,062,938.98
40	2	1	1	1885	75310	1863	74351	0.998	0.998	275.62	297.52	85,158.95	3,415,296.21	76,908.96	3,088,716.79	52,578.99	2,115,517.97
41	2	1	1	1888	77198	1861	76212	0.998	0.998	332.59	298.38	89,429.61	3,504,725.82	81,439.63	3,170,156.42	57,109.66	2,172,627.63
42	2	1	1	76253	153451	1882	78094	0.961	0.980	361.39	299.90	91,313.12	3,596,038.93	83,603.13	3,253,759.56	59,273.16	2,231,900.79
43	2	1	1	(72476)	80975	1838	79932	0.959	0.998	255.46	298.87	82,960.78	3,678,999.71	74,650.79	3,328,410.35	50,320.82	2,282,221.61
44	2	1	1	1907	82882	1898	81830	0.998	0.998	368.76	300.50	87,600.78	3,766,600.50	79,670.80	3,408,081.15	55,340.83	2,337,562.44
45	2	1	1	1860	84742	1825	83655	0.998	0.998	254.59	299.49	83,246.61	3,849,847.11	74,926.62	3,483,007.77	50,596.65	2,388,159.10
46	2	1	1	1821	86563	1806	85461	0.998	0.998	269.83	298.84	82,562.44	3,932,409.55	74,097.46	3,557,105.23	49,767.49	2,437,926.58
47	2	1	1	1928	88491	1903	87364	0.998	0.998	422.79	301.54	90,114.62	4,022,524.17	82,469.63	3,639,574.86	58,139.66	2,496,066.24
48	2	1	1	1911	90402	1882	89246	0.998	0.998	304.22	301.60	87,091.12	4,109,615.28	79,136.13	3,718,710.99	54,806.16	2,550,872.40
49	2	1	1	1927	92329	1894	91140	0.998	0.998	376.96	303.16	88,214.12	4,197,829.40	80,269.13	3,798,980.12	55,939.16	2,606,811.57
50	2	1	1	1891	94220	1870	93010	0.999	0.998	282.84	302.76	87,686.11	4,285,515.51	79,716.13	3,878,696.25	55,386.16	2,662,197.72
51	2	1	1	1866	96086	1852	94862	0.998	0.998	280.90	302.33	83,523.11	4,369,038.63	75,228.13	3,953,924.38	50,898.16	2,713,095.88
52	2	1	1	1865	97951	1843	96705	0.998	0.998	293.79	302.17	88,142.61	4,457,181.24	80,137.63	4,034,062.00	55,807.66	2,768,903.54
53	2	1	1	1971	99922	1928	98633	0.998	0.998	391.64	303.92	92,777.79	4,549,959.02	85,267.80	4,119,329.81	60,937.83	2,829,841.37
54	2	1	1	1981	101903	1936	100569	0.998	0.998	356.62	304.93	89,784.12	4,639,743.15	82,019.14	4,201,348.94	57,689.17	2,887,530.53
55	2	1	1	1877	103780	1860	102429	0.998	0.998	331.24	305.41	87,135.45	4,726,878.59	79,035.46	4,280,384.40	54,705.49	2,942,236.03
56	2	1	1	1930	105710	1917	104346	0.998	0.998	322.20	305.71	91,498.96	4,818,377.55	83,898.97	4,364,283.37	59,569.00	3,001,805.02
57	2	1	1	1909	107619	1885	106231	0.998	0.998	346.95	306.45	86,281.62	4,904,659.16	78,236.63	4,442,520.00	53,906.66	3,055,711.68
58	2	1	1	1885	109504	1849	108080	0.998	0.998	281.64	306.02	85,685.61	4,990,344.77	77,570.63	4,520,090.63	53,240.66	3,108,952.34
59	2	1	1	1789	111293	1785	109865	0.998	0.998	315.03	306.17	84,655.94	5,075,000.71	76,295.95	4,596,386.58	51,965.98	3,160,918.32
60	2	1	1	1886	113179	1860	111715	0.998	0.998	321.29	306.42	86,397.78	5,161,398.49	78,342.79	4,674,729.38	54,012.82	3,214,931.15

Replication Number	Independent Variables: MAS	MOH	MIX	All Products: Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Cycle Time	MOH LOW: Period NOI	Cumulative NOI	MOH MED: Period NOI	Cumulative NOI	MOH HIGH: Period NOI	Cumulative NOI
1	2	1	2	2389	2389	2128	2128	0.922	0.922	746.49	746.49	106,901.02	106,901.02	101,661.54	101,661.54	77,482.58	77,482.58
2	2	1	2	2412	4801	2122	4250	0.898	0.910	735.21	740.86	107,685.40	214,586.42	102,440.92	204,102.47	78,261.98	155,744.56
3	2	1	2	2305	7106	2133	6383	0.921	0.913	739.23	740.32	104,962.54	319,548.96	99,443.06	303,545.53	75,264.10	231,008.66
4	2	1	2	2285	9391	2105	8488	0.912	0.913	736.11	739.27	104,808.64	424,357.61	99,189.16	402,734.69	75,010.20	306,018.85
5	2	1	2	2339	11730	2149	10637	0.913	0.913	752.75	742.00	104,704.20	529,061.80	99,134.72	501,869.40	74,955.76	380,974.61
6	2	1	2	2330	14060	2115	12752	0.924	0.917	748.55	743.08	106,849.68	635,911.48	101,446.20	603,314.60	77,266.24	458,240.85
7	2	1	2	2347	16407	2134	14886	0.919	0.917	760.68	744.17	105,471.09	741,382.57	100,025.36	703,339.96	75,846.40	534,087.25
8	2	1	2	2347	18755	2134	17019	0.919	0.917	762.60	746.23	105,471.09	846,853.66	100,025.36	803,365.33	75,846.40	609,933.65
9	2	1	2	2347	21102	2134	19153	0.919	0.917	764.62	746.27	105,471.09	952,324.76	100,025.36	903,390.69	75,846.40	685,780.05
10	2	1	2	2347	23449	2134	21286	0.919	0.917	766.46	747.29	105,471.09	1,057,795.85	100,025.36	1,003,416.05	75,846.40	761,626.46
11	2	1	2	2387	25836	2165	23451	0.916	0.917	768.37	749.23	106,278.86	1,164,074.70	100,929.37	1,104,346.42	76,750.41	838,376.87
12	2	1	2	2338	28174	2106	25557	0.918	0.917	770.71	751.00	107,428.75	1,271,503.44	102,074.27	1,206,419.69	77,895.31	916,272.18
13	2	1	2	2394	30569	2151	27708	0.918	0.917	765.60	752.14	103,587.40	1,375,090.85	97,932.92	1,304,352.61	73,753.96	990,026.14
14	2	1	2	2327	32895	2129	29837	0.916	0.917	731.87	750.70	107,068.13	1,482,158.97	101,723.66	1,406,076.26	77,544.69	1,067,570.83
15	2	1	2	2326	35221	2110	31947	0.919	0.917	767.27	751.13	104,722.16	1,586,881.13	99,172.68	1,505,248.94	74,993.72	1,142,564.55
16	2	1	2	2254	37475	2066	34003	0.910	0.917	751.44	751.16	107,720.67	1,694,601.71	102,266.09	1,607,515.03	78,087.13	1,220,651.68
17	2	1	2	2336	39811	2123	36126	0.918	0.917	760.65	751.11	107,212.51	1,801,814.21	101,888.03	1,709,403.06	77,709.07	1,298,360.76
18	2	1	2	2276	42087	2094	38220	0.921	0.917	721.51	749.48	106,609.51	1,908,423.72	101,065.03	1,810,468.08	76,886.07	1,375,246.81
19	2	1	2	2414	44501	2173	40393	0.918	0.917	771.11	750.66	106,412.68	2,014,836.40	101,183.20	1,911,651.28	77,004.24	1,452,251.05
20	2	1	2	2357	46858	2135	42528	0.913	0.917	762.02	751.23	106,152.75	2,120,989.14	100,638.27	2,012,289.56	76,459.31	1,528,710.36
21	2	1	2	2292	49150	2109	44637	0.924	0.917	746.36	750.96	108,234.06	2,229,223.20	103,049.58	2,115,339.13	78,870.62	1,607,580.98
22	2	1	2	2312	51462	2111	46748	0.916	0.917	731.70	750.08	106,474.26	2,335,697.46	101,049.78	2,216,388.91	76,870.82	1,684,451.80
23	2	1	2	2278	53740	2103	48851	0.913	0.917	708.49	748.29	106,297.44	2,441,994.90	100,822.96	2,317,211.87	76,644.00	1,761,095.80
24	2	1	2	2348	56088	2145	50996	0.926	0.917	718.57	747.04	104,925.78	2,546,920.88	99,381.30	2,416,593.17	75,202.34	1,836,298.14
25	2	1	2	2300	58388	2121	53117	0.919	0.916	756.85	747.43	104,395.30	2,651,315.98	98,700.82	2,515,293.99	74,521.86	1,910,820.00
26	2	1	2	2370	60758	2125	55242	0.912	0.917	736.96	747.03	106,025.71	2,757,341.69	100,656.23	2,615,950.22	76,477.27	1,987,297.28
27	2	1	2	2350	63108	2137	57379	0.916	0.917	767.90	747.80	107,015.95	2,864,357.64	101,761.47	2,717,711.69	77,582.51	2,064,879.79
28	2	1	2	2397	65505	2146	59525	0.916	0.917	756.66	748.12	104,734.88	2,969,092.53	99,335.41	2,817,047.10	75,156.46	2,140,036.24
29	2	1	2	2280	67785	2106	61631	0.914	0.917	695.00	746.31	105,684.75	3,074,777.28	100,100.27	2,917,147.37	75,921.31	2,215,957.54
30	2	1	2	2401	70186	2138	63769	0.916	0.917	775.33	747.28	105,985.06	3,180,762.33	100,560.58	3,017,707.94	76,381.62	2,292,339.16
31	2	1	2	2307	72493	2109	65878	0.915	0.917	733.82	746.95	106,990.06	3,287,752.39	101,630.58	3,119,338.52	77,461.62	2,369,790.78
32	2	1	2	2358	74851	2129	68007	0.915	0.917	743.99	746.76	104,475.13	3,392,227.52	98,840.65	3,218,179.17	74,661.69	2,444,452.47
33	2	1	2	2283	77134	2111	70118	0.916	0.917	744.90	746.71	107,079.26	3,499,306.78	101,649.78	3,319,828.95	77,470.82	2,521,923.29
34	2	1	2	2321	79455	2109	72227	0.916	0.917	717.28	745.85	105,583.06	3,604,889.84	100,073.58	3,419,902.53	75,894.62	2,597,817.91
35	2	1	2	2326	81781	2079	74306	0.915	0.917	689.72	744.28	105,091.95	3,709,981.79	99,512.47	3,519,415.00	75,333.51	2,673,151.42
36	2	1	2	2224	84005	2085	76391	0.918	0.917	634.66	741.28	105,106.57	3,815,088.36	99,507.09	3,618,922.10	75,328.14	2,748,479.56
37	2	1	2	2349	86354	2146	78537	0.914	0.917	764.60	741.66	105,634.88	3,920,723.25	100,175.41	3,719,097.50	75,996.45	2,824,476.01
38	2	1	2	2369	88723	2123	80660	0.917	0.917	772.36	742.46	104,576.51	4,025,299.76	99,032.03	3,818,129.53	74,853.07	2,899,329.07
39	2	1	2	2283	91006	2116	82776	0.916	0.917	718.95	741.85	106,198.78	4,131,498.54	100,634.30	3,918,763.83	76,465.34	2,975,784.41
40	2	1	2	2304	93310	2120	84896	0.916	0.917	769.86	742.30	106,236.19	4,237,734.73	100,816.72	4,019,580.54	76,637.76	3,052,422.17
41	2	1	2	2337	95647	2153	87049	0.921	0.917	751.20	742.52	104,978.61	4,342,713.34	99,464.13	4,119,044.67	75,285.17	3,127,707.34
42	2	1	2	2308	97955	2109	89158	0.916	0.917	765.87	743.07	104,691.06	4,447,404.40	99,191.58	4,218,236.25	75,012.62	3,202,719.96
43	2	1	2	2238	100193	2071	91229	0.914	0.917	726.10	742.68	107,362.13	4,554,766.52	101,742.66	4,319,978.90	77,563.69	3,280,283.64
44	2	1	2	2315	102508	2127	93356	0.909	0.917	743.34	742.70	105,893.92	4,660,660.44	100,444.44	4,420,423.34	76,265.48	3,356,549.12
45	2	1	2	2268	104776	2113	95469	0.916	0.917	748.46	742.03	106,276.47	4,766,936.91	100,786.99	4,521,210.33	76,608.03	3,433,157.16
46	2	1	2	2321	107097	2125	97594	0.916	0.917	776.98	743.57	105,421.71	4,872,358.63	99,852.23	4,621,062.56	75,673.27	3,508,830.43
47	2	1	2	2276	109373	2107	99701	0.912	0.916	703.42	742.72	106,622.85	4,978,981.48	101,083.37	4,722,146.93	76,904.41	3,585,734.84
48	2	1	2	2337	111710	2136	101837	0.915	0.916	736.11	742.58	105,147.85	5,084,129.33	99,698.37	4,821,844.30	75,519.41	3,661,254.25
49	2	1	2	2346	114056	2122	103959	0.915	0.916	743.60	742.60	105,301.40	5,189,430.73	99,851.92	4,921,696.22	75,672.96	3,736,927.21
50	2	1	2	2330	116396	2117	106076	0.911	0.916	765.03	743.06	105,899.88	5,295,330.61	100,360.40	5,022,056.63	76,181.45	3,813,108.66
51	2	1	2	2366	118752	2113	108189	0.918	0.916	761.64	743.42	106,989.47	5,402,320.08	101,614.99	5,123,671.62	77,436.03	3,890,544.69
52	2	1	2	2318	121070	2139	110328	0.919	0.916	724.00	743.04	105,256.16	5,507,576.24	98,761.68	5,223,433.30	75,582.72	3,966,127.41
53	2	1	2	2402	123472	2165	112493	0.922	0.916	719.72	742.59	105,642.85	5,613,219.09	100,293.37	5,323,726.67	76,114.41	4,042,241.82
54	2	1	2	2376	125848	2134	114627	0.909	0.916	770.67	743.11	105,896.64	5,719,115.74	100,447.16	5,424,173.83	76,268.20	4,118,510.03
55	2	1	2	2358	128206	2148	116775	0.915	0.916	761.95	743.46	106,297.09	5,825,412.83	100,962.61	5,525,136.46	76,783.65	4,195,293.68
56	2	1	2	2403	130609	2126	118901	0.916	0.916	762.70	743.80	106,366.82	5,931,779.64	100,997.34	5,626,133.78	76,818.38	4,272,112.06
57	2	1	2	2348	132957	2135	121036	0.918	0.916	778.81	744.42	105,237.75	6,037,017.39	99,678.27	5,725,812.06	75,499.31	4,347,611.37
58	2	1	2	2299	135256	2109	123145	0.917	0.916	737.04	744.29	106,238.06	6,143,255.45	100,808.58	5,826,620.63	76,629.62	4,424,240.98
59	2	1	2	2308	137564	2117	125262	0.916	0.916	738.36	744.19	106,027.88	6,249,283.33	100,483.40	5,927,104.03	76,304.45	4,500,545.43
60	2	1	2	2271	139835	2116	127378	0.919	0.916	756.81	744.40	106,054.78	6,355,338.11	100,595.30	6,027,699.33	76,416.34	4,576,961.77

MRP LOW MED

MRP LOW HIGH

Replication Number	Independent Variables: MAS	MOH	MIX	All Products: Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Cycle Time	MOH LOW: Period NOI	Cumulative NOI	MOH MED: Period NOI	Cumulative NO	MOH HIGH: Period NOI	Cumulative NO
1	2	1	3	3199	3199	2173	2173	0.686	0.686	677.41	677.41	114,769.74	114,769.74	111,589.12	111,589.12	88,317.89	88,317.89
2	2	1	3	3431	6630	2225	4398	0.676	0.681	649.93	663.51	115,090.65	229,860.39	112,120.03	223,709.16	88,848.80	177,166.69
3	2	1	3	3298	9928	2197	6595	0.673	0.679	660.84	662.62	115,200.31	345,060.71	112,124.70	335,833.85	88,853.46	266,020.14
4	2	1	3	3163	13091	2196	8791	0.676	0.678	680.32	667.02	115,177.97	460,238.67	111,987.35	447,821.20	88,716.11	354,736.26
5	2	1	3	3240	16331	2194	10985	0.692	0.678	667.57	666.14	116,014.09	576,252.76	111,753.47	559,574.67	88,482.23	443,218.49
6	2	1	3	3203	19534	2175	13140	0.683	0.679	668.34	666.67	116,747.62	692,000.38	113,827.00	673,401.67	90,555.77	533,774.26
7	2	1	3	3223	22757	2193	15333	0.677	0.679	668.42	666.06	115,285.58	807,285.96	112,196.21	785,597.89	88,924.98	622,699.23
8	2	1	3	3223	25981	2193	17525	0.721	0.684	669.16	666.46	115,285.58	922,571.55	112,196.21	897,794.10	88,924.98	711,624.21
9	2	1	3	3223	29204	2193	19718	0.682	0.684	669.90	666.83	115,285.58	1,037,857.13	112,196.21	1,009,990.32	88,924.98	800,549.19
10	2	1	3	3223	32427	2193	21910	0.682	0.684	670.64	667.22	115,285.58	1,153,142.71	112,196.21	1,122,186.53	88,924.98	889,474.17
11	2	1	3	3207	35634	2203	24113	0.686	0.684	671.34	667.59	115,847.96	1,268,990.67	112,802.34	1,234,988.87	89,531.10	979,005.27
12	2	1	3	3236	38870	2198	26311	0.688	0.684	671.25	667.90	115,984.26	1,384,974.92	112,928.64	1,347,917.51	89,657.40	1,068,662.67
13	2	1	3	3223	42093	2198	28509	0.686	0.684	674.77	668.40	115,592.26	1,500,567.18	112,601.64	1,460,519.14	89,330.40	1,157,993.07
14	2	1	3	3230	45323	2196	30705	0.683	0.684	671.70	668.66	115,746.37	1,616,313.55	112,685.76	1,573,204.90	89,414.52	1,247,407.59
15	2	1	3	3361	48684	2211	32916	0.688	0.685	662.54	667.58	114,988.49	1,731,302.04	111,952.86	1,685,157.76	88,681.63	1,336,089.22
16	2	1	3	3331	52015	2226	35142	0.681	0.684	663.20	667.30	115,382.59	1,846,684.63	112,326.97	1,797,484.74	89,055.74	1,425,144.96
17	2	1	3	3187	55202	2174	37316	0.681	0.684	685.32	668.36	115,704.68	1,962,389.31	112,594.06	1,910,078.80	89,322.83	1,514,467.78
18	2	1	3	3214	58416	2193	39509	0.686	0.684	665.36	668.18	116,294.55	2,078,683.86	113,333.93	2,023,412.73	90,062.70	1,604,530.48
19	2	1	3	3214	61630	2184	41693	0.686	0.684	677.96	668.70	115,874.09	2,194,557.95	112,803.47	2,136,216.20	89,532.23	1,694,062.71
20	2	1	3	3236	64866	2188	43881	0.690	0.685	666.41	668.58	114,624.85	2,309,182.80	111,414.23	2,247,630.43	88,142.99	1,782,205.71
21	2	1	3	3177	68043	2196	46077	0.677	0.684	685.36	669.38	115,351.37	2,424,534.17	112,175.76	2,359,806.19	88,904.52	1,871,110.23
22	2	1	3	3231	71274	2208	48285	0.685	0.684	678.74	669.61	114,893.66	2,539,427.83	111,803.04	2,471,609.23	88,531.81	1,959,642.03
23	2	1	3	3170	74444	2174	50459	0.695	0.684	670.72	669.85	114,805.68	2,654,233.51	111,550.06	2,583,159.30	88,278.83	2,047,920.86
24	2	1	3	3312	77756	2172	52631	0.684	0.684	662.84	669.14	115,958.80	2,770,192.31	112,948.18	2,696,107.48	89,676.95	2,137,597.81
25	2	1	3	3339	81095	2214	54846	0.689	0.685	667.16	669.06	115,114.30	2,885,306.62	112,138.69	2,808,246.16	88,867.45	2,226,465.26
26	2	1	3	3213	84308	2192	57037	0.683	0.684	672.46	669.19	115,964.61	3,001,271.23	112,928.99	2,921,176.16	89,657.76	2,316,123.01
27	2	1	3	3206	87514	2201	59238	0.689	0.685	669.06	669.15	114,994.08	3,116,265.31	111,818.46	3,032,993.62	88,547.22	2,404,670.24
28	2	1	3	3190	90704	2188	61406	0.688	0.685	674.03	669.32	115,468.04	3,231,733.34	112,342.42	3,146,336.04	89,071.18	2,493,741.42
29	2	1	3	3155	93859	2158	63564	0.690	0.685	673.88	669.47	115,477.63	3,347,210.98	112,187.01	3,257,523.05	89,915.78	2,582,657.20
30	2	1	3	3258	97117	2176	65740	0.686	0.685	674.22	669.63	116,550.56	3,463,761.54	113,618.94	3,371,142.99	90,348.71	2,673,005.90
31	2	1	3	3248	100365	2193	67933	0.693	0.685	662.16	669.39	115,934.55	3,579,696.09	112,838.93	3,483,981.93	89,567.70	2,762,573.60
32	2	1	3	3182	103547	2187	70120	0.671	0.684	683.95	669.94	116,636.91	3,696,332.00	113,625.29	3,597,607.22	90,354.05	2,852,927.66
33	2	1	3	3230	106777	2214	72334	0.689	0.685	670.19	669.86	114,986.30	3,811,218.30	111,746.69	3,709,352.90	88,474.45	2,941,402.11
34	2	1	3	3302	110079	2206	74540	0.691	0.685	666.25	669.75	115,310.78	3,926,529.08	112,295.16	3,821,648.07	89,023.93	3,030,426.03
35	2	1	3	3239	113318	2189	76729	0.682	0.685	672.40	669.82	115,888.79	4,042,417.87	112,878.17	3,934,526.24	89,606.94	3,120,032.97
36	2	1	3	3190	116508	2192	78921	0.686	0.685	675.84	669.99	115,654.61	4,158,072.48	112,568.99	4,047,095.23	89,297.76	3,209,330.72
37	2	1	3	3295	119803	2194	81115	0.689	0.685	660.71	669.47	115,043.49	4,273,115.98	111,902.87	4,158,998.11	88,631.64	3,297,962.36
38	2	1	3	3277	123080	2178	83293	0.686	0.685	667.85	669.17	115,646.44	4,388,761.42	112,509.83	4,271,507.93	89,238.69	3,387,200.95
39	2	1	3	3301	126381	2208	85501	0.687	0.685	683.85	669.03	115,114.66	4,503,876.08	112,034.04	4,383,541.97	88,762.81	3,475,963.76
40	2	1	3	3111	129492	2199	87700	0.683	0.685	695.01	669.68	115,791.20	4,619,667.28	112,700.58	4,496,242.55	89,429.34	3,565,393.10
41	2	1	3	3215	132707	2202	89902	0.693	0.685	680.38	669.48	116,599.02	4,736,266.30	113,678.40	4,609,920.96	90,407.16	3,655,800.26
42	2	1	3	3183	135890	2182	92084	0.683	0.685	680.98	669.73	115,233.21	4,851,499.50	112,092.59	4,722,013.54	88,821.35	3,744,621.81
43	2	1	3	3142	139032	2182	94266	0.686	0.685	678.73	669.93	115,303.21	4,966,802.71	112,122.59	4,834,136.13	88,851.35	3,833,472.97
44	2	1	3	3207	142239	2202	96468	0.684	0.685	681.43	670.20	114,731.02	5,081,533.72	111,560.40	4,945,696.53	88,289.16	3,921,762.13
45	2	1	3	3316	145555	2172	98640	0.690	0.685	648.55	669.72	117,144.80	5,198,678.52	114,274.18	5,059,970.71	91,002.95	4,012,765.07
46	2	1	3	3240	148795	2203	100843	0.686	0.685	666.82	669.66	116,599.98	5,315,278.48	113,624.34	5,173,596.05	90,353.10	4,103,118.18
47	2	1	3	3158	151953	2202	103045	0.686	0.685	682.35	669.93	114,762.02	5,430,040.50	111,596.40	5,285,191.45	88,325.16	4,191,443.34
48	2	1	3	3173	155126	2193	105238	0.687	0.685	681.91	670.18	114,833.55	5,544,874.05	111,662.93	5,396,854.38	88,391.70	4,279,835.04
49	2	1	3	3195	158331	2192	107430	0.690	0.685	663.93	670.05	114,321.61	5,659,195.66	111,020.99	5,507,875.37	87,749.76	4,367,584.80
50	2	1	3	3252	161583	2210	109640	0.690	0.685	681.28	669.87	114,600.54	5,773,796.21	111,464.92	5,619,330.30	88,193.69	4,455,768.48
51	2	1	3	3300	164883	2262	111852	0.686	0.685	659.81	669.96	118,595.45	5,892,391.66	115,804.93	5,735,135.13	92,533.60	4,548,302.08
52	2	1	3	3205	168088	2200	114052	0.679	0.685	674.89	670.18	115,984.14	6,008,375.80	112,778.52	5,847,913.65	89,507.28	4,637,809.36
53	2	1	3	3285	171373	2115	116217	0.694	0.685	665.10	669.52	110,060.19	6,118,435.99	106,369.57	5,954,283.22	83,098.33	4,720,907.70
54	2	1	3	3161	174534	2174	118391	0.693	0.685	666.51	669.46	113,181.68	6,231,617.66	109,741.06	6,064,024.28	86,469.83	4,807,377.52
55	2	1	3	4166	178700	2192	120583	0.702	0.686	678.77	669.63	115,154.61	6,346,772.27	112,013.09	6,176,038.28	88,742.76	4,896,120.28
56	2	1	3	2240	180940	2190	122773	0.658	0.685	667.81	669.42	114,432.73	6,461,205.01	111,132.11	6,287,170.39	87,860.88	4,983,981.16
57	2	1	3	3149	184089	2184	124957	0.676	0.685	689.47	669.77	115,444.09	6,576,649.09	112,278.47	6,399,448.86	89,007.23	5,072,988.39
58	2	1	3	3212	187301	2198	127155	0.689	0.685	673.57	669.84	116,162.26	6,692,811.35	113,186.64	6,512,635.49	89,915.40	5,162,903.79
59	2	1	3	3212	190513	2194	129349	0.681	0.685	669.23	669.83	115,516.49	6,808,327.84	112,400.87	6,625,036.37	89,129.64	5,252,033.43
60	2	1	3	3126	193639	2156	131505	0.694	0.685	687.55	670.12	114,378.75	6,922,706.59	111,098.13	6,736,134.50	87,826.90	5,339,860.32

MPS LOW LOW

Replication Number	Independent Variables: MAS	MOH	MIX	All Products: Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Cycle Time	MOH LOW: Period NOI	Cumulative NOI	MOH MED: Period NOI	Cumulative NOI	MOH HIGH: Period NOI	Cumulative NOI
1	1	1	1	1849	1849	1825	1825	0.992	0.992	300.34	300.34	84,212.16	84,212.16	75,884.38	75,884.38	51,588.82	51,588.82
2	1	1	1	1909	3758	1869	3694	0.992	0.992	300.00	300.16	85,850.53	170,062.69	77,742.75	153,627.13	53,447.19	105,036.01
3	1	1	1	1907	5665	1883	5577	0.992	0.992	509.12	371.09	93,288.91	263,351.60	85,721.13	239,348.26	61,425.56	166,461.57
4	1	1	1	1824	7489	1804	7381	0.992	0.992	287.83	353.21	85,644.07	348,995.67	77,391.29	316,739.55	53,095.73	219,557.31
5	1	1	1	1866	9355	1793	9174	0.992	0.992	313.14	346.38	82,671.99	431,667.66	74,184.20	390,923.75	49,888.64	269,445.95
6	1	1	1	1897	11252	1908	11082	0.992	0.992	291.66	336.13	87,432.39	519,100.05	79,684.61	470,608.37	55,289.05	324,735.00
7	1	1	1	1902	13154	1868	12950	0.992	0.992	355.63	338.94	87,022.88	606,122.93	79,022.60	549,630.96	54,727.03	379,462.04
8	1	1	1	1902	15056	1868	14817	0.992	0.992	361.32	341.76	87,022.88	693,145.80	79,022.60	628,653.66	54,727.03	434,189.07
9	1	1	1	1902	16957	1868	16685	0.992	0.992	367.02	344.59	87,022.88	780,168.68	79,022.60	707,676.15	54,727.03	488,916.10
10	1	1	1	1902	18859	1868	18552	0.992	0.992	372.71	347.42	87,022.88	867,191.56	79,022.60	786,698.75	54,727.03	543,643.14
11	1	1	1	1898	20757	1855	20407	0.987	0.992	432.52	355.16	90,686.14	957,877.69	82,808.36	869,407.10	58,512.79	602,155.93
12	1	1	1	1870	22627	1853	22260	0.992	0.992	299.16	350.49	83,949.94	1,041,827.63	75,762.16	945,169.26	51,466.60	653,622.53
13	1	1	1	1886	24513	1876	24136	0.992	0.992	301.59	346.69	86,245.22	1,128,072.85	78,217.44	1,023,386.70	53,921.88	707,544.41
14	1	1	1	1963	26476	1885	26021	0.992	0.992	388.35	349.71	89,875.11	1,217,947.96	82,067.33	1,105,454.03	57,771.77	765,316.18
15	1	1	1	1845	28321	1847	27868	0.992	0.992	404.86	353.37	90,296.34	1,308,244.30	82,359.56	1,187,812.59	58,063.00	823,379.18
16	1	1	1	1851	30172	1827	29695	0.992	0.992	337.47	352.39	83,338.36	1,391,582.66	74,785.58	1,262,598.17	50,490.02	873,869.19
17	1	1	1	1917	32089	1849	31544	0.992	0.992	529.68	362.78	90,200.54	1,481,783.20	82,342.76	1,344,940.93	58,047.20	931,916.39
18	1	1	1	1827	33916	1822	33366	0.992	0.992	277.04	358.10	85,168.86	1,566,952.06	77,006.08	1,421,947.01	52,710.62	984,626.91
19	1	1	1	1864	35780	1847	35213	0.992	0.992	234.10	351.59	86,399.34	1,653,351.40	78,371.56	1,500,318.57	54,076.00	1,038,702.91
20	1	1	1	1836	37616	1814	37027	0.992	0.992	241.11	346.18	82,023.07	1,735,374.47	73,535.29	1,573,853.86	49,239.73	1,087,942.64
21	1	1	1	1895	39511	1873	38900	0.992	0.992	311.75	344.52	86,360.92	1,821,735.39	78,388.14	1,652,242.00	54,092.58	1,142,035.22
22	1	1	1	1862	41373	1832	40732	0.992	0.992	329.32	343.84	84,897.85	1,906,633.24	76,630.07	1,728,872.07	52,334.51	1,194,369.73
23	1	1	1	1888	43261	1863	42595	0.992	0.992	395.47	346.10	87,012.93	1,993,646.17	78,950.15	1,807,822.22	54,654.59	1,249,024.32
24	1	1	1	1862	45123	1852	44447	0.992	0.992	253.89	342.26	82,962.84	2,076,609.01	74,645.06	1,882,467.28	50,349.50	1,299,373.81
25	1	1	1	1841	46964	1816	46263	0.992	0.992	294.49	340.38	83,970.27	2,160,579.27	75,712.49	1,958,179.76	51,416.92	1,350,790.74
26	1	1	1	1956	48920	1858	48121	0.992	0.992	461.49	344.67	93,434.43	2,254,013.71	85,886.65	2,044,066.41	61,591.09	1,412,381.83
27	1	1	1	1934	50854	1937	50058	0.992	0.992	348.93	344.84	89,240.27	2,343,253.98	81,462.49	2,125,518.91	57,166.93	1,469,538.76
28	1	1	1	1899	52753	1884	51942	0.992	0.992	363.61	346.52	87,674.01	2,430,927.99	79,771.23	2,205,290.14	55,475.67	1,525,014.43
29	1	1	1	1874	54627	1868	53810	0.992	0.992	272.41	342.98	85,328.43	2,516,256.42	77,155.65	2,282,446.79	52,860.09	1,577,874.52
30	1	1	1	1811	56438	1792	55602	0.992	0.992	303.91	341.72	82,823.88	2,599,080.30	74,441.10	2,356,886.89	50,145.54	1,628,020.06
31	1	1	1	1844	58282	1821	57423	0.992	0.992	349.60	341.94	85,907.76	2,684,988.06	77,559.98	2,434,446.87	53,264.42	1,681,284.48
32	1	1	1	1861	60143	1830	59253	0.992	0.992	281.06	340.06	84,981.65	2,769,969.72	76,709.87	2,511,156.74	52,413.31	1,733,697.79
33	1	1	1	1913	62056	1882	61135	0.992	0.992	318.15	339.38	84,458.81	2,854,428.53	76,301.03	2,587,456.78	52,005.47	1,785,703.26
34	1	1	1	1859	63915	1833	62968	0.992	0.992	328.03	339.05	89,401.95	2,943,830.49	81,344.17	2,668,800.95	57,048.61	1,842,751.88
35	1	1	1	1893	65808	1840	64808	0.992	0.992	374.86	340.07	85,868.65	3,029,699.13	77,805.87	2,746,606.82	53,510.31	1,896,262.18
36	1	1	1	1842	67650	1815	66623	0.992	0.992	263.65	337.99	83,212.17	3,112,911.30	74,784.39	2,821,391.20	50,488.82	1,946,751.01
37	1	1	1	1789	69439	1786	68409	0.992	0.992	221.77	334.96	78,791.29	3,191,702.59	70,138.51	2,891,529.71	45,842.95	1,992,593.96
38	1	1	1	1807	71246	1782	70191	0.992	0.992	305.88	334.21	82,029.89	3,273,732.48	73,462.11	2,964,991.82	49,166.65	2,041,760.60
39	1	1	1	1847	73093	1814	72005	0.992	0.992	270.96	332.62	84,380.07	3,358,112.55	76,067.29	3,041,049.11	51,771.73	2,093,622.23
40	1	1	1	1841	74934	1832	73837	0.992	0.992	358.54	333.26	83,924.85	3,442,037.40	75,577.07	3,116,626.18	51,281.61	2,144,803.74
41	1	1	1	1849	76783	1810	75647	0.992	0.992	309.71	332.70	81,651.67	3,523,689.07	73,143.89	3,189,770.07	48,848.33	2,193,652.07
42	1	1	1	1840	78623	1798	77445	0.992	0.992	320.35	332.41	82,925.48	3,606,614.55	74,537.70	3,264,307.77	50,242.14	2,243,894.21
43	1	1	1	1888	80511	1871	79316	0.992	0.992	283.47	330.79	87,681.72	3,694,296.27	79,723.94	3,344,031.71	55,428.38	2,299,322.59
44	1	1	1	1853	82364	1841	81157	0.992	0.992	256.76	329.11	81,060.75	3,775,357.02	72,577.97	3,416,609.68	48,282.40	2,347,604.99
45	1	1	1	1964	84328	1907	83064	0.992	0.992	487.29	332.28	89,814.30	3,865,171.32	82,046.51	3,498,656.19	57,750.95	2,405,355.95
46	1	1	1	1809	86137	1789	84853	0.992	0.992	311.49	331.84	82,552.59	3,947,723.90	74,059.81	3,572,716.00	49,764.24	2,455,120.19
47	1	1	1	1941	88078	1893	86746	0.992	0.992	297.10	331.08	85,697.91	4,033,421.81	77,675.13	3,650,391.13	53,379.56	2,508,499.76
48	1	1	1	1824	89902	1797	88543	0.992	0.992	277.12	329.99	81,325.38	4,114,747.19	72,862.60	3,723,253.72	48,567.04	2,557,066.80
49	1	1	1	1933	91835	1905	90448	0.992	0.992	269.93	328.72	86,381.10	4,201,128.29	78,528.32	3,801,782.04	54,232.76	2,611,299.55
50	1	1	1	1883	93718	1836	92284	0.992	0.992	259.09	327.34	86,552.25	4,287,680.54	78,434.47	3,880,216.51	54,138.91	2,665,438.46
51	1	1	1	1812	95530	1803	94087	0.992	0.992	231.04	325.49	79,344.98	4,366,025.51	69,662.20	3,949,878.71	46,366.63	2,710,805.09
52	1	1	1	1885	97415	1872	95959	0.992	0.992	284.09	324.68	87,618.92	4,453,644.33	79,596.04	4,029,474.75	55,300.48	2,766,105.58
53	1	1	1	1925	99340	1880	97839	0.992	0.992	262.98	323.50	86,651.62	4,540,295.95	78,623.94	4,108,098.59	54,328.27	2,820,433.85
54	1	1	1	1925	101265	1890	99729	0.992	0.992	479.74	326.44	93,152.61	4,633,448.55	85,624.83	4,193,723.41	61,329.27	2,881,763.12
55	1	1	1	1879	103144	1849	101578	0.992	0.992	362.35	326.91	85,362.54	4,718,811.10	78,244.76	4,271,968.17	53,949.20	2,935,712.32
56	1	1	1	1886	105030	1876	103454	0.992	0.992	305.25	326.52	86,067.22	4,805,878.32	77,959.44	4,349,927.61	53,663.88	2,989,376.19
57	1	1	1	1918	106948	1842	105296	0.992	0.992	253.72	325.25	82,469.85	4,888,348.16	74,262.07	4,424,189.68	49,966.50	3,039,342.70
58	1	1	1	1962	108910	1939	107235	0.992	0.992	436.66	327.26	90,517.47	4,978,865.63	82,774.69	4,506,964.37	58,479.13	3,097,821.83
59	1	1	1	1916	110826	1906	109141	0.992	0.992	386.84	328.30	87,338.20	5,066,203.83	79,405.42	4,586,369.78	55,109.85	3,152,931.68
60	1	1	1	1926	112752	1866	111007	0.992	0.992	325.39	328.27	89,614.23	5,155,818.06	81,806.45	4,668,176.23	57,510.89	3,210,442.57

MPS LOW MED

Replication Number	Independent Variables			All Products								MOH					
										LOW				MED		HIGH	
	MAS	MOH	MIX	Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Cycle Time	Period NOI	Cumulative NOI	Period NOI	Cumulative NOI	Period NOI	Cumulative NOI
1	1	1	2	2357	2357	1659	1659	0.731	0.731	704.93	704.93	99,824.01	99,824.01	93,964.60	93,964.60	70,635.80	70,635.80
2	1	1	2	2408	4765	1709	3368	0.723	0.727	687.83	696.25	104,125.32	203,949.33	98,830.92	192,795.52	75,502.11	146,137.91
3	1	1	2	2272	7037	1681	5049	0.736	0.730	719.23	703.90	100,620.23	304,569.56	95,000.82	287,796.35	71,672.01	217,809.92
4	1	1	2	2410	9447	1675	6724	0.711	0.725	685.08	699.46	102,544.35	407,113.91	97,099.95	384,896.29	73,771.14	291,581.06
5	1	1	2	2293	11740	1636	8360	0.733	0.729	709.77	701.49	101,461.64	508,575.55	95,732.24	480,628.53	72,403.43	363,984.49
6	1	1	2	2311	14051	1707	10067	0.726	0.728	709.64	702.86	103,002.03	611,577.59	97,532.63	578,161.15	74,203.82	438,188.31
7	1	1	2	2405	16456	1709	11776	0.724	0.728	694.50	701.66	102,008.86	713,586.45	96,506.96	674,668.12	73,178.15	511,366.46
8	1	1	2	2405	18861	1709	13485	0.724	0.727	691.65	700.38	102,008.86	815,595.31	96,506.96	771,175.07	73,178.15	584,544.60
9	1	1	2	2405	21266	1709	15195	0.724	0.727	688.81	699.08	102,008.86	917,604.17	96,506.96	867,682.03	73,178.15	657,722.75
10	1	1	2	2405	23671	1709	16904	0.724	0.726	685.96	697.75	102,008.86	1,019,613.03	96,506.96	964,189.99	73,178.15	730,900.90
11	1	1	2	2323	25994	1664	18568	0.737	0.727	697.08	697.69	103,131.28	1,122,744.31	97,666.87	1,061,856.86	74,338.06	805,238.96
12	1	1	2	2397	28391	1708	20266	0.717	0.726	698.14	697.73	99,594.18	1,222,338.49	93,879.77	1,155,735.63	70,550.97	875,789.93
13	1	1	2	2371	30762	1662	21928	0.731	0.727	699.00	697.76	102,024.45	1,324,362.93	96,485.04	1,252,220.68	73,156.23	948,946.16
14	1	1	2	2380	33142	1620	23548	0.726	0.727	689.09	697.16	101,163.30	1,425,526.24	95,383.90	1,347,604.57	72,055.09	1,021,001.25
15	1	1	2	2314	35456	1791	25339	0.721	0.726	699.79	697.34	101,205.32	1,526,731.56	95,750.92	1,443,355.49	72,422.11	1,093,423.36
16	1	1	2	2342	37798	1685	27024	0.734	0.727	701.43	697.60	102,161.81	1,628,893.37	96,727.41	1,540,082.90	73,398.60	1,166,821.96
17	1	1	2	2341	40139	1765	28789	0.722	0.727	690.65	697.17	98,924.52	1,727,817.89	93,285.11	1,633,368.01	69,956.31	1,236,778.27
18	1	1	2	2289	42428	1706	30495	0.729	0.727	686.04	696.55	99,958.89	1,827,776.77	94,309.48	1,727,677.50	70,980.67	1,307,758.94
19	1	1	2	2340	44768	1723	32218	0.730	0.727	696.43	696.54	100,900.37	1,928,677.15	95,375.97	1,823,053.46	72,047.16	1,379,806.10
20	1	1	2	2351	47119	1624	33842	0.729	0.727	702.43	696.82	100,708.89	2,029,386.03	94,869.48	1,917,922.95	71,540.67	1,451,346.77
21	1	1	2	2379	49498	1687	35529	0.726	0.727	692.97	696.64	102,460.11	2,131,846.14	96,990.70	2,014,913.65	73,661.89	1,525,008.67
22	1	1	2	2371	51869	1695	37224	0.726	0.727	692.54	696.46	104,381.28	2,236,227.42	98,991.87	2,113,905.52	75,663.06	1,600,671.73
23	1	1	2	2319	54188	1614	38838	0.729	0.727	708.81	696.97	100,141.42	2,336,368.84	94,267.02	2,208,172.54	70,938.21	1,671,609.94
24	1	1	2	2337	56525	1648	40486	0.727	0.727	699.84	697.08	99,772.40	2,436,141.24	93,912.99	2,302,085.54	70,584.19	1,742,194.13
25	1	1	2	2308	58833	1704	42190	0.721	0.727	699.87	697.19	98,486.59	2,534,627.83	92,657.19	2,394,742.72	69,328.38	1,811,522.51
26	1	1	2	2358	61191	1738	43928	0.723	0.727	704.74	697.49	102,323.57	2,636,951.40	96,854.16	2,491,596.89	73,525.35	1,885,047.86
27	1	1	2	2334	63525	1668	45585	0.728	0.727	694.41	697.38	100,300.88	2,737,252.28	94,521.46	2,586,118.35	71,192.65	1,956,240.51
28	1	1	2	2336	65861	1709	47295	0.731	0.727	702.10	697.55	101,489.32	2,838,741.59	95,974.92	2,682,093.27	72,646.11	2,029,886.62
29	1	1	2	2343	68204	1648	48943	0.731	0.727	697.64	697.56	101,737.40	2,940,478.99	96,117.99	2,778,211.26	72,789.19	2,101,675.81
30	1	1	2	2427	70631	1650	50593	0.722	0.727	699.84	697.30	102,624.69	3,043,103.69	97,065.29	2,875,276.56	73,735.48	2,175,412.29
31	1	1	2	2344	72975	1610	52203	0.726	0.727	705.58	697.58	100,227.84	3,143,331.52	94,329.44	2,969,604.98	70,999.63	2,246,411.91
32	1	1	2	2329	75304	1711	53914	0.729	0.727	703.24	697.76	102,725.62	3,246,057.14	97,276.21	3,066,881.20	73,947.40	2,320,359.32
33	1	1	2	2312	77616	1700	55614	0.735	0.727	698.33	697.78	100,274.01	3,346,331.14	94,719.60	3,161,600.80	71,390.79	2,391,750.11
34	1	1	2	2371	79987	1625	57239	0.729	0.727	700.37	697.86	100,115.03	3,446,446.18	94,330.63	3,255,931.43	71,001.82	2,462,751.93
35	1	1	2	2428	82415	1713	58952	0.724	0.727	691.12	697.66	104,523.91	3,550,970.09	99,204.51	3,355,135.93	75,875.70	2,538,627.63
36	1	1	2	2286	84701	1690	60642	0.731	0.727	713.62	698.10	102,215.54	3,653,185.63	96,646.14	3,451,782.07	73,317.33	2,611,944.96
37	1	1	2	2419	87120	1742	62384	0.728	0.727	685.77	697.78	103,035.15	3,756,220.78	97,770.75	3,549,552.82	74,441.94	2,686,386.90
38	1	1	2	2423	89543	1792	64176	0.719	0.727	678.62	697.22	100,297.47	3,856,518.25	94,873.06	3,644,425.89	71,544.26	2,757,931.16
39	1	1	2	2357	91900	1663	65839	0.730	0.727	695.20	697.17	102,140.59	3,958,658.85	96,591.19	3,741,017.08	73,262.38	2,831,193.54
40	1	1	2	2336	94236	1592	67431	0.726	0.727	708.14	697.43	101,787.21	4,060,446.05	95,912.80	3,836,929.88	72,583.99	2,903,777.53
41	1	1	2	2308	96544	1717	69148	0.728	0.727	705.27	697.62	101,173.49	4,161,619.55	95,609.09	3,932,638.97	72,280.28	2,976,057.81
42	1	1	2	2394	98938	1740	70888	0.722	0.727	683.32	697.27	101,597.86	4,263,217.41	96,133.48	4,028,872.43	72,804.85	3,048,862.46
43	1	1	2	2328	101266	1688	72576	0.732	0.727	708.62	697.54	103,076.25	4,366,293.66	97,651.95	4,126,324.27	74,323.04	3,123,185.50
44	1	1	2	2377	103643	1733	74309	0.723	0.727	685.85	697.27	102,037.84	4,468,331.50	96,563.43	4,222,887.70	73,234.62	3,196,420.12
45	1	1	2	2314	105957	1755	76064	0.721	0.727	695.93	697.23	100,668.05	4,568,999.55	95,058.65	4,317,946.35	71,729.84	3,268,149.96
46	1	1	2	2331	108288	1639	77703	0.733	0.727	705.86	697.42	102,798.08	4,671,797.63	97,223.68	4,415,170.03	73,894.87	3,342,044.83
47	1	1	2	613177	721465	1661	79364	0.571	0.594	695.40	697.37	102,063.30	4,773,860.93	96,558.90	4,511,728.93	73,230.09	3,415,274.92
48	1	1	2	(608412)	113053	1718	81082	0.569	0.727	692.53	697.27	101,355.64	4,875,216.59	95,766.24	4,607,495.17	72,437.43	3,487,712.35
49	1	1	2	2240	115293	1674	82756	0.724	0.727	701.82	697.36	97,223.20	4,972,439.78	91,128.80	4,698,623.97	67,799.99	3,555,512.34
50	1	1	2	2344	117637	1724	84480	0.726	0.727	699.81	697.21	101,113.52	5,073,553.30	95,569.11	4,794,193.08	72,240.31	3,627,752.65
51	1	1	2	2220	119857	1759	86239	0.739	0.727	705.83	697.40	103,193.64	5,176,746.94	97,979.24	4,892,172.32	74,650.43	3,702,403.07
52	1	1	2	2372	122229	1763	88002	0.718	0.727	692.34	697.10	100,433.23	5,277,180.16	94,863.82	4,987,036.14	71,535.01	3,773,938.09
53	1	1	2	2241	124470	1666	89668	0.724	0.727	722.71	697.57	100,627.57	5,377,807.73	94,753.17	5,081,789.30	71,424.35	3,845,362.44
54	1	1	2	2298	126768	1700	91368	0.725	0.727	711.04	697.82	101,112.01	5,478,919.74	95,487.60	5,177,276.91	72,158.79	3,917,521.24
55	1	1	2	2264	129032	1635	93003	0.733	0.727	725.05	698.30	98,949.50	5,577,869.24	93,100.09	5,270,377.00	69,771.28	3,987,292.52
56	1	1	2	2379	131411	1597	94600	0.724	0.727	695.92	698.26	102,568.94	5,680,438.18	96,779.53	5,367,156.53	73,450.72	4,060,743.25
57	1	1	2	2332	133743	1625	96215	0.724	0.727	705.74	698.39	100,538.03	5,780,976.21	94,693.63	5,461,850.16	71,364.82	4,132,108.07
58	1	1	2	2323	136066	1662	97887	0.726	0.727	708.38	698.56	100,503.98	5,881,480.19	94,724.58	5,556,574.74	71,395.77	4,203,503.84
59	1	1	2	2364	138430	1710	99577	0.723	0.727	695.18	698.50	99,884.47	5,981,364.67	94,195.07	5,650,769.81	70,866.26	4,274,360.10
60	1	1	2	2385	140815	1729	101306	0.722	0.727	689.34	698.34	101,333.25	6,082,697.92	95,908.95	5,746,668.66	72,480.04	4,346,840.13

Replication Number	Independent Variables			All Products								MOH					
												LOW		MED		HIGH	
	MAS	MOH	MIX	Period Demand	Total Demand	Period Shipped	Total Shipped	Period DFR	Total DFR	Period Cycle Time	Cycle Time	Period NOI	Cumulative NOI	Period NOI	Cumulative NOI	Period NOI	Cumulative NOI
1	1	1	3	3197	3197	1158	1158	0.374	0.374	612.46	612.46	99,446.39	99,446.39	94,263.11	94,263.11	72,166.66	72,166.66
2	1	1	3	3283	6480	1244	2402	0.375	0.374	605.69	608.96	104,035.50	203,481.89	99,587.22	193,850.33	77,490.67	149,657.23
3	1	1	3	3180	9660	1149	3551	0.383	0.377	619.93	612.50	100,270.19	303,752.08	95,056.92	288,907.25	72,960.36	222,617.59
4	1	1	3	3159	12819	1193	4744	0.371	0.375	639.58	619.31	104,072.71	407,824.79	99,314.44	388,221.69	77,217.88	299,835.47
5	1	1	3	3239	16058	1178	5922	0.376	0.376	614.65	618.39	100,194.72	508,019.51	95,146.44	483,368.13	73,049.89	372,885.36
6	1	1	3	3270	19328	1152	7074	0.374	0.375	611.81	617.32	100,172.58	608,192.10	94,989.31	578,357.44	72,892.76	445,778.12
7	1	1	3	3252	22580	1157	8231	0.376	0.375	619.21	617.58	100,634.79	708,826.89	95,522.76	673,880.20	73,426.21	519,204.33
8	1	1	3	3252	25832	1157	9389	0.376	0.375	619.26	617.79	100,634.79	809,461.68	95,522.76	769,402.97	73,426.21	592,630.54
9	1	1	3	3252	29083	1157	10546	0.376	0.375	619.32	617.96	100,634.79	910,096.47	95,522.76	864,925.73	73,426.21	666,056.75
10	1	1	3	3252	32335	1157	11703	0.376	0.375	619.38	618.10	100,634.79	1,010,731.26	95,522.76	960,448.49	73,426.21	739,482.96
11	1	1	3	3255	35590	1118	12821	0.383	0.376	601.43	616.66	101,214.73	1,111,945.99	95,826.46	1,056,274.95	73,729.90	813,212.86
12	1	1	3	3336	38926	1198	14019	0.373	0.376	611.84	616.23	104,087.04	1,216,033.04	99,398.77	1,155,673.72	77,302.21	890,515.08
13	1	1	3	3251	42177	1211	15203	0.373	0.376	605.21	616.46	102,530.11	1,318,563.15	97,771.83	1,253,445.55	75,675.28	966,190.35
14	1	1	3	3349	45526	1255	16485	0.381	0.376	584.76	613.03	105,669.63	1,424,232.77	101,336.36	1,354,781.90	79,239.80	1,045,430.15
15	1	1	3	3178	48704	1195	17680	0.376	0.376	628.40	614.07	101,594.65	1,525,827.42	96,766.37	1,451,548.27	74,669.82	1,120,099.97
16	1	1	3	3326	52030	1109	18789	0.376	0.376	604.11	613.48	97,649.54	1,623,476.96	92,036.26	1,543,584.53	69,939.71	1,190,039.68
17	1	1	3	3197	55227	1220	20009	0.367	0.375	610.12	613.27	98,252.30	1,721,729.26	93,249.03	1,636,833.56	71,152.47	1,261,192.15
18	1	1	3	3194	58421	1184	21193	0.379	0.376	616.76	613.47	102,256.52	1,823,985.78	97,273.24	1,734,106.80	75,176.69	1,336,368.84
19	1	1	3	3186	61607	1276	22469	0.379	0.376	608.64	613.20	104,936.42	1,928,922.20	100,728.16	1,834,834.94	78,631.59	1,415,000.43
20	1	1	3	3231	64838	1206	23675	0.376	0.376	610.72	613.07	100,518.78	2,029,440.97	95,650.50	1,930,485.44	73,553.95	1,488,554.37
21	1	1	3	3201	68039	1306	24981	0.367	0.375	616.58	613.25	102,763.41	2,132,204.39	98,585.14	2,029,070.58	76,488.58	1,565,042.96
22	1	1	3	3269	71308	1298	26279	0.374	0.375	598.86	612.53	102,520.68	2,234,725.07	98,292.41	2,127,362.98	76,195.85	1,641,238.81
23	1	1	3	3270	74578	1170	27449	0.378	0.375	598.11	611.92	102,165.99	2,336,891.06	97,142.71	2,224,505.69	75,046.16	1,716,284.96
24	1	1	3	3188	77766	1203	28652	0.371	0.375	625.94	612.51	101,907.38	2,438,798.43	97,089.10	2,321,594.79	74,992.55	1,791,277.51
25	1	1	3	3155	80921	1149	29801	0.378	0.375	626.24	613.04	101,220.19	2,540,018.63	96,031.92	2,417,626.71	73,935.36	1,865,212.87
26	1	1	3	3201	84122	1126	30927	0.373	0.375	639.64	614.00	101,790.47	2,641,809.09	96,557.19	2,514,183.90	74,460.64	1,939,673.51
27	1	1	3	3109	87231	1277	32204	0.379	0.375	612.96	613.98	100,737.89	2,742,546.98	96,209.61	2,610,393.51	74,113.06	2,013,786.57
28	1	1	3	3274	90505	1236	33440	0.374	0.375	599.67	613.43	101,528.77	2,844,075.75	96,870.49	2,707,264.00	74,773.94	2,088,560.50
29	1	1	3	3225	93730	1274	34714	0.374	0.375	601.96	613.01	101,451.49	2,946,527.24	97,018.21	2,804,282.21	74,921.66	2,163,482.16
30	1	1	3	3274	97004	1205	35919	0.377	0.375	606.93	612.81	102,391.31	3,047,918.54	97,673.03	2,901,955.24	75,576.48	2,239,058.64
31	1	1	3	3254	100258	1188	37107	0.375	0.375	619.03	613.01	102,096.38	3,150,014.93	97,208.10	2,999,163.35	75,111.55	2,314,170.19
32	1	1	3	3246	103514	1277	38384	0.373	0.375	599.81	612.57	104,269.89	3,254,284.81	99,926.61	3,099,089.96	77,830.06	2,392,000.25
33	1	1	3	3226	106740	1244	39628	0.366	0.375	623.16	612.90	102,170.50	3,356,455.31	97,652.22	3,196,742.18	75,555.67	2,467,555.92
34	1	1	3	3265	110005	1249	40877	0.376	0.375	605.47	612.67	102,793.83	3,459,249.14	98,315.55	3,295,057.73	76,219.00	2,543,774.92
35	1	1	3	3362	113367	1167	42044	0.385	0.375	579.99	611.77	100,138.59	3,559,387.73	96,050.31	3,390,108.04	72,953.76	2,616,728.68
36	1	1	3	3304	116671	1234	43278	0.373	0.375	605.24	611.58	102,637.83	3,662,025.56	98,059.56	3,488,167.60	75,963.00	2,692,691.58
37	1	1	3	3129	119800	1243	44521	0.385	0.376	606.76	611.46	101,795.03	3,763,820.59	97,166.75	3,585,334.36	75,070.20	2,767,761.88
38	1	1	3	3199	122999	1202	45723	0.379	0.376	620.11	611.67	101,457.91	3,865,278.50	96,594.63	3,681,928.99	74,498.08	2,842,259.96
39	1	1	3	3245	126244	1219	46942	0.385	0.376	589.85	611.11	104,024.84	3,969,303.34	99,441.56	3,781,370.55	77,345.01	2,919,604.97
40	1	1	3	3196	129440	1201	48143	0.379	0.376	620.73	611.35	100,647.44	4,069,950.79	95,809.17	3,877,179.72	73,712.61	2,993,317.58
41	1	1	3	3208	132648	1173	49316	0.382	0.376	615.22	611.44	100,831.39	4,170,782.17	95,818.11	3,972,997.83	73,721.56	3,067,039.14
42	1	1	3	3184	135832	1256	50572	0.389	0.376	590.86	610.93	103,882.09	4,274,664.27	99,463.82	4,072,461.65	77,367.28	3,144,406.40
43	1	1	3	3267	139099	1146	51718	0.378	0.376	600.75	610.70	99,859.79	4,374,524.06	94,611.52	4,167,073.16	72,514.96	3,216,921.37
44	1	1	3	3228	142327	1282	53000	0.371	0.376	607.74	610.63	103,400.22	4,477,924.28	99,086.94	4,266,160.11	76,990.39	3,293,911.76
45	1	1	3	3359	145686	1140	54140	0.383	0.376	583.27	610.06	100,864.99	4,578,789.27	95,661.72	4,361,821.82	73,565.16	3,367,476.92
46	1	1	3	3191	148877	1233	55373	0.379	0.376	608.46	610.02	100,785.37	4,679,574.64	95,987.09	4,457,808.91	73,890.54	3,441,367.46
47	1	1	3	3176	152053	1197	56570	0.378	0.377	596.89	609.74	102,424.58	4,781,999.22	97,521.30	4,555,330.22	75,424.75	3,516,792.21
48	1	1	3	3263	155316	1149	57719	0.385	0.377	618.85	609.92	102,790.19	4,884,789.41	97,726.92	4,653,057.13	75,630.35	3,592,422.57
49	1	1	3	3161	158477	1245	58964	0.378	0.377	598.29	609.64	100,809.98	4,985,599.38	96,121.69	4,749,178.82	74,025.13	3,666,447.70
50	1	1	3	3295	161772	1199	60163	0.386	0.377	612.93	609.70	102,547.51	5,088,146.89	97,814.23	4,846,993.05	75,717.68	3,742,165.38
51	1	1	3	3327	165099	1196	61359	0.386	0.377	579.19	609.11	101,207.11	5,189,354.00	96,288.84	4,943,281.89	74,192.28	3,816,357.66
52	1	1	3	3250	168349	1175	62534	0.386	0.377	590.75	608.76	100,253.32	5,289,607.32	95,220.04	5,038,501.93	73,123.49	3,889,481.15
53	1	1	3	3229	171578	1147	63681	0.392	0.377	621.78	609.00	99,448.26	5,389,055.58	94,259.98	5,132,761.91	72,163.43	3,961,644.58
54	1	1	3	3254	174832	1238	64919	0.377	0.377	611.59	609.05	102,931.70	5,491,987.28	98,393.42	5,231,155.34	76,296.87	4,037,941.45
55	1	1	3	3308	178140	1229	66148	0.370	0.377	605.82	608.99	103,530.50	5,595,517.78	98,977.23	5,330,132.56	76,880.67	4,114,822.12
56	1	1	3	3319	181459	1278	67426	0.377	0.377	595.95	608.76	102,625.35	5,698,143.13	98,297.08	5,428,429.64	76,200.52	4,191,022.65
57	1	1	3	3291	184750	1229	68655	0.380	0.377	598.04	608.39	101,801.50	5,799,944.64	97,123.23	5,525,552.96	75,026.67	4,266,049.32
58	1	1	3	3244	187994	1196	69851	0.374	0.377	617.09	608.54	101,703.11	5,901,647.75	96,864.84	5,622,417.70	74,768.28	4,340,817.60
59	1	1	3	3192	191186	1254	71105	0.376	0.377	616.28	608.67	102,723.16	6,004,370.91	98,249.89	5,720,667.58	76,153.33	4,416,970.93
60	1	1	3	3231	194417	1211	72316	0.374	0.377	614.35	608.77	101,867.11	6,106,238.02	97,078.83	5,817,746.42	74,982.28	4,491,953.21

MPS LOW HIGH