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Numerical Analyses and Integration of Split Lot Sizing Using Lean Benchmark Model for Small Lot Manufacturing in High Mix Low Volume Production

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NUMERICAL ANALYSES AND INTEGRATION OF SPLIT LOT SIZING USING LEAN BENCHMARK MODEL FOR SMALL LOT MANUFACTURING IN HIGH MIX LOW VOLUME PRODUCTION

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in Manufacturing Systems Engineering
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By

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2020

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ABSTRACT OF THESIS

NUMERICAL ANALYSES AND INTEGRATION OF SPLIT LOT SIZING USING LEAN BENCHMARK MODEL FOR SMALL LOT MANUFACTURING IN HIGH MIX LOW VOLUME PRODUCTION

As the global demand for automobiles has increased rapidly over the last fifty years, customers have become more particular about the characteristics of the autos they want. This change in demand, in part has pushed manufacturing to become more flexible and created a demand for alternative, more efficient processes like the High Mix Low Volume (HMLV) production of vehicles. During HMLV, manufacturers create production lot sizes and schedule to synchronize the production processes to meet customer demand on time. The demand for the automobile parts may not be uniform or parts may not be consumed by the customer immediately, Due to this variation in demand, companies avoid shortages by large production lots and storing excess inventory. However, excess inventory has to be managed differently during the production large lots. It increases the inventory holding

cost; hence it is essential to know what, when and how much to produce. An excellent example of introducing controls for efficiencies is the Toyota Production System, which allows Toyota Motors to progress implement Just in Time (JIT) production, However, to achieve the JIT, needs for producing small lots have to be met.

Hence, this thesis aims to assess a lot-sizing model that focuses on how to combine the production methods of high to low demand parts one machine to achieve JIT. The method was divided in two parts; first, it assesses the variable production of high to medium demand parts within a fixed amount of time described as Fixed Period Variable Amount (FPVA). The split lot technique used to minimize the inventory. Second, parts that have assess low demand were assessed within a Fixed Amount Variable Period (FAVP).

It is proposed that a time-oriented method with the external changeover parameter can appropriately minimize the inventory of FAVP parts and avoid idling of the workforce. Also discussed the kaizen or continuous improvement approach for changeover with directed sequencing approaches to minimize longer changeover times, significant obstacle for the production of small lot production.

The outcome of the propose model is then compared with two industry lot sizing and scheduling models, conventional lot sizing and lean benchmark lot sizing. The objective of conventional model is to minimize the cost without considering and HMLV

environment and external changeover parameter. The objective of the lean benchmark model is to minimize inventory without creating idle time for the workforce. The thesis also investigates the integration and working of the Kanban scheduling system in the lean benchmark model

Keywords: Lean Manufacturing, Small lot manufacturing, Changeover, HMLV, Kanban

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To my family

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1. INTRODUCTION

1.1 Small Lot Production

'Production' is a transformation process in which the inputs of raw materials inventory, labor, machines, capital, and management are transformed into the output finished products with the use of production processes. Manufacturing is at its best when efficient use of production processes and resources are employed to produce products. The processes are the most essential ingredient that establish the condition needed for various components of the production system to build robust output. Products are manufactured depending upon the nature of the customer demand, may be stochastic, deterministic or high and low.

One of the ways manufacturers achieve smooth production flow is by stocking inventory, this Stocking includes raw materials, work in progress (WIP) inventory, or finished goods inventory. Inventory stocking is dual edge issue because it can incur considerable cost and is often considered as waste. However, it can be very crucial for meeting customer demand. One approach to minimize inventory is to use Just in Time manufacturing (JIT).

JIT is one of the pillars of the Toyota Production System. (TPS). The goal of JIT is to reduce WIP inventory while balancing the need and replenishment of inventory that reduce or eliminate the need for an inventory [1]. JIT manufacturing fulfills the customer demand with the shortest lead time possible to produce saleable product. During JIT inventory stagnation is to be minimized; such minimization can achieve piece by piece flow sequence within the manufacturing process, condition of which exist during, the production of small increments of products even for the system that has an overall large annual capacity. For JIT, the production of increments of products i.e. small lot production is valuable and essential [2].

A production lot can be defined as the quantity of production of a product on a machine [3]. Just in Time manufacturing ideally allows manufacturers to have almost no inventory or to achieve piece by piece flow and still able to fulfill the customer demand on time. However, in practicality, due to machine breakdowns, downtimes, or supplier delay may create disruptions; consequently, some amount of excess inventory kept for safety net for these unpredictable circumstances. Small lot production with small amounts of inventory minimizes cost by minimizing inventory stagnation within its required storage space.

As the global demand for the automobiles has increased rapidly over last fifty years. Customers have become more particular about the characteristics of the autos they want. This change in demand, in part, has pushed manufacturing to become more flexible and has created a need to utilize more efficient, alternative processes like High Mix Low Volume (HMLV) production of vehicles. During HMLV processes, the demand for automobile parts may not be uniform or parts may not be consumed, inventories have to be managed differently than in a large production lot, High efficiencies require knowledge of what, when and how much to produce, a goal of which is embodied within Toyota Production System (TPS); TPS enables Toyota Motors to implement JIT production method using HMLV production. To successfully achieve JIT, the need for producing small lots must be understood and met.

For the implementation of JIT, a manufacturer needs to strive to achieve as close to a one-piece flow production as is possible. When only one product is manufactured on one machine at a time and no changeover process needed, it is known as a single-purpose or dedicated machine [4]. Due to the HMLV, the production of one product per machine is not possible not efficient. Hence, rather than using dedicated machines, the multipurpose machine is becoming prevalent in HMLV environment. The multipurpose machines establish production of multiple products on a single machine. Increased sophistication of design helps in making it more efficient to use multipurpose machines, but their configuration and/or components need to be changed to accommodate the variety of parts that are to be manufactured. The process of changing dies and machines configuration is known as changeover. A plot of amount of production from a machine with the time during changeover is presented in figure 1-1.

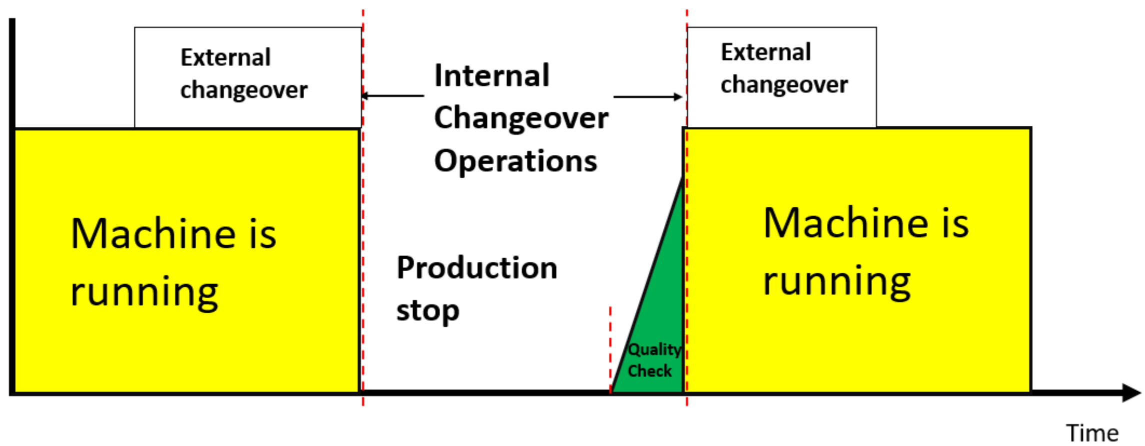

Figure 1-1 Changeover Process

Changeover comprised of two activities, internal changeover and external changeovers. The internal changeover is a series of operations that must be carried when the production is stopped to change from one part and start the production of the next part. It consists of removing the die which was currently running in the machine and replace it with the dies of part from staging to the machine that is going to manufacture. It also consists of changing the material and machine configuration. The external changeover is the series of operations that must be carried while the machine is running. The external changeover is divided into two parts, prepping and cleaning. Prepping consists of moving the dies of the product from the die storage area to staging. These operations of the external changeover are carried before the start of the internal changeover. The cleaning process carried after the internal changeover is finished. The internal changeover process continues until the first good quality part is manufactured. After the production starts, dies of the previous parts are moved to the die storage area. All these operations carried on a multipurpose machine that can run several parts. It is essential to balance the production of high demand for low demand products due to an increase in the use of the multipurpose machine.

The use of HMLV production requires the use of multipurpose machine and is controlled by the lot size as shown in the figure 1-2. As the variety of products increases the lot size decrease because it is necessary to reduce lot size if several parts are to be produce on one line with highest flexibility and lowest investment.

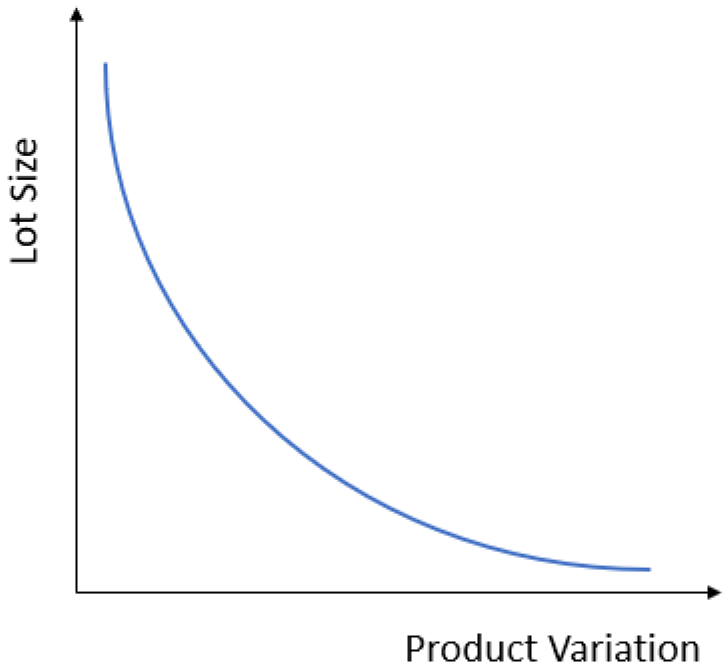

Figure 1-2 Lot Size and Product Variation Correlation

If smaller production lots are accompanied by long changeover times, it may result in idling time for the workforce due to smaller production capacity and long changeover times then it may create idling time of the workforce and inefficiencies are introduced. These large production lots can sometimes be defective. Hence investment and production hours associated with that defective lot would be waste. Sometimes these defective inventories may not be identified due to huge inventory stored in the warehouse which is one of the biggest drawbacks of large production lots. However, the Toyota Production System emphasizes eliminating overproduction and reducing work in progress. Mr. Taiichi Ohno pursued a JIT system to produce "What is needed? When is needed? How much amount is needed?"[5]. A reduction in the production lot size reduces the lead time resulting in less stagnation of parts. It increases the productivity of workers value-added work by giving a full-time workload. The changes in the quality of products can be easily detected and adjusted as they occur. Small lot manufacturing can quickly adapt to fluctuation in demand. However, large production lots increase the overall machine utilization to avoid changeover.

Lot sizing and scheduling is a widely discussed and seriously considered topic among companies and academia. Most lot-sizing and scheduling decisions based on labor cost, setup cost, and available capacity. Companies create production scheduling plans intending to maximize the utilization of available machine capacity and reduce the number of changeovers, which is the reason for increased production lot sizes. However, if available machine capacity is decreased and the number of workforce hours is fixed, unwanted idling time for the workforce results; hence, it is vital to provide a full-time workload to increase productivity. In small-lot production, this time is utilized by more frequent changeovers. It allows utilizing the full capacity of the workforce instead of utilizing the capacity of the machine to provide the full workload, but long changeover time is a bottleneck. It is essential to do changeover kaizen to reduce the changeover time. It also helps to be flexible when product demand is high, keeping the net cost low while maintaining the labor cost [6].

This thesis assesses and then critically discusses the advantages of small lot manufacturing in HMLV and how scheduling decisions can be made in a lean benchmark company with the significance of changeover kaizen. It also compares the traditional lot size method with the lean benchmarking lot-sizing model and methods and proposes new model for HMLV manufacturing environment.

1.2 Lean Manufacturing

1.2.1 The TPS house

The Toyota Production Systems also known as Lean Manufacturing was developed by Toyota Motor Corporation (TMC) as a consequence of and after the 1973 world oil crisis. Its primary purpose to eliminate waste and continuously improve (Kaizen) manufacturing practices with minimum investment. Two main pillars of lean manufacturing are JIT and Jidoka i.e. the detection of problem or defects at an early stage that enables production to proceed only after resolving the problem at their root cause JIT is discussed in section 1.2.3

Jidoka is known as a built-in quality approach, where the goal is to prevent the defect from occurring and not to have defects of parts move into processes following the one in which defects were created. It is every worker's responsibility to provide quality products to the customer by following standardized processes or operations. Standardization of tasks or processes establishes the required conditions to build better quality products. As operations and processes are standardized, it becomes easy for the worker to identify abnormal work or highlight the problem. Abnormal work conditions can be improved by problem-solving or kaizen activities. Kaizen embraces a strategy where everyone has a chance to suggest or make process improvements. These kaizen activities allow improvement in eliminating the recurrences of defects, lead time reduction, waste reduction.

It may be difficult to see problems when they are hidden, and the reason for them is a large amount of inventory which can hide the problem. In TPS, there are three factors which are known as Muda, Mura and Muri, where Muda is known as seven waste, Mura known as unevenness of workload, and Muri known as overburden. If we eliminate waste, it will eliminate unevenness of workload, and hence reducing the overburden of workers. Similarly, if we eliminate unnecessary inventory, it will highlight the problems for improvements.

1.2.2 Seven Wastes in Lean Manufacturing

From the philosophy of TMC, the cost of the product is decided by the customer, which in turn encourages the eradication of waste and the establishment of profits. In TPS, the productivity of workers is essential and fundamental; hence cost is to be reduced and increase the quality of the product. There are seven types of wastes in manufacturing namely conveyance, inventory, motion, waiting, over-processing, overproduction, defects.

Conveyance

Conveyance adds no value to the product, and the customer is not willing to pay for it [2]. Any unnecessary conveyance such as conveyance from the warehouse to a factory or warehouse to any respected place is known as waste. Hence within TPS, it is crucial to improve the in-plant layout by occupying less space and reducing the conveyance distance.

Inventory

Inventory defined by the amount of raw material, work in progress or finished products in the processes. There are two types of inventories known as necessary inventory and natural inventory [2]. Natural inventory may accumulate when there is fluctuating market demand, overproduction, lot production. In necessary inventory, parts are produced earlier than required because of longer production cycles or fluctuation in demand. It is also known as early production.

Motion

The completion of task by workers is accompanied by their motion. In TPS, the ability to complete a task with the least movements or motions is essentials for saving time and avoiding waste [2]. If workers are spending more time walking or doing redundant operations, these non-value-added work activities increase the task time, which will eventually increase the lead time.

Waiting

It is a type of waste that occurs when the machine is waiting for a worker or worker is waiting for a machine due to longer operation times. When inventory or operations are not moving or utilized then waiting occurs. It can be in the form of machine downtime or lot production delays.

Over-processing

Over-processing is a type of waste that will add more form, fit or function to the product than is necessary [2]. However, adding more value to the product that a customer is not willing to pay for is over-processing. For example, if a part requires less surface finish but the manufacturer adds a high surface finish. It is over processing. Moreover, it will increase the cost of the process hence increase the cost of the vehicle.

Defects

When defects occur in manufacturing, these parts are sent back for reworking or discarded. Some defects may require a significant amount of time and reworking, which may increase the cost.

Overproduction

In manufacturing, overproduction is known as the mother of all waste [2]. Making products in a large amount than customer demand or producing early than the product is needed leads to excess inventory known as overproduction. For example, if the number of product requirements is 1000, and the manufacturer produces 5000 products, this situation is known as quantitative over-production, whereas if the product requirement is on 10th March and the product is manufactured on the 5th March, this type of production is known as early over-production. The TPS view of these issues is that waste occurs whenever company manufacturers products that are not going to be sold immediately There is a considerable amount of capital cost tied to warehouse storage, work in progress, production process, labor cost, and finished products. More work in progress means workers must use more equipment to move the inventory from one place to another, which leads to excess conveyance. This excess Conveyance requires time to move products, which ultimately leads to excess motion, because of these excess inventory causes unevenness of workload; hence, problems are hidden. The main goal is to eliminate excess inventory by using the Just in Time production concept.

1.2.3 Just in Time Production (JIT)

JIT is the pillar of the TPS, which means producing what is required when is required, and how much amount is required. In the concept of Just in Time, if implemented to perfection with the pursuit of kaizen manufacturers accomplish stockless or no-inventory production eliminating warehouse space, also eliminated inventory holding cost and waste [2].

Nevertheless, it is challenging to implement JIT manufacturing in industries like the automobile or semiconductor manufacturing because they both exist within the HMLV environment in which a significant amount of time used in changeover processes. As previously discussed, however, the use of Changeover Kaizen does enable manufacturers to significantly improve changeover times. allows manufacturers to improve changeover times.

1.2.4 The Kanban System

The Kanban system was developed within the TPS to implement JIT manufacturing and considered to be a pull system. It is a tool in the form of a card usually kept inside the rectangular vinyl bag and the bags are kept in poly boxes which control the production of the required part at the necessary time and in the required quantities. Kanban systems enable manufacturers to adapt to small changes in demand and control overproduction. Whereas in traditional manufacturing systems Material Resource Planning method is used to create production schedules for all machines, processes, and assembly lines, and supplying parts from preceding to succeeding process. This traditional system is also knowns as a push system. Push systems have less capacity to adapt to changes concerning demand. If there is any fluctuation in demand for a shorter or longer period, the company has to change the production schedules for all machines, processes, workforce. On the other hand, the Pull system showed in figure 1-3. The process is producing the required part by the customer. Manufactured parts are stored in the warehouse with production Kanban located in front of the process and customer. When the customer requires inventory, the withdrawal Kanban is sent to the process. This withdrawal Kanban is replaced with production Kanban and send to the customer. The replaced production Kanban is sent back to the process to replenish the withdrew inventory.

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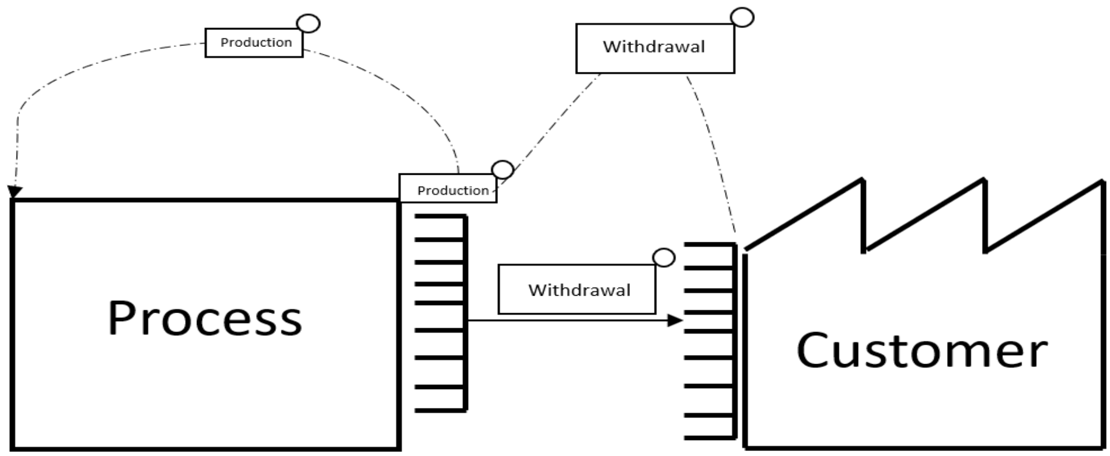

Figure 1-3 Kanban path [7]

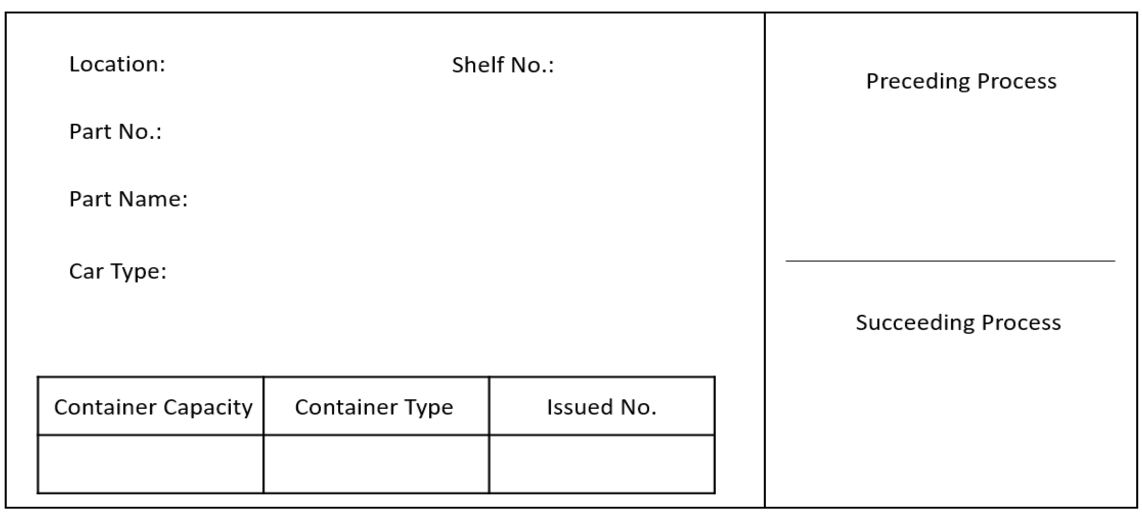

Figure 1-4 Withdrawal Kanban [7]

A withdrawal Kanban and a production Kanban are two types of Kanban; they are depicted in figures 1-4 and 1-5, respectively. The withdrawal Kanban is used by the subsequent process to withdraw parts from the preceding process. It indicates the type of the part, their quantity, identification of processes involved, and where it is stored. On the other hand, production Kanban is used to signal the process to produce parts. It indicates the type of the part, amount to produce, where to produce, and where production is completed [2].

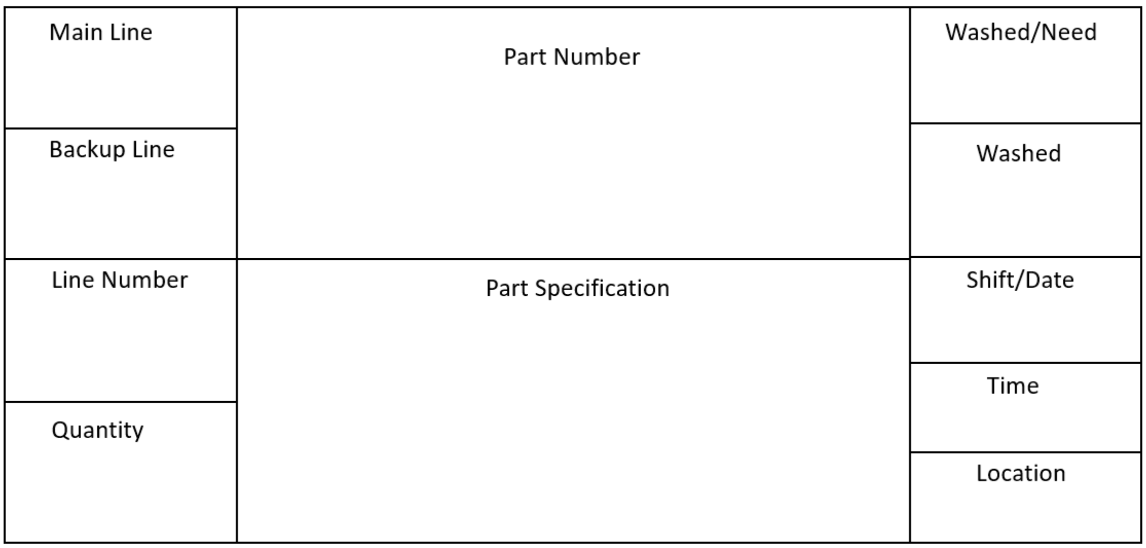

Figure 1-5 Production Kanban [7]

Figure 1-5 depicts the production Kanban; identified are part number which parts need to be produced, the line number, type of machine and backup line for any machine downtime or delay. Line number indicates the type of machine line, for example, stamping, forging. Part Specification is given in the middle part. On the right side, time for the production, location of part to be stored and shift number is shown.

In cases of lot production systems like stamping, casting or forging, a special type of Kanban is used to indicate the order point. It is known as Signal Kanban. The shape of the signal Kanban is triangular made with metal plate compare to other Kanban. This Signal Kanban is attached to one of the containers of the production lot at the order point [2]. If parts are pulled by subsequent process till order point, then the production of withdrew parts is started for replenishment. The order point is a quantity that covers the amount of product from the time of detaching a Kanban when parts are pulled by the customer to the conveyance of pallets. This time is an accumulation of lead time when signal Kanban is detached, parts are produced, and the first container comes to store. Figure 1.6 depicts the Signal Kanban on which the part number, its name, QPC (Quantity Per Container), and lot size, along with the material flow which it was made, its location and the machine used for its manufacturing. The right section of the figure shows the stack of containers and signals Kanban is placed on the container. When the next process pulls the signal Kanban on the second container, then this signal Kanban is detached to tell the preceding process for the production of 500 more Fender.

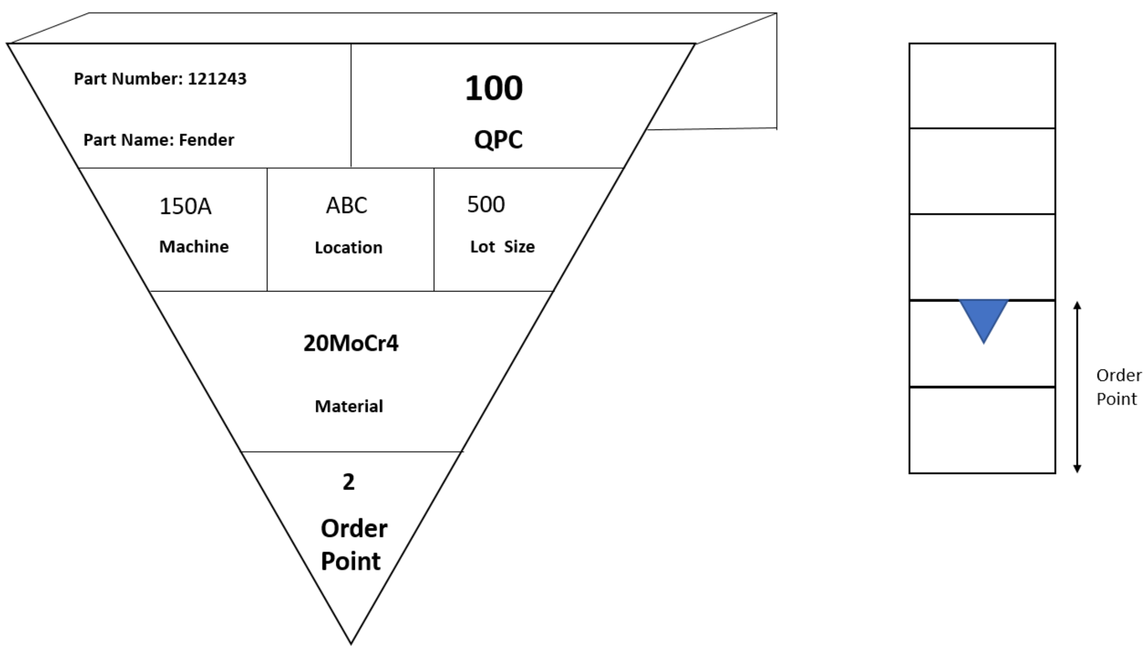

Figure 1-6 Signal Kanban [7]

To the author's knowledge, no professional literature available which considers HMLV environment with external changeover for manufacturing, although the wide variety of literature can be found on lot sizing and scheduling. Inventory holding cost and changeover costs were considered. [8] in a model study and extension of the models were investigated by other authors which considered a cost framework and backlogging. Some of these models give exact optimal solutions and some models developed in order to find approximate solutions which are also known as heuristics which gives approximate solutions [9]. Similarly, dynamic programming also has a drawback that these problems are Non-Polynomial-hard which means compute time taken to solve these problems increases substantially as the number of parts increases.

It is to be realized that amount of inventory is always positive and the production cost incurred whenever a part is produced in the period,

$$Total\ cost = SC_i + H_i \bullet I_{i,t}$$

where SC_i is a setup cost of item *i* and $H_i \bullet I_{i,t}$ is a holding cost of item. H_i is a unit holding cost of part *i* and $I_{i,t}$ is the number of parts *i* stored at the end of period *t* [10]. In the early publications in which lot sizing and scheduling were assessed, only uncapacitated cases with no capacity constraint imposed on production. [11] an extension to the uncapacitated problem which consisted backorders. Later, when the lot-sizing problems introduced with capacity constraint, these problems referred to as the Capacitated Lot-Sizing Problem (CLSP). CLSP problems are the hardest problems in lot sizing and scheduling. Introducing capacity constraints increases the complexity of decisions based on time [12, 13]. The objective of CLSP problems is to minimize the holding cost and setup cost. Some authors considered multi-level machines and multi-machines [14, 15]. $\sum a_i \bullet X_{i,t} \leq Cap_t$ is a capacity constraint that imposes restrictions on the cumulative sum of production time. Where a_i is the unit production time of part i and $X_{i,t}$ is the production lot size of part i in period t [16]. Setup times were assessed in [17]. Another modeling effort assessed discrete lot-sizing and scheduling problems (DLSP) in which a multi-item problem where a single machine model used. In this problem, only one part is allowed to produce in one period using full available capacity where the inventory of parts can be stored regardless of the demand for the period [18]. This proportional lot sizing and scheduling model keep all the constraints of DLSP, except more than one part is allow to produce in one period [16, 19, 20]. Authors used different instances such as production carryover, setup splitting, setup crossover [16]. In production carryover, when there is idling time at the end of the period, production of part carried at the end of the current period and next period [9]. Production carryover with back orders has also been modeled [21]. In setup splitting, when enough capacity is left at the end of the period, a changeover is carried in the current period and production is carried in the next period [22, 23]. Setup carryover is known when the changeover starts at the end of the period and ends at the beginning of the next period. The reasons for setup crossover implemented because of longer changeover time [24]. Some authors combined the setup splitting and production carryover.

The scant amount of literature available on lean manufacturing lot sizing and scheduling. Some authors also discussed the basic lot-sizing techniques used by the lean benchmark model and concept used to increase productivity on lot production machines. [25]. [2] discussed the concept of order point in TPS. The author also talks about how the

Just in Time manufacturing should be implemented in production. Assessment of models for JIT manufacturing and disucsions about importance have also been published [1]

In the 80s, vehicle customization increased significantly; thus, mass production was not an efficient way of production [2]. As a consequence, detailed production planning becomes a necessity, especially for automotive manufacturers. In the large-scale manufacturing environment, various decisions have to be made and fulfill manufacturers responsibility for customer demand such as the decision of stocking or to produce the products to meet customer demand. For example, stocking decisions have to be made on several factors such as time from ordering to time from receiving the order, backorders, satisfying the full customer demand. So, the problem is to avoid overproduction and stocking of items. The study of such type of problem is known as lot sizing, inventory control or production planning. When customization goes up it is crucial to fulfilling the customer demand on time without any delays. It can be done by producing all items is large quantities however, one of its most significant drawbacks is mass production increases the material and information stagnation for a longer time. Thus, reduce the amount of inventory stored in the warehouse by avoiding mass production which increases the holding cost and production cost.

3.1 Lot Sizing Attributes and Parameters

In today's economy, no manufacturer is an ideal or complete one, but some elements are common to all manufacturers such as labor, machines, money, and management, etc. To be competitive in the industry, companies have to streamline the production activities and attain the maximum utilization of the firm's resources to enhance productivity. Hence, production planning control is needed, as it serves as a useful tool to coordinate the activities of the production systems. Production planning is also known as Lot Sizing. Production planning and control are needed to achieve:

I. Uninterrupted production flow to meet customer demand.
II. Effective utilization of firm or resources.
III. Production objectives with respect to quality, quantity, cost and JIT delivery.
IV. supply the required quality products to the customer.

The function production control guiding the flow of products through manufacturing processes, initiating from raw materials to finished products to meet the objective of the company with minimum investment and efficient production flow. Lot sizing is like a navigation system; navigator creates a plan and sets a course towards an objective, but this plan is not completed by doing so. Navigator always modifies the plan for the errors.

To understand the meaning of lot sizing, let us define the terms. Production is a sequence of operations that transforms raw material from a given to a final product form.

- Production planning is an essential prerequisite of production control. Production control cannot be done without planning. It began with an analysis of given data, based on the utilization of the firm's resources. It is outlined so that desirable targets can be attained effectively. Production planning is mainly concerned with specifying how the production resources in the manufacturing system are to be employed over a given future period in response to the predicted or forecasted demand for the product.
- Production control supervises operations with the aid of a control mechanism that information about the progress of work. Basically controlling is the process that

measures current performances and guides it toward certain predetermined objectives. Specifically, production control, thus, is means by which actual performances of production units are consistently evaluated with the help of standards.

In lot sizing, preplanning function mainly concerned with developing plans for production systems development and design. Depending upon period, this function can be classified as [26]:

- Long term planning: It is a crucial prerequisite for the design and maintenance of the production control system. Long-range planning is usually done for 5-6 years or more
- Medium-term planning: It is a plan for one or two years in advance.
- Short term planning: It is a plan for months or weeks or day or shift. Its primary purpose is to provide regular and systematic integration of operating capabilities and inventory requirements.

After the analysis of data collected at the preplanning stage, the selection of appropriate materials, methods, and facilities is made at the production planning stage. To ensure smoothening of operations, raw materials, semi-finished products, must be made available as and when required. Planning for material includes preparing plans for production, replenishment of material that is being ordered by the customer. Machine and equipment planning are related to the detailed analysis of available production facilities, equipment downtime, and schedules. An optimal method is to find out after examining various methods critically with constraints.

For capacity planning, the determination of productive capacity requirements is a critical aspect in designing a new system as well as in expanding an existing one. Capacity decisions for short term planning are difficult because fluctuation in demand or machine downtime, changeover time needs to be considered, which may affect the available capacity significantly [26]. Capacity is defined as a measure of the ability to produce products or rates of output. Machine capacity can be measured in terms of time, quantity, quality or location [27]. In this paper, capacity will be referred to as machine time capacity.

In a manufacturing environment, Machine Analysis has two objectives: First, to determine the approximate maximum capacity of each process and hence of all processes and the plant. Second, within the factory where several factors included in the machine capacity, to provide the basis for calculating the time of operation on a specific part. It is essential to know the requirements of each process or customer. Overproduction and shortages of materials or products in the system are avoided by synchronization lot size within the process. This synchronization of lot production within the process and other processes is established using a Kanban visual tool. Kanban production instruction tool is utilized to achieve the JIT production environment.

3.2 Conventional Model

The lot-sizing calculations are affected by machine analysis when both changeover and production time requirements are determined for a part. In conventional lot size modeling, as discussed earlier, when the variation of products goes up, and the demand of products decreases. These low demands for the parts and high changeover times affect the lot size significantly causing the lot-size to increase to avoid the inventory shortages and huge changeover cost. However, in this high mix low volume environment, it is crucial to meet customer demand on time. These large lots are the reason for material stagnation, enormous inventory holding cost, high-quality defects, longer lead times.

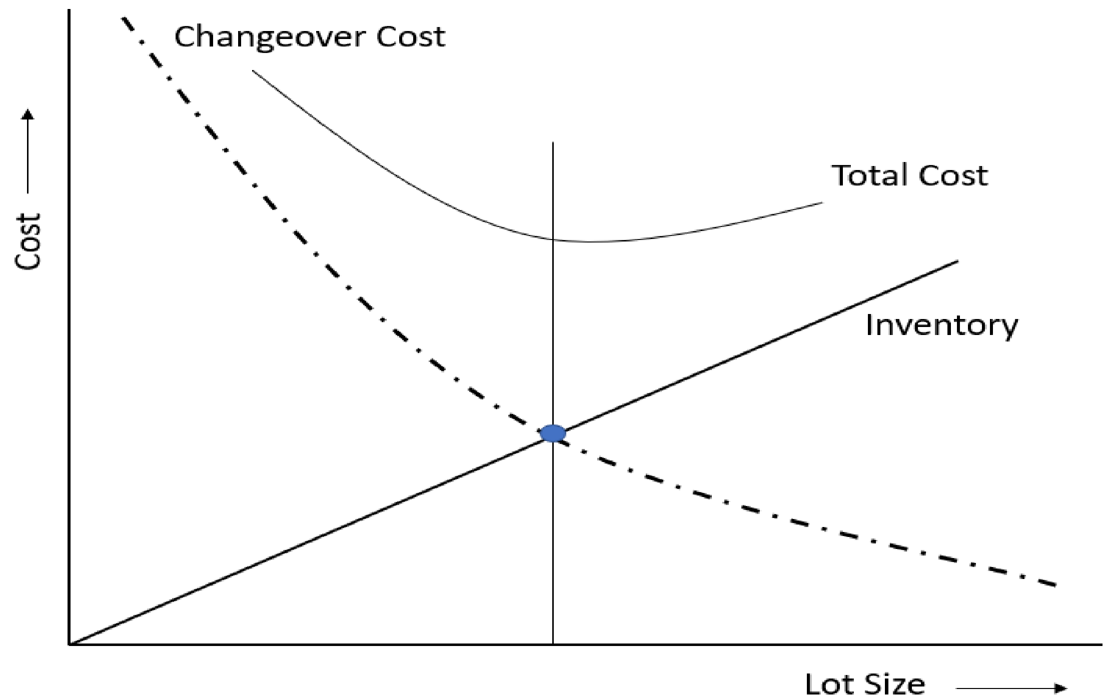

Figure 3-1 Traditional Model[7]

The relationship between the cost of production and lot sizes are as depicted in figure 3-1. In conventional modeling, the time of each changeover is considered constant making the model more cost-oriented. When the lot size increases, changeover cost decreases hence increasing the inventory holding cost. Contrarily, if the size of the production lot decreases, overall changeover cost increases. It also increases the total cost. It is essential to find the optimal lot size which that will balance both inventory and cost. This conventional model is also known as the Capacitated Lot Sizing model [27]. The objective of traditional modeling is to minimize total cost. The mixed-integer optimization formulation for conventional modeling is as follows.

P_i : Cycle time of each unit of part i

Cap_t : Available time or capacity of each period t

$d_{i,t}$: Demand of part i in period t

h_i : Holding cost of each unit of part i

S_i : Changeover time of part i

C_i : Changeover cost of part i

b : Big number, which is upper bound on production quantities.

Binary variable $I_{i,t}$ which indicates whether to hold inventory or not to hold inventory at the end of period t based on its production amount in the period. Integer variable $X_{i,t}$ is used to indicate the production quantity or lot size of part i in period t. Binary variable $Y_{i,t}$ is used to indicate whether part i changeover takes place in period t.

Formulation

$$\text{Minimize Cost} = \sum_{i}^{N} \sum_{t}^{T} (S_i\, Y_{i,t} + h_i\, I_{i,t}) \qquad \text{(A)}$$

$$I_{i,t-1} + X_{i,t} = d_{i,t} + I_{i,t} \qquad \forall_i \text{ and } t \qquad \text{(B)}$$

$$\sum_{i=1}^{N} P_i\, X_{i,t} + \sum_{i=1}^{N} S_i\, Y_{i,t} \leq Cap_t \qquad \forall_t \qquad \text{(C)}$$

$$X_{i,t} \leq b_{i,t}\, Y_{i,t} \qquad \forall_i \text{ and } t \qquad \text{(D)}$$

$$X_{i,t} \geq 0,\ I_{i,t} \geq 0 \qquad \forall_i \text{ and } t \qquad \text{(E)}$$

$$Y_{i,t} \in \{0,1\} \qquad \forall_i \text{ and } t \qquad \text{(F)}$$

This conventional mathematical formulation considers only internal change over time, where the goal of the objective function (A) is to minimize the changeover cost and inventory holding cost. Equation (B) is an inventory balance equation that specifies the input inventory required should be equal to output inventory. Equation (C) ensures total production time and changeover time of the parts in the period should not exceed the total available capacity of that period. Equation (D) considers the part *i* will be produced in period *t* only if changeover takes place in that period. Equation (E) ensures the variable X and I are positive variables.

3.3 Results

The model tested with the demand data in table 3-1. The total time available is four shifts i.e. 450 minutes per shift after considering operational availability which is 95%. In case to avoid any infeasible solutions, the available time kept 480 minutes. Internal changeover time is considered 10 minutes for each part. This model does not consider external changeover but in practice, external changeover time is 30 minutes. The demand for every part in every period should complete without any backorders or shortages. From the given table, the production of high demand to low demand parts considered. Lot sizes of all high demand parts and medium demand parts are twice the actual demand. All the excess inventory required for part *i* in period *t+1* is produced in the current period *t,* which creates high inventory holding cost.

Table 3-1 Data and result for conventional model

Part No	Demand/Shift	Lot Size	Total Container
1	790	790	16
2	272	543	5
3	272	543	5
4	272	543	4
5	272	543	4
6	200	400	5
7	200	400	2
8	200	400	5
9	200	400	5
10	200	400	4
11	200	400	4
12	75	300	5
13	75	300	3
14	75	300	5
15	75	300	5
16	43	172	3
17	43	172	3
18	43	172	3
19	43	172	3

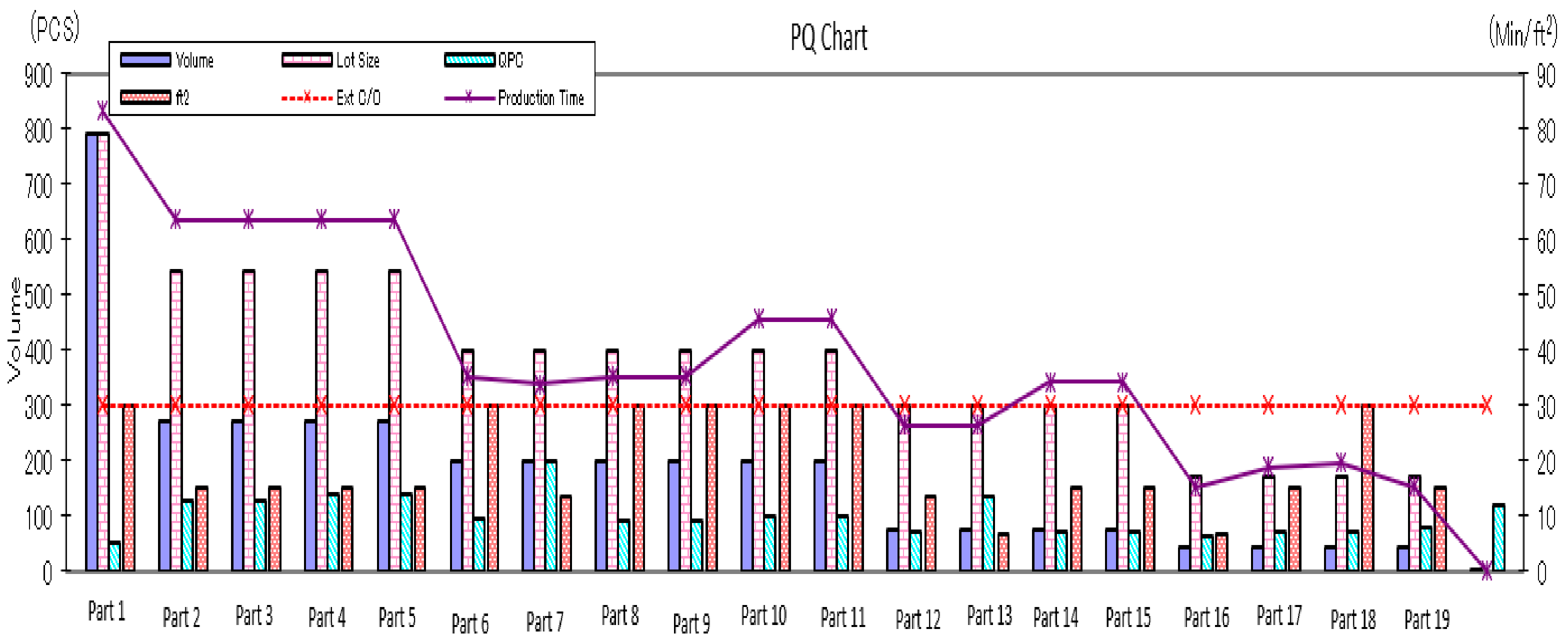

Figure 3-2 Production Quantity Chart for conventional model

Although customer demand may complete on time, inventory stagnation will occur for an entire period which increases the possibilities of quality defects and increases the lead time [28]. However, in the PQ chart, lot sizes of parts from 12,13 and parts 16-19 are set to four times a shift regardless of external changeover time.

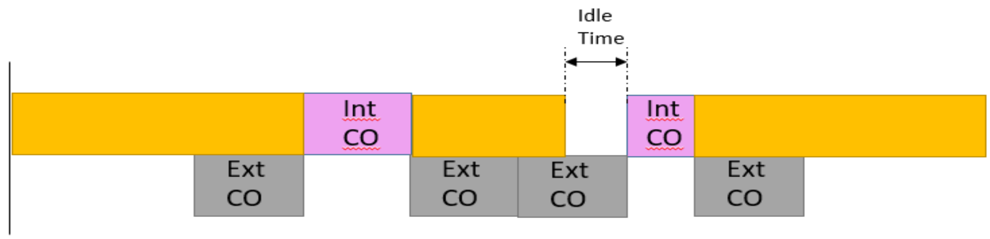

Figure 3-3 Idling occur due to external changeover

Hence, the production times of these parts are below the external changeover (Ext CO) time limit. It will create situations like idling, as depicted in figure 3-4, where labor is waiting for the machine in a shift. The cost of internal and external changeover is one unit for every one minute. In low volume, if the production time is less than both (part 12 and part 13) internal (Int CO) and external changeover time, production of part *i+1* has to wait for finishing the second external changeover of part *i-1*, 1st external changeover of part *i*, and internal changeover from the product *i* to *i+1*. In lean manufacturing, the idling of the workforce is a waste which leads to low productivity [2]. In the Gantt chart, production time exceeded the available production time when operational availability is 100%. Whereas, when operational availability is 95% model created an infeasible solution.

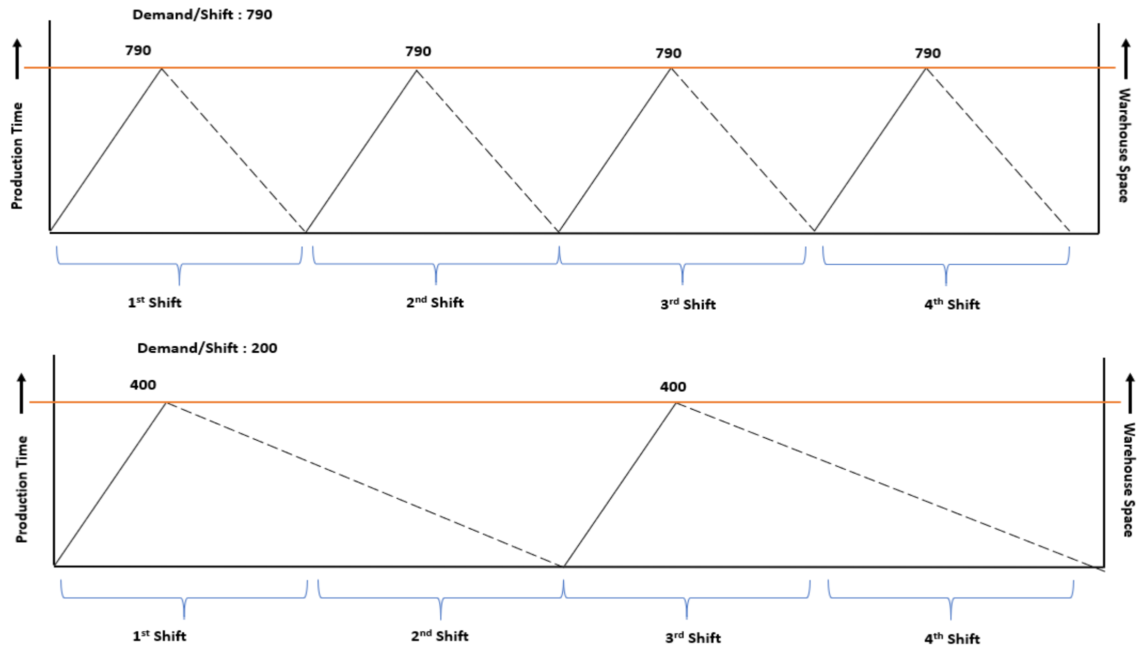

Figure 3-4 Inventory Level of part 1 and 6

Drawbacks of this conventional model are that it does not contemplate a high mix low volume environment. The inventory level of these large lot sizes requires more inventory storage space. Similarly, High demand parts such as part 1 consume maximum storage space. From figure 3.5, the production of demand 790 and 200 showed over the planning horizon with storage level on the right axis. Continuous lines indicate the production of the part in period respectively and dashed lines show the following process pulls the parts at a constant pace over the periods. The production of high volume can be split into two sperate lot size, producing the same part twice in one shift. Besides, medium level demand parts are possible to produce every shift.

Thinking of traditional modeling contradicts lean manufacturing thinking. Lot sizes of most parts raised due to substantial changeover costs. In practice, changeover cost is directly proportional to the time for the changeover. These longer changeover times can be reduced by developing people to think deeply and doing Kaizen. [29] explains the concept of 'Hitozukuri' means human development. The author emphasizes on two types of improvements, gradual and significant. Gradual improvements are the small, steady improvements that take place. Whereas significant improvement occurs when a breakthrough or major innovation takes place, creating 'S' shape improvement curve. Kaizen thinking is one of the essential parts of the Toyota Production System house. Next chapter will focus on Toyota Lot Sizing model and thinking behind the model.

CHAPTER 4. LEAN BENCHMARK LOT SIZING AND SCHEDULING MODEL

This chapter discusses one of the lean benchmarking models. As we know, Toyota Production Systems (TPS) is based on three critical pillars known as Just in Time and Jidoka is a Japanese term known as Automation with human touch [2]. The Sakichi Toyoda initially developed this concept, who was the founder of Toyota Industries. The significance of Jidoka is that it does not create defects, or it does not allow to pass defects to the customer. Besides, Just in Time is the concept developed by Taichi Ohno. It is the production of exactly what customer wants, exactly when he wants and the exact amount he wants. It helped the company to have less inventory into the system, balance finances, and still complete customer orders. To implement this system company uses a tool known as Kanban. It can be either in physical format or electronic signal. It ties up the upstream and downstream process by signaling what, how much, and when. This system is also called a pull system. Whenever a customer or downstream process pulls the inventory, a Kanban signal goes to the upstream process indicating that the pulled inventory needs to be replenished.

However, in production departments such as stamping, casting, and forging, the parts are manufactured based on predetermined lot size because of their long changeover times. Hence it is necessary to have a production schedule to meet the customer demand. This lot of size scheduling problem is not only prevalent in TPS but also other manufacturers face this problem. The only factor that makes Toyota Production System standout is its pursuit of small lot manufacturing. As one of the lean benchmarking models, I will be explaining the purpose and functioning of the Fixed-Fixed system and the thinking behind this model.

In addition, I will be discussing the Lot Size and Scheduling of two parallel machines that utilizes Yosedome method.

TPS uses the order point system for the lot making procedure. It is a boundary condition of the warehouse when the amount of remaining inventory provides parts to the customer from the time when order is received until the parts delivery is made to the warehouse. The purpose of the order point is to ensure that parts pulled by the customer or the following process are replenished in a predetermined lot size before they run out of parts. TPS decides the order point based upon fluctuations in demand of parts from the downstream process and conveyance time. The order point is calculated from the time taken for a Kanban when it is detached from the store, time is taken in the chute, production time, and conveyance time to consumption time of one Kanban by the customer.

$$Order\ Point = \frac{Replenishment\ lead\ time + \alpha}{Consumption\ time\ of\ one\ kanban}$$

α denotes fluctuation in demands.

In lot production departments, production is done as per the schedules but from figure 1.1, as the variation of parts increases the demand for the part decreases. When demand for parts fluctuates, it becomes difficult to maintain the inventory level of the part resulting in shortages or backorders. In this HMLV environment, it is also not efficient to produce each part in large lots. Some parts may not be pulled for a more extended period because of low customer demand. In this case like low demand, idling may occur because of longer changeover time. In response to this, the company set a higher-order point to avoid shortages and idling. But higher-order point increases the frequency of order which resulted in customers ordering the part early. These early orders disrupt the production sequence frequently. Hence to meet the customer demand production sequence is decided based on production quantities from the warehouse not the order in which orders are received. It becomes difficult in the order point system to manage low volume and high-volume parts together. A large lot size of the parts causes a delay in the production of not only the current part but also the parts after. Even sometimes after the order point is set higher, the process is still not able to meet the customer demand of the required part on time because of the waiting time of order. TPS developed a model, Fixed-Fixed system. This system is not discussed in the literature extensively.

In literature, there has been a lot of research on lot-size and scheduling, but there is no literature that considers the lot size and scheduling of two categories, high volume demand and low volume demand together.

4.1 Fixed-Fixed System and Thinking

Based on the demand of the parts from the customer, the Fixed-Fixed method is divided into two categories High volume demand and low volume demand parts. In lot production departments, the amount of quantity pulled depends upon the pace of customer pulling each container or Kanban as per the customization of the product. Therefore, to keep up with the pace of customer demand, lot sizes are determined based on the amount of quantity pulled by the customer in a certain period. The production amount or lot size is equal to the first part pulled after the end of production of respective part by the customer or downstream process to last part pulled before the start of production of the respective part by the customer or downstream process during the period of time. This type of production is usually carried for high volume parts in Fixed Period Variable Amount (FPVA). However, for low volume demand parts, the quantity of parts pulled by the customer or downstream process fluctuates significantly. It is not efficient to produce this part in FPVA manner as it creates idling time due to long changeover times, result, consuming a large amount of production time. Hence, the production amount to produce for the respective parts is predetermined regardless of the quantity pulled by the customer in order to avoid shortages and worker idling. This type of production is called a Fixed Amount Variable Period (FAVP). Production schedules of these parts are not determined by management whereas it depends upon time. As per the TPS philosophy, do not produce that cannot be sold immediately. Hence, there are always efforts made to reduce the production quantity of FAVP parts. The following sections will discuss FPVA and FAVP systems in depth.

4.1.1 Fixed Period Variable Amount (FPVA)

In the manufacturing environment, processes such as stamping, forging, casting, or heat treatment use lot production because of long changeover times to meet the customer demand, unlike assembly line where there is no changeover involved. Therefore, the time taken for the production is longer as compared to an assembly line environment. Parts demands may vary depending upon customer requirements over the planning horizon. As discussed earlier in the section, the lower-order point system disrupts the production sequence pattern because orders are received faster. Then the manufacturer has to decide the production sequence by looking at the amount of inventory available at the end of the previous period for the particular part. Increase order point increases the inventory carrying cost resulting in loner lead times and inventory stagnation. Hence in response to this lean benchmark company developed a system for stochastic demand of the product known as Fixed Period Variable Amount.as a part of the Fixed-Fixed system.

On a stamping machine, more than 10 parts are produced over the planning horizon using lot-sizing techniques. In pursuit of JIT production, these machines are placed next to the customer/process/die storage area to avoid any lead time delays and small lots, longer changeover time. For the stamping process, their customer is body weld. The amount of inventory pulled by the body weld or customer differs every 5 to 6 weeks [30]. Nevertheless, this variation is uniformly distributed hence negligible for some parts because the number of cars coming out of the line is constant every day. Sequence and lot sizes of these parts decided in advance for every month and the production of these parts spanned over the two days of the planning horizon with four periods. The lot size of the part in FPVA depends upon the parts pulled by the customer over the two days of the period. Quantity pulled is varied by little deviation from the amount produced during the production run. In general, lot size calculated from the demand of parts for a period by the time taken by changeover for that period. There are 10% changeover time guidelines concerning production time.

$$Lot\ Size = \frac{\sum Demand\ of\ Every\ part\ for\ a\ time\ period}{\sum Changeover\ time\ for\ a\ time\ period}$$

However, on a low workload production equipment, these changes over time may exceed 20% of the total time available. However, lot sizes determined are directly proportional to the production frequency of a given part in the planning horizon. Production frequency is defined by it is the amount of time part produced over the planning horizon. Besides, lot size is also determined based on the Quantity Per Container (QPC) amount. Hence in the FPVA system, lot-size is determined in two quantities. The lot-size is calculated from the equation.

$Q_i = d_i \bullet T_i$

Where Q_i : Production quantity of part *i*

d_i : Demand of part *i*

T_i : Production frequency of part *i*

From the above equation, lot-size is directly proportional to the frequency of production. If the production frequency increases, lot size decreases. But, in order to avoid partial containers lot size is rounded up to the multiple of QPC nearest integer solution. T_i is decided by the management with respect to the shortest changeover time by considering changeover compatibility and sequence..

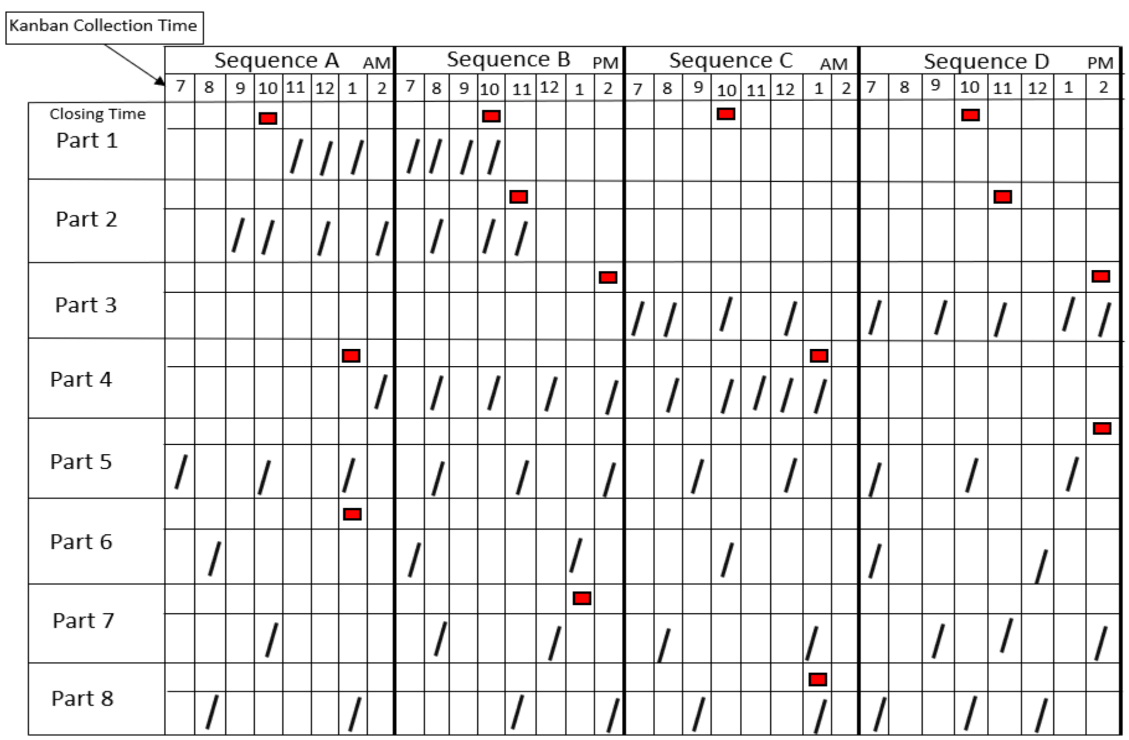

Figure 4-1 Representation of FPVA Sorting Board

Production of FPVA parts is controlled and visualized using a Fixed-Fixed sorting and scheduling board. These boards are visual management systems which are used to synchronize production with the lot-size calculations and sequences. Sorting and scheduling post utilize Kanban to indicate the production frequency and production sequence. From the lot-size and Kanban calculations, respective Kanban are attached to sorting posts by their predetermined production sequence. The figure 4-1 shows a closer representation of the sorting board. Sorting board indicates the time of production, amount of production, part number whereas scheduling board is used to indicate the time at which production of a part must be started and the sequence in which production must be done. In FPVA stamping production, parts withdrawal is based on the following process demand i.e. body weld. Parts are produced in a predetermined sequence but the quantity of parts to be produced is decided based upon what was sold or pulled by the customer over the period. In each time period, Kanban or containers pulled by the customer are the same because the customer is pulling at a constant pace. But the collection of Kanban is carried out at a certain time interval for example from the figure it can be seen 7 am to 2 pm and 7 pm to 2 am also known as Kanban collection time. Kanban is collected at a time interval of 1hour for morning and night shifts. This Kanban goes into 'Kanban post' as per the sequence decided by Heijunka. However, the production of parts is carried respectively to a predetermined sequence. All collected Kanban goes into the respective parts number slots as per the frequency of production decided by management. It can be seen that the production frequency of every part may differ for example, every shift, alternate shift, or every four times in a planning horizon. Therefore, every parts' production cycle is visualized with the help of closing time. Closing time is indicated with the help of a red mark. Closing time is the representation of time from the production of a certain part finished to the time of production of that part starts. In a nutshell, it is a time when the production of part is not carried, and the collection of Kanban ends from the decided production frequency. Practically, there is a buffer time kept before the start of the production because some amount of time is required for material or information flow.

Closing time for FPVA products should be decided in such a way that closing time should not be the same. From the following figure, when closing time is the same for products, it causes the material and information stagnation after the signal has been sent for the production.

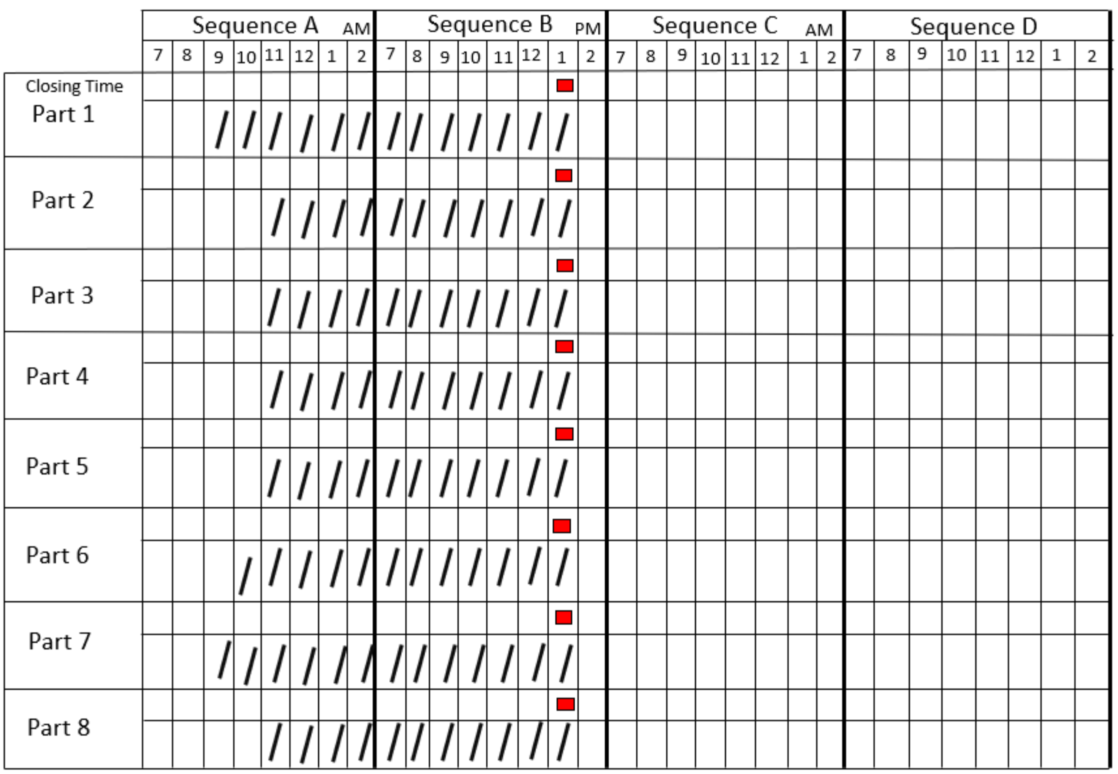

Figure 4-2 FAVP Sorting Board (Bad Example)

For example, let say every part takes 60 minutes to manufacture. If the production of part one is in process, part two will wait for 60 minutes from the first unit of part one to the last unit of part one. Similarly, part eight will wait for 480 minutes to be manufactured. Hence, closing time should be decided as per the sequence chosen by management and production frequency.

4.1.2 Fixed Amount Variable Period (FAVP)

At the beginning of the automotive industry, when ford started production of its cars, they were producing only one model. Hence any change in demand would be absorbed by increasing or decreasing the production of car. However, after the 1950s, the customer starts wanting variation in their vehicles. Not all cars were the same. This gradual increase in the customization of cars increased the variability in parts requirements. This customization gives rise to high mix low volume environment. From customer demand, some parts may occasionally need because of parts variability. Hence the production of these parts every time was not possible. Toyota developed a system in order to meet the customer demand of the small volume parts. It is called a Fixed Amount Variable period (FAVP). Unlike FPVA, this type has a fixed lot size which is determined regardless of the time taken by the customer to pull. In this section, we will discuss the FAVP system in detail.

In the FPVA system, parts are produced in a lot size amount, which was sold during the last period in a predetermined sequence to avoid overproduction. However, with customized parts, customer demand is low, and the customer pull rate varies a lot. So, if the FPVA system is used to determine the lot size. There may be cases when the customer did not pull apart but may pull in the next period. As there are many variations in customization, the lot size of these low volume parts is set fixed. Customers will pull the parts when they want. Just as FPVA, this is also having a sorting board. But the visualization of these boards is different. FPVA board is set vertically whereas the FAVP board is set horizontally. The figure 4-3 shows the representation of the FAVP sorting board.

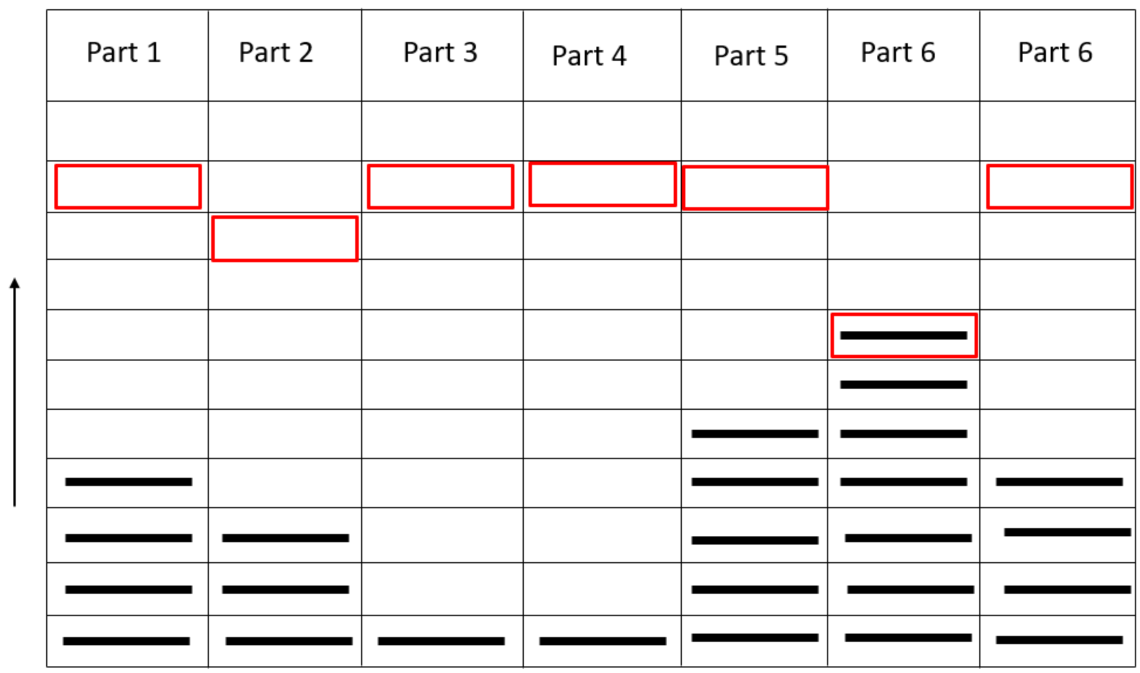

Figure 4-3 FAVP Sorting Board

In contrast with FPVA, in FAVP system lot size is visualized with the help of the red rectangles. Low volume does not require Kanban collection or closing time because the lot size amount is set fixed. Whenever the customer pulls a container or a certain amount, a Kanban is sent to the upstream process. This Kanban goes into the FAVP Production sorting board. When the number of Kanban equals to the Kanban calculated based on the lot size amount, production of low volume part is carried. The lot size of the FAVP part is calculated from the cumulative sum of all FAVP with twice the variation in demand to a total number of the period available in a demanding period. In our case, this demand period is one day hence two shifts. Partial containers are avoided by multiplying and dividing by QPC and rounded up.

$$Lot\ size = \frac{\sum Fixed\ Amount\ Variable\ Part\ demand \cdot 2}{Total\ number\ of\ demand\ period}$$

Besides, management does not decide the sequence of FAVP parts, but the parts are manufactured when Kanban count reaches to lot size determined from the above equation. From the figure 4.3 of FAVP sorting board Kanban count of part 6 is equal to the lot size set. Hence part 6 production signal will go into Kanban post for the stamping department regardless of sequence. However, the production of FAVP parts is set at the end of each period to avoid the fluctuation in the FPVA production sequence. Some free time is available at the end of every period; therefore, FAVP parts are also called free seats or reserved seats. The Fixed-Fixed system is the combination of FAVP production of small volume parts and FPVA production of high-volume parts.

The above methods, FPVA and FAVP, are used for the manufacturing of high and low volume parts. These parts demand may vary depending upon the variability during the production. Hence it is necessary to integrate these two types of manufacturing techniques in order to achieve smooth production flow: Toyota combined FPVA and FAVP techniques giving the name Fixed-Fixed system. It is also a tool that decides the classification of part, whether FPVA or FAVP. The main factors of the Fixed-Fixed system are the Production Quantity chart, production sequence table or Gantt chart and one of the crucial factors, thinking behind the Fixed-Fixed system

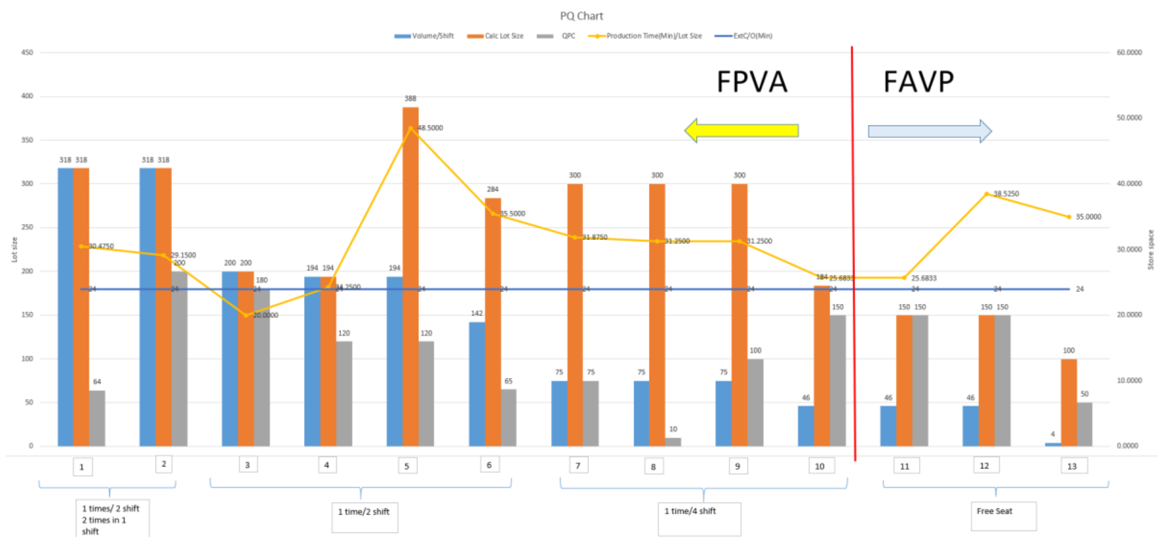

Figure 4-4 Production Quantity Chart

Figure 4-4 depicts the visual representation of the Production Quantity (PQ) chart used in lean benchmark model. PQ chart combines the different parameters of production to analyze the data. The chart shows the lot sizes calculated from equation (1) and (2) comparing it with daily demand or volume, and QPC. The lot sizes and the number of changeovers per period required decide the production frequency of every part. The cycle time of each unit production time gives the production time of the entire lot size. There is a production guideline that the high-volume parts should consume the utmost 90% to 92% of production time to carry the production of low volume part in the sequence. As per the given guideline, parts 1 to 10 are classified as FPVA parts whereas part numbers 11 to 13 are classified as FAVP part or free seat. In the PQ chart, the external changeover time is shown, which acts as constrained to the production time. If the production time of any lot size goes below the external change over time, it will create an idling time for the workforce which is a waste. In the PQ chart, part 3 production time is 20 minutes, but the external changeover takes 24 minutes. Hence, it will create 4 minutes of idling time for the workforce. One of the ways to avoid this situation is to increase the lot size of part 3. Following real-world example will show the working of Fixed-Fixed system

The table 4-1 shows the case which considers a high mix low volume environment where demand is stochastic for high demand part. The cumulative sum of the demand separates high volume parts with low volume parts. This demand is 86% in part 11, hence parts 12 to 20 are FAVP parts. Internal and external changeover times are 10 minutes and 30 minutes for each part, respectively. The operational availability of machines is 95%. The total time available for the production is 450 minutes every shift, and two shifts are available in a day

4.2 Results

Table 4-1 Data for Lean Benchmark Model

Part No	Demand/Shift	Lot Size	Production Frequency	Total Containers
1	790	790	1	16
2	272	543	2	5
3	272	543	2	5
4	272	543	2	4
5	272	543	2	4
6	200	399	2	5
7	200	399	2	2

8	200	798	4	9
9	200	798	4	9
10	200	798	4	8
11	200	798	4	8
12	75	504	6.7	7
13	75	540	7.2	4
14	75	504	6.7	7
15	75	504	6.7	7
16	43	512	11.9	8
17	43	504	11.7	7
18	43	504	11.7	7
19	43	480	11.1	6
20	4	480	137.1	4

Figure 4-5 and 4-6 shows the output, the production quantity chart, and the Gantt chart obtained from the production data. Lot sizes of FPVA parts are calculated from the production frequency of each part, whereas lot sizes of FAVP parts are calculated from the equation discussed earlier. The demand for part 1 is 790 per day; hence, it will be run every shift. On the contrary, part 2-7 demand is comparatively low concerning part one. Idling is avoided by decreasing the frequency of production, resulting in increased lot sizes. The part 8-11 lot sizes have been increased to meet the guideline of FPVA production. For the

FAVP parts, stochastic low demand causes production in a large lot. The low volume parts cannot do small-lot production because of changeover kaizen pace may not match up with production time. Production of FAVP part is shown at the end of every shift

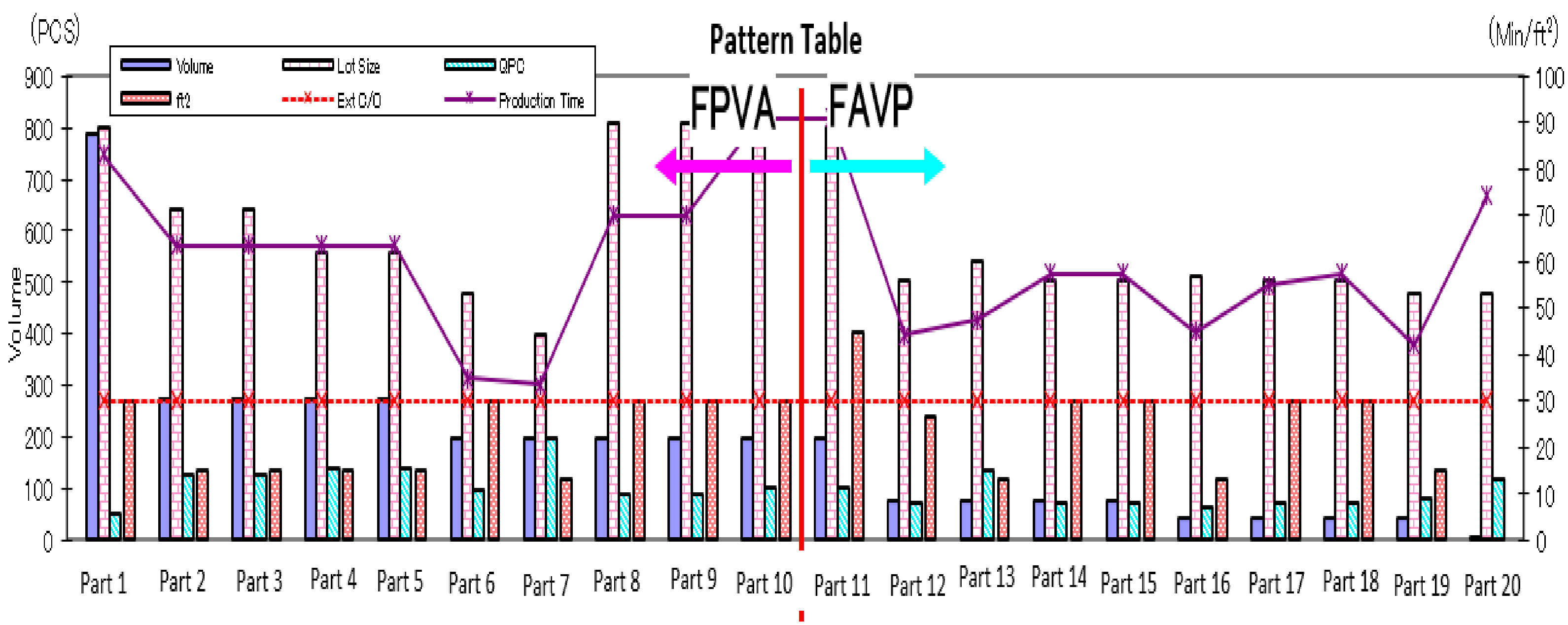

Figure 4-5 PQ Chart for Lean Benchmark model

However, the production of large lots is against the Toyota Production System. The only way to carry the production of part 3 or to reduce the lot size is the Changeover Kaizen.

Changeover Kaizen is a crucial thinking, which is a part of TPS for the pursuit of JIT manufacturing. It is known for continuously reducing changeover time by performing kaizen activities. TPS believes that if a company does not push its people to think deeply, people will not develop. Companies use the correlation of lot size and cost to find the optimal lot size for the lowest inventory holding cost. It may help the companies to find the optimal lowest cost. As in a traditional manufacturing environment, changeover time is assumed constant. [20] discussed the upper and lower bounds of the inventory, where upper bound is the total capacity of warehouse and lower bound is considered total safety stock in the current period making it more unrealistic.

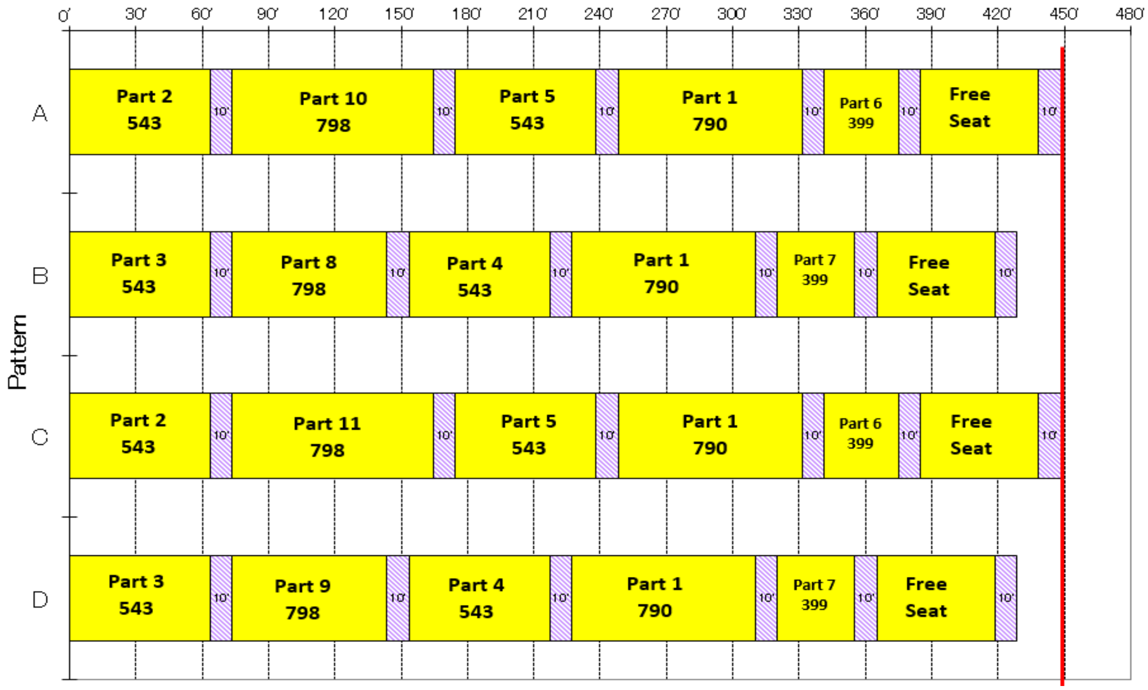

Figure 4-6 Pattern Table for Lean Benchmark Model

However, in real instances, lower bounds are the total amount of time required for a changeover and there should be any upper bound because the goal should be to reduce the total available inventory from the system. Therefore, one of its limitations of traditional manufacturing is that search space remains restricted around the cost line (black dashed line). This cost-oriented thinking will give an optimal lot size from the number of solutions by keeping the search space small.

On the contrary, this thinking opposes JIT manufacturing, focusing more on the cost side; hence stopping the development of people. If a company focuses on reducing the changeover times using the concept of Changeover kaizen, it will increase the number of solutions, giving larger search space. These kaizen activities will open up the possibilities to reduce the inventory and lot size. When people focus on optimizing parameters, it will automatically optimize the cost. Changeover time is directly proportional to changeover cost. From the figure 4-7, it can be seen that when changeover time is reduced, the optimal lot size is shifted towards the left reducing total inventory and total cost from the system.

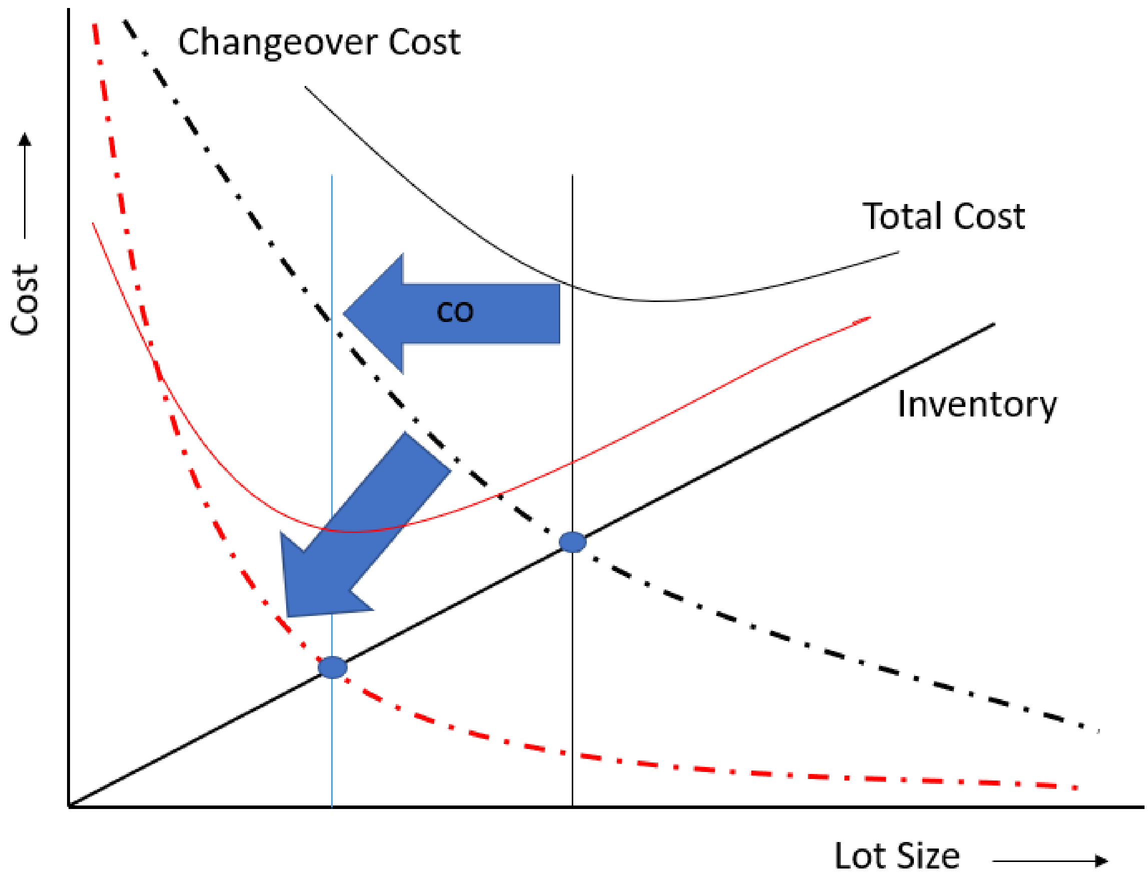

Figure 4-7 Lean Benchmark Thinking[7]

Just in Time manufacturing is one of the essential factors of the Toyota Production System. It is more than just a stock replenishment policy. Just in Time is a way of thinking to improve continuously. In [5], the idea of JIT developed from American supermarkets. During world war two, the company was facing financial problems. It was not efficient to have a large amount of inventory in the system. On the contrary, thinking of Just in time helps companies fulfill customer demand by having a small amount of inventory in the system. Just in manufacturing achieves the highest quality with the shortest lead and at low cost. American manufacturers are implementing Just in Time production to reduce total lead time and make the efficient use of their resources and labor [6].

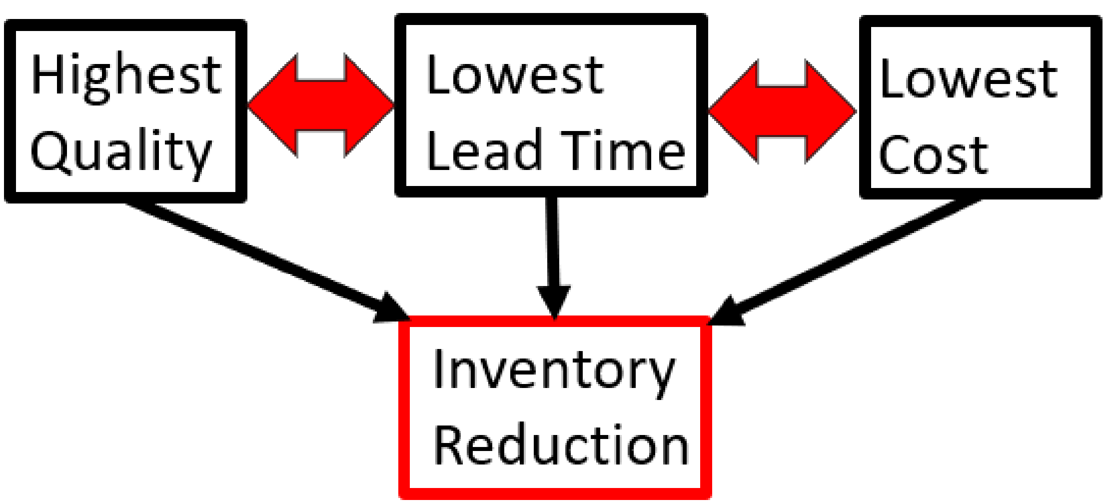

Figure 5-1. Just in Time

However, in practice for the implementation of Just in Time or producing a lower amount of inventory may not be financially efficient because of the changeover parameter. If the production time of a part is less than changeover time causes idling time for the workforce. In lean manufacturing, idling is known as waste; hence the workforce must not be idling. In order to increase the efficiency of the capacity, it is important to increase the number of changeovers for small-lot manufacturing. The pursuit of changeover kaizen can achieve stockless production, which will avoid situations like idling by more frequent changeovers, excess inventory or production cost; hence efforts should be made to reduce the changeover time. Ample research available which optimizes production activities by utilizing changeovers differently. [22, 31-33] discussed the setup carryover operation. Setup carryover is known when at the end of every period *t* part *i* is produced and without changing over this setup state is preserved. In the beginning of the period *t+1* part *i* is produced. [19, 34] use the concept of linked lot sizes where the production quantity of part *i* connected at the end of every period *t* continues at the beginning of the period *t+1*. Setup carryover eliminates the changeover of a part, and linked lot sizes divide the production into two periods [19]. However, both of these production techniques do not reduce the inventory holding cost or size of the production lot as the focus is reducing the cost of production.

One of the factors to optimize the production is to optimize the parameters. As a part of the research, this chapter will discuss in-depth and focusing on optimizing changeover times and production lots for small lot production. One of the ways of optimizing the changeover times is by finding optimal production sequences using changeover compatibility. By utilizing and integrating Lean thinking, this chapter proposes the models that will give optimal sequences; large production lots can be split into a period, resulting in a significant reduction in space utilization, production model for low demand parts.

5.1 Single Machine Model with Multiple Lots and Split Lot Sizes

In traditional lot sizing and scheduling, the function of the objective was to reduce the holding inventory and reduce the total changeover cost. This model, in order to find the optimal lot size and total cost, the model increased the lot size sufficient enough that it will compensate for periods in a row. Hence, then production lot size is increased correspondingly increasing the inventory holding space to avoid the high changeover cost.

5.1.1 Split lot Model using Fixed Period Variable Amount (FPVA)

However, as per Just in Time manufacturing, it is crucial to meet the customer demand on time without any backorders or shortages. In order to make improvements in traditional model results, high volume demands split into two production quantities. The proposed model uses the concept of split lot-sizing as an extension to conventional model which is focused on high volume to medium volume parts. Let $Z_{i,t}$ be the binary variable which will be 1 if the part is setup in the period t: or 0 if not setup. $X1_{i,t}$ and $X2_{i,t}$ are the production quantities which indicates the lot size if split. Equation (C) modified by multiplying it with Operational Availability (OA), $\sum_{i=1}^{N} P_i X_{i,t} + \sum_{i=1}^{N} S_i Z_{i,t} \leq Cap_t OA$.

$$\sum_i Z_{i,t} \leq 1 \qquad \forall t \qquad \text{(G)}$$

$$2 \bullet Z_{i,t} - Z1_{i,t-1} \leq Z_{i,t} \qquad \forall i \text{ and } t \qquad \text{(H)}$$

$$Z_{i,t} + Z1_{i,t-1} \leq 1 \qquad \forall i \text{ and } t \qquad \text{(I)}$$

$$X_{i,t} \cdot Z_{i,t} = X1_{i,t} \cdot Z_{i,t} + X2_{it} \cdot G1_{i,t} \qquad \forall i \text{ and } t \qquad \text{(J)}$$

$$X_{i,t} \cdot Z_{i,t} \leq M \cdot G1_{i,t} \qquad \forall i \text{ and } t \qquad \text{(K)}$$

$$X_{i,t} \cdot P_{i,t} \geq ExtCO \cdot G1_{i,t} \qquad \forall i \text{ and } t \qquad \text{(L)}$$

$$X2_{i,t} \cdot P_{i,t} \geq ExtCO \cdot Z_{i,t+1} \qquad \forall i \text{ and } t \qquad \text{(M)}$$

Equation (G) ensures if the production of part is set up at the beginning of the period *t*. Both equations (H) and (I) balance the flow of inventory, which means if the production is setup for part *i* once in period *t* or if it is required to setup twice in the period *t*. Equations (J) ensures if the product is split, it will be split into two production quantities. If part *i* is not split and produced once in period *t* then $Z1_{i,t}$ becomes 1 if not 0 which is ensured by equation (K). $M \cdot G1_{i,t}$ is a big number. Equations (L) and (M) are external changeover bounds that avoid the idling, which is caused by reducing the production lot size. All production frequencies, whether the full production lot size or split lot sizes, are decided based on the idling. The proposed model tested with the data shown in Table 3-1. Internal changeover is 10 mins and external changeover is 30 mins. The following figure 5-2 shows the pattern table of the production lot splitting of high demand parts.

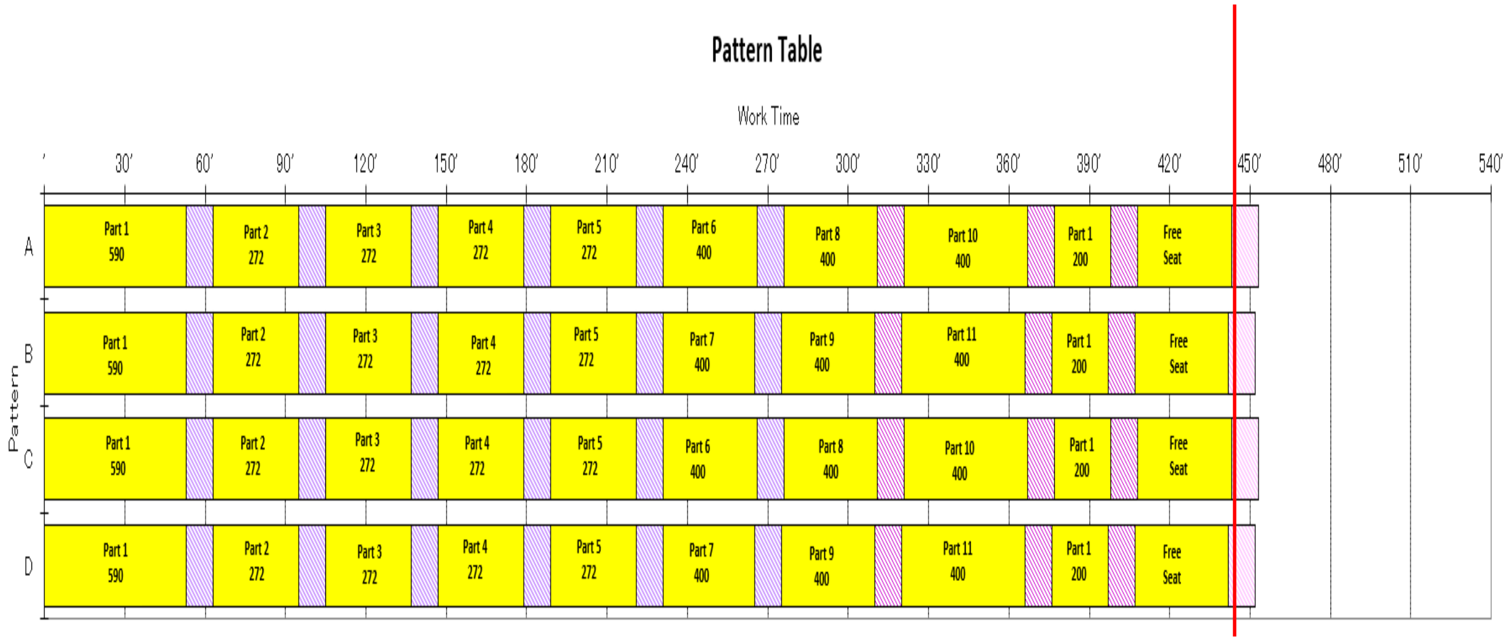

Figure 5-2 High Demand parts Splitting using Lot Splitting Mode

Production of high demand parts should be carried at a particular interval. Splitting this high-demand over the shift reduces the production lot size of one alternate shift part, results in reduced overall inventory holding cost. As a result of a conventional model, the highest production quantity is 790, where production carried every period. Whereas from the high-volume demand split into two production quantities i.e. 590 and 200. At the beginning of every period, production is setup for the production quantity 590. When production is finished, the customer pulls the inventory at a constant pace. Parts consumption is shown by a drop in the red dashed line. Meanwhile, the production of other parts carried.

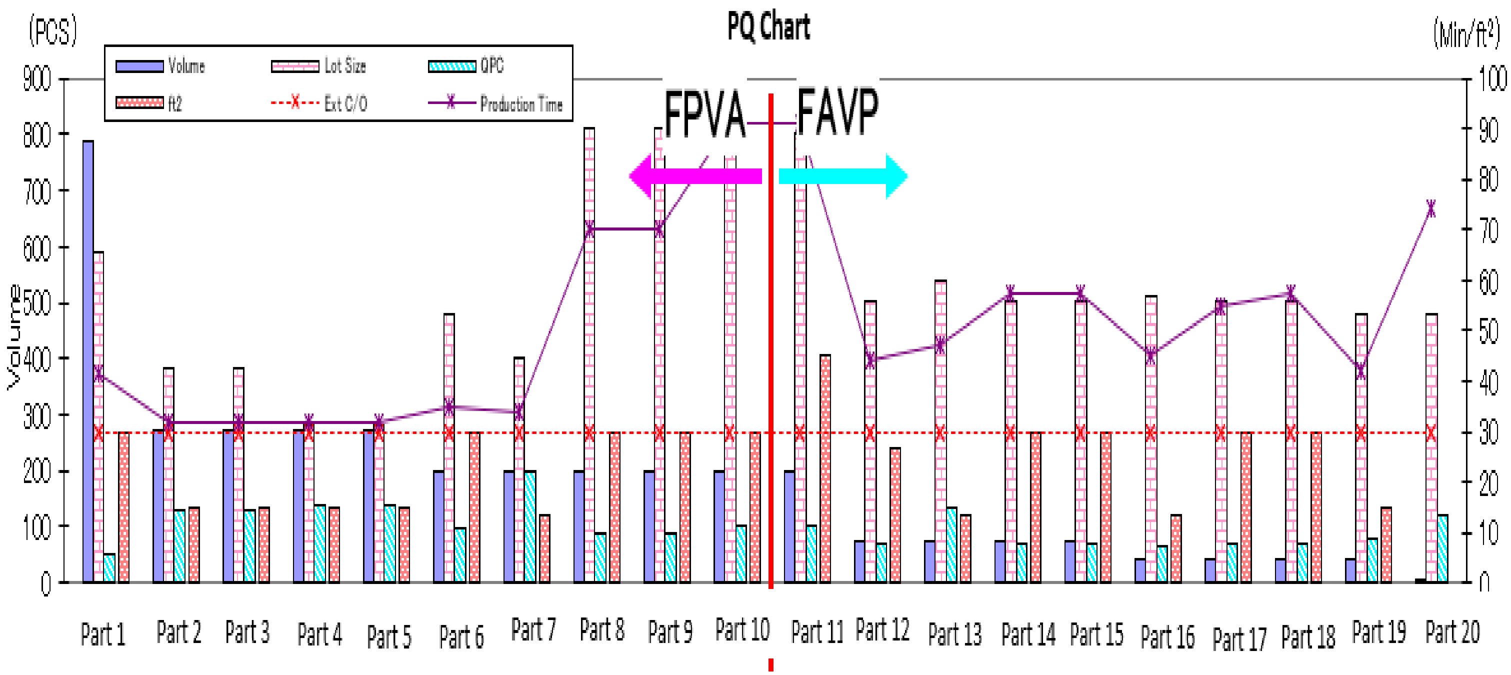

Figure 5-3 Lot Splitting PQ Chart

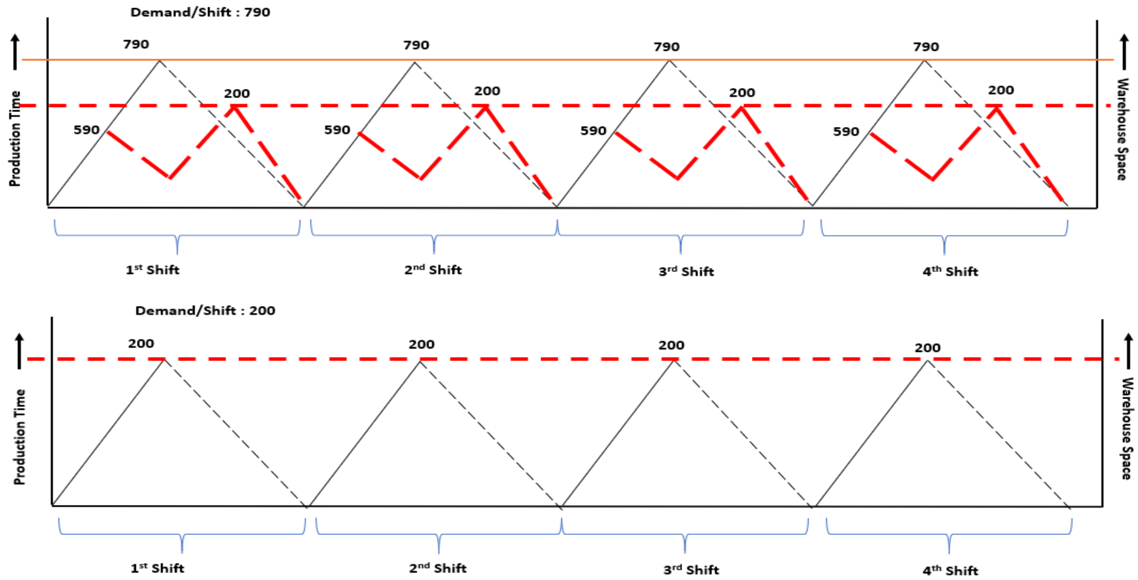

Figure 5-4. Production Lot Splitting Concept for part 1 and 8

Next production quantity 200 should be produced before the production of the free seat or when the inventory reaches the order point.

Also, one of the ways of carrying split lot production is by carrying it immediately by using other mediator products for staging. Figure 5.5 explains the working of split lot using the staging method.

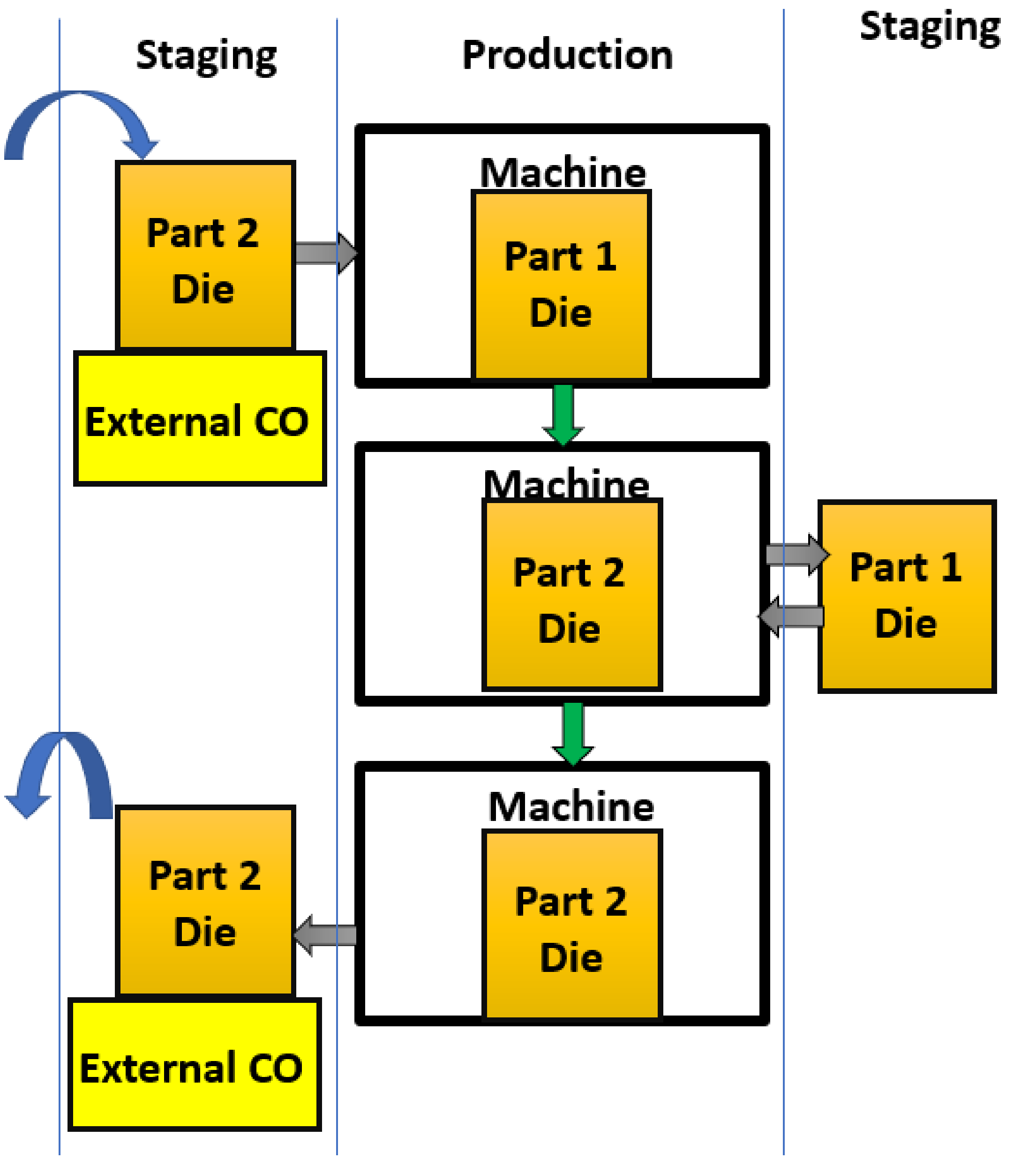

Figure 5-5 Split lot concept

In the staging method, the production of the high demand part split with the help of the second part. For instance, if the part demand is 790 and it is split into two quantities 590 and 200 respectively from the lot-sizing model. During the production of these quantities, the production of the second part with medium demand is carried. Staging is beneficial when there is a need to eliminate external changeover activity. When the staging is undergoing during the first production quantity of high-volume part, external changeover carried to bring the dies of the second part from the dies storage area to the staging area. These dies kept beside the machine for staging. When production stops, internal changeover starts to replace the die of the first part with the second part. At the end of the internal changeover dies of the first part kept beside the machine without carrying external changeover. Production of the second part starts after the internal changeover. Later the production of the second part. Internal changeover carried to replace the dies od first and second parts. External changeover carried to move the dies of the second part to storage area. Benefits of staging are that it eliminates the one external changeover to implement Just in Time.

For the splitting of large production lots, available production capacity may not be sufficient. If the lot splitting occurs labors may have to work overtime to fulfill the production requirements, or sometimes solutions will be infeasible. Hence, the production of medium demand parts should be reduced, producing them frequently. One of the advantages of limiting medium demand production is a reduction in overall inventory holding cost and space. The production rate of FPVA parts reduced significantly, shown in figures 5-2 and 5.3 respectively. Production lot size of parts 8, 9, 10 kept high to maintain productivity by avoiding idling time. However, Production of FAVP parts is high compared to its consumption and demand rate.

5.1.2 New Model using Fixed Period Variable Amount (FAVP)

The fixed period variable amount (FPVA) parts demand varies from high demand to medium demand; hence it may not make a significant impact on the WIP reduction. On the contrary, the fixed amount variable period (FAVP) part demand is low. Large production lots will be inefficient as the inventory will occupy significant amount of space. In addition, withdrawal and required amount of these parts cannot be determined since it depends on the following process. Low demand and consumption nature of FAVP parts increases the excess inventory in the warehouse. For the pursuit of JIT, this is where most WIP reduction should be achieved. In the lean benchmark model as discussed in section 4.3.2, production of low demand parts carried based on predetermined production lot size. Lot sizes are determined from the cumulative sum of all low volume parts to avoid changeover idling. This quantity-oriented approach is one of the reasons for the large production lots. However, the factor which affects the size of the production lots is changeover time to avoid the changeover idling. So, combining the quantity-oriented approach to a time-oriented approach in order to reduce the size of the production lot by avoiding idling. It considers external changeover as boundary condition because external changeover takes more time compared to internal changeover time as it involves prepping the production dies and moving the previous dies to the storage area. If the total production time of total demand is smaller than the external changeover time, then the production lot is decided based on the quantity-based approach. If $P_i \; d_{i,t} > ExtCO$ then, $\frac{ExtCO}{Pi}$. rounding up to the nearest integer gives total production lot size. Else $Roundup(\frac{(P_i \; d_{i,t})}{\boldsymbol{QPC}})\; QPC$. In table 3, lot size indicates the results obtained by this model

.

Table 5-1 Results of Split lot model for FPVA and FAVP

Part No	Demand/Shift	Lot Size	QPC	Roundup Lot Size	Production Frequency	Total Container
1	790	590+200	50	600+200	1	12
2	272	272	128	384	2	3
3	272	272	128	384	2	3
4	272	543	140	560	2	4
5	272	543	140	560	2	4
6	200	400	96	480	2	5
7	200	400	200	400	2	2
8	200	400	90	450	4	5
9	200	400	90	450	4	5
10	200	400	100	400	4	4
11	200	400	100	400	4	4
12	75	360	72	360	4.8	5
13	75	360	135	405	5.4	3
14	75	277	72	288	3.8	4
15	75	277	72	288	3.8	4
16	43	360	64	384	8.9	6
17	43	291	72	360	8.4	5
18	43	277	72	288	6.7	4
19	43	360	80	400	9.3	5
20	4	205	120	240	68.6	2
Total	3550	7633		8081		

However, if the production of the FAVP part carried based on the above model, then there are higher possibilities of creating partial containers. Production of the partial container is assumed to be waste because it occupies more space than the production lot size. Hence to avoid the partial container circumstances model considers QPC size. The production lot size obtained from the model is rounded up to the nearest integer solution after divide and multiplied by the QPC size. The overall solution of this model showed in table 3. Large QPC sizes are one of the biggest causes of large production lots for FAVP parts.

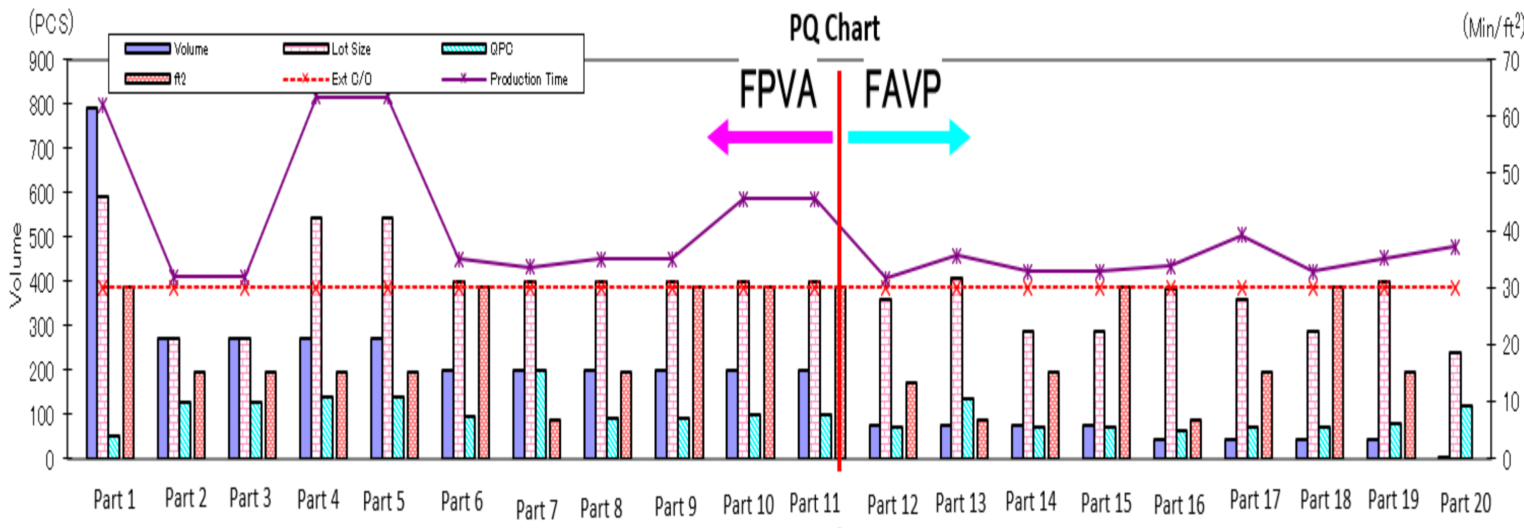

Figure 5-6 PQ Chart for Low Volume Parts in lot splitting

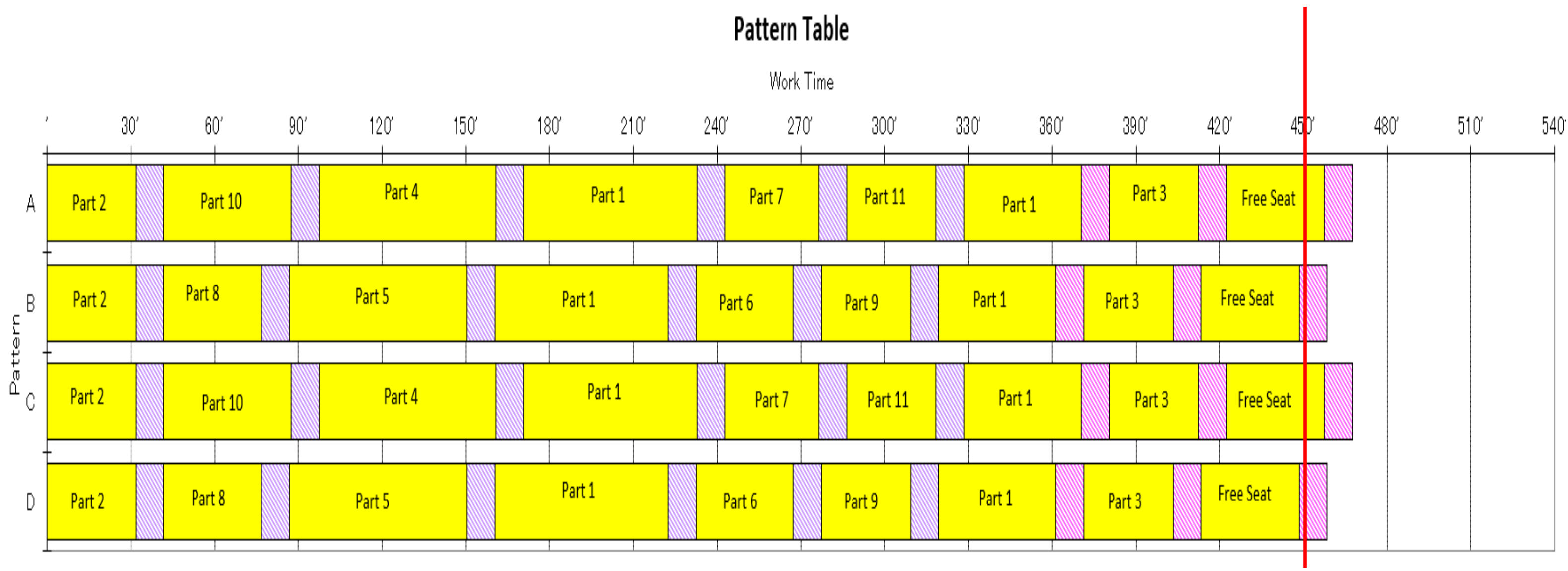

Figure 5-7 Pattern Table for lot splitting in FPVA and FAVP

Results of the FAVP model are visualized using PQ chart and pattern table. The production quantity chart indicates there is no changeover idling time, as all production time is above the external changeover limit. Lot sizes of FAVP parts reduced significantly. From the PQ chart and pattern table, the production of almost three FPVA parts carried frequently. Production of part 1 carried twice in a shift. In addition, production part 2 and part 3 carried every shift. All free seats are almost within reach of available time.

5.1.3 Sequencing decisions

When FPVA and FAVP parts are combined, it becomes difficult to reduce the production lot size after a specific limit since the external changeover limit. Changeover time plays a vital role in utilizing the production capacity. Some researchers discussed that when the demand is low, it is not efficient to produce in frequent manner [35]. However, as discussed, the significance of changeover kaizen to achieve Just in Time manufacturing. One of the ways of changeover kaizen is to find the optimal work sequences in industries like automotive, food or chemical industries. In literature, researchers have used the traveling salesman problem to find the shortest walking sequence. It is achieved by using the third part k or also known as shortcut part which takes less time compared from i to j. $S(j,k) < S(i,j) + S(j,i)$ This concept is known as triangular inequality. More precisely, in mathematics triangular inequality states the sum of the two sides of the triangle is the longest than the third side. Similarly, production sequences should be decided in the manufacturing industries.

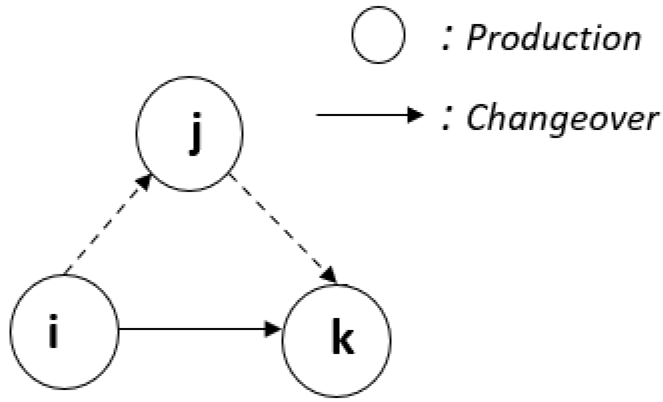

Figure 5-8 Triangular equality [26]

In manufacturing industries, as shown in figure 5-8, the changeover from part *i* to part k takes more time. However, this long changeover avoided by using part *j* because it takes comparatively less time. In this case, triangular equality should not hold. Authors such as [36] discussed the sequence-dependent changeover time in the literature. The objective function is to minimize the time. [37] which denotes minimization of changeover time by $\sum S_{i,j,t} \bullet (L_{i,t} - Z_{i,t})$ if changeover occurs, where $S_{i,j,t}$ is if changeover from part i to part j and $L_{i,t}$ shows the number of the changeover. $\sum L_{i,t} = 2$ which balances the changeover flow from the previous period to current period and ensures the number of changeover so that no production repeats [38]. The working of these models is discussed in figure 5-9. While deciding the production sequence based on the production lot size, changeovers that take the shortest amount of time from the given number of parts are selected first. In the table 5-2, part 1 takes five units compared to the rest of the parts hence selected in the sequence. Similarly, from part 2 next changeover with the lowest units is selected respectively.

Part No.	1.	2.	3.	4.	5.	6.
1.	X	5	6	5	9	8
2.	5	X	5	4	7	6
3.	4	4	X	5	6	3
4.	3	8	3	X	5	4
5.	2	4	3	3	X	3
6.	9	3	4	3	3	X

Figure 5-9 Illustrative table for Scheduling concept

However, during sequencing output may contains instances like sub tour formations. It is a sequence that is formed but connected and separated to the main sequence of the production. One of the examples of the connected sub tour is split lot concept where the production of parts starts and after an interval, production starts for the same part in the same period [26].

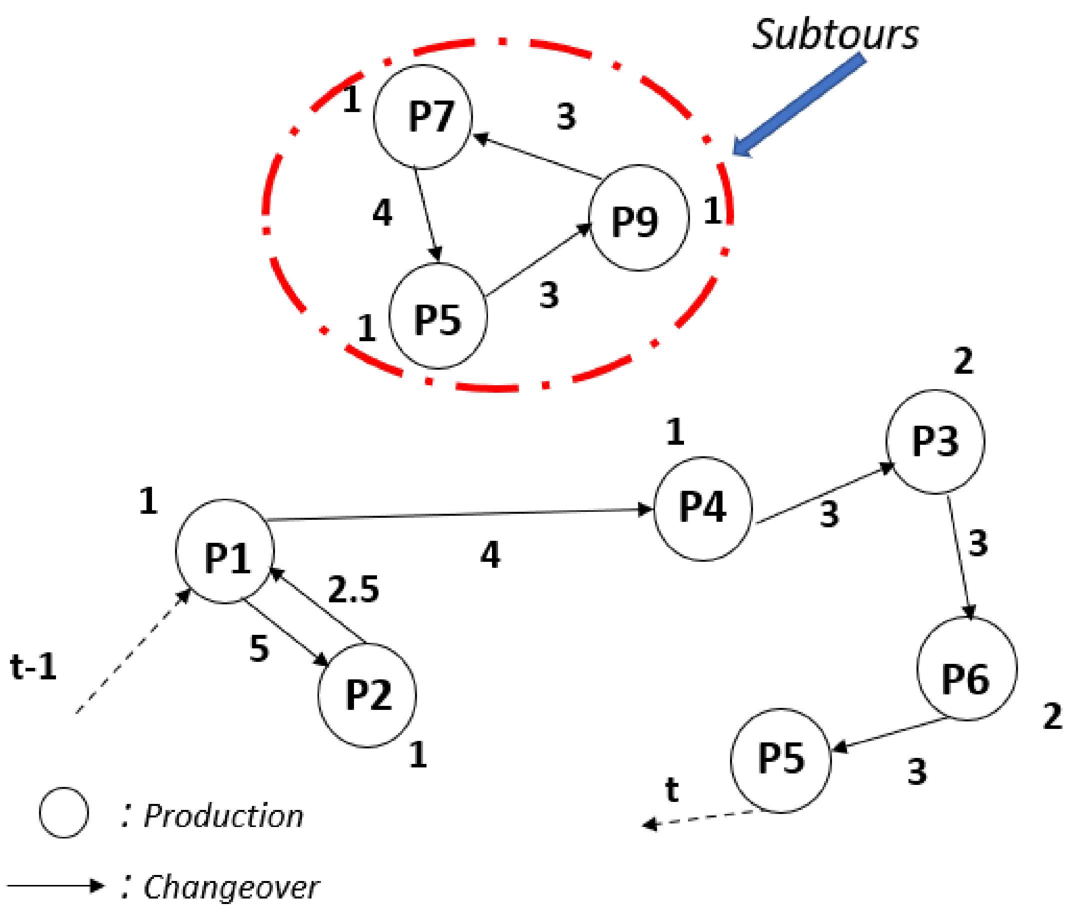

Figure 5-10 Subtour formation

Some subtours are not connected to the main sequence but they are considered as the overall output of solution which may be reasons for infeasible solutions. In figure 5-9 production from P1-P2-P1 is a connected subtour or split lots whereas, P7-P9-P5 is a separated subtour which is part of the solution but not connected to the main sequence hence should be avoided. $\sum N(L_{i,t} - Z_{i,t}) - N \bullet Z_{i,t} \leq N - 1$ is subtour elimination constraint which eliminates the separated subtours from the main sequence [37]. Where N is the total number parts which manufactured on the machine.

5.2 Parallel Machine Concept using the external changeover time limit and Yosedome

After the sequencing decisions, when the changeover time decreases or if zero changeover time achieved, the situation may occur when available production time is equal to the total demand in the period. It will create an idling situation for the workforce.

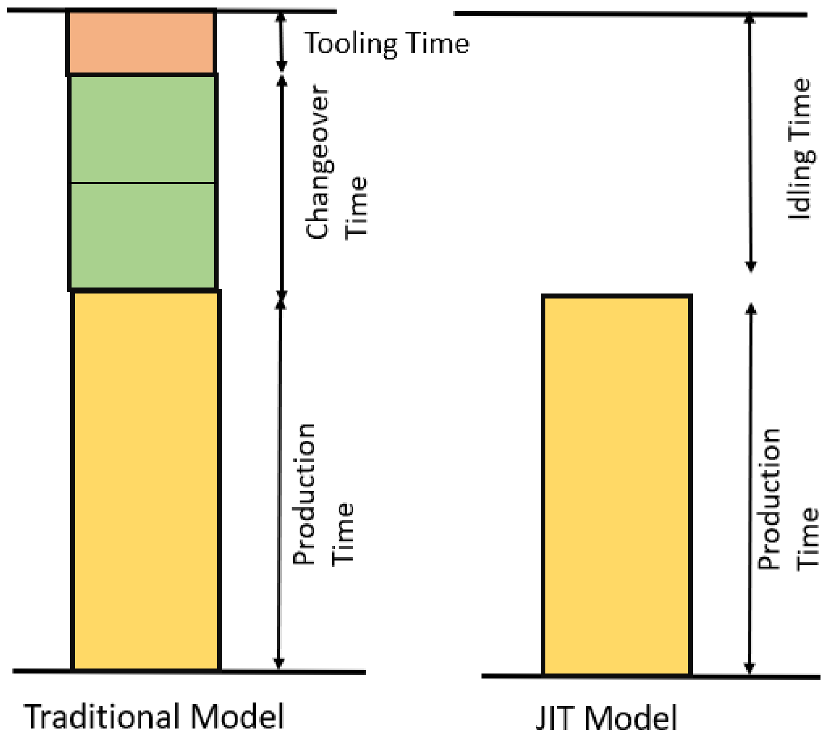

Figure 5-11 Capacity Utilization for Yosedome

From the left diagram in figure 5-10 shows, when changeover times are long and production time is equal to the time taken for production of overall demand. In the right diagram, when zero changeover time achieved or reduced, idling time increases. As per traditional modeling due to longer changeovers and large production lots a situation where production capacity may exceed. While contradicting the traditional model, JIT has shorter changeover time and small production lots; hence it may create situation like fewer labor hours. In order to avoid these unnecessary idling, the lean benchmark model uses a concept known as Yosedome method. It is defined by when the idling time increases among the multiple machines, the productivity of the machines and workforce is increased by either combining the workload or reducing the machine capacity. Moreover, when the workload on machines reduces, combine the production on less number of the machine so that other machines will not be running [25]. For example, in situations when two machines are running with full production capacity for the first month but after the 6-month demand for parts decreases due to some reasons. Hence now production of every machine decreased resulting in the idling of the workforce. In solution, the workload of these two machines can be combined with the production capacity of six shifts available. Four shifts on the first machine and two shifts on the second machine, respectively. The advantages of this method are providing full-time work for the labor. It increases the productivity of the workforce. The use of Yosedome in manufacturing helps to prevent large lot manufacturing.

CHAPTER 6. CONCLUSION AND FUTURE WORK

6.1 Conclusion

Lot sizing and scheduling is a vital factor in the production environment. The thesis consists of two industry lot-sizing models and a proposed model. First conventional model, which considers large lot production. Second, the lean benchmark model, which integrates the thinking of changeover kaizen and makes improvements toward small-lot production. One of the advantages of the lean benchmark model is that it considers HMLV environment. Lot sizing and scheduling follow the pattern which enables the company to be consistent in the production without disruption. However, both models have limitations. The conventional model is not based on HMLV environment and external changeover; hence it creates many idling situations for low demand. In contrast, some drawbacks of the lean model is that in the low demand system, the lot sizing of low demand system is quantity oriented which resulted in large lots for FAVP.

Based on the thinking of small-lot production from the lean benchmark model, this thesis focuses on two critical phenomena, production of small lots using split lot method and pursuit of changeover kaizen to achieve JIT. A model proposed for the minimization of inventory of low demand parts. The comparison of models and the conclusion of the thesis is given below.

Table 6-1 Lot Size Comparison for three models

Part No	Lot Size	Lean Benchmark Model	Split Lot Model
1	790	790	590+200
2	543	543	272
3	543	543	272
4	543	543	543
5	543	543	543
6	400	399	400
7	400	399	400
8	400	798	400
9	400	798	400
10	400	798	400
11	400	798	400
12	300	504	360
13	300	540	405
14	300	504	288
15	300	504	288
16	172	512	384
17	172	504	360
18	172	504	288
19	172	480	400
20		480	240

Table 6-1 shows a comparison of all three models. The lot sizes of the first five parts in the conventional and lean benchmark model are the same whereas it reduced to half in the split lot model. In the conventional model, the lot sizes of all remaining parts are relatively less. However, due to the drawback of not considering the HMLV environment and external changeover, in this model, low volume part lot sizes are small. These lot sizes created idling time for the workforce. It is one of the vital factors for space utilized by this model is relatively low. In Split lot model compared to the lean benchmark, the model had small lot sizes in both FAVP and FPVA

In table 6-2 and table 6-3 result of all three models are compared in terms of total inventory. First, in the FPVA table, the cumulative sum of lot sizes and the space utilized of the conventional model are 7860, and the space utilized is 189.71 ft^2. Since it creates idling time and does not consider external changeover. Hence this model may not be comparable to other models.

In contrast, in the lean benchmark model, a specific production pattern followed. The model starts the production of low demand parts after the end of production of high demand parts, based on when Kanban reaches the predetermined lot size and external changeover

Table 6-2 FPVA Space Utilization

Model	Total Containers	∑ Lot sizes	Total area covered by Footprints (ft^2)
Conventional (No HMLV)	89	7860	189.71
Lean Benchmark	75	6952	171.42
Split lot Model (FPVA)	51	4620	115.74

The results obtained from the proposed model for both the FPVA and FAVP systems show significant improvements. In FPVA and FAVP, total footprints of the split model are 51 and 38, respectively, whereas the lean benchmark model has 75 and 57. The low number of containers is the outcome of a lot size reduction achieved by the model. The small production lot sizes resulted in reduced space utilization from 171.42 ft^2 to 115.7 ft^2.

Table 6-3 FAVP Space Utilization

Model	Total Containers	∑ Lot sizes	The total area covered by Footprints (ft^2)
Conventional	-	-	-
Lean Benchmark	57	4532	103.53

Split lot Model (FAVP)	38	3013	68

Besides, lot sizes of FAVP parts reduce almost by 20% and space in the warehouse reduced from 103.53 ft^2 to 68 ft^2.

The next improvements that should be focused are changeover time reduction which is the most prominent factor in achieving JIT. If people are assuming changeover time is fixed, then they are not being developed. The company should force its people to think deeply

Table 6-4 If 5 mins External Changeover

Model	Total Containers	∑ Lot sizes
Split lot Model (FPVA)	27	1734
Split lot Model (FAVP)	17	884

about the improvements. From table 6-4, If the changeover kaizen reduces the time of the external and internal changeover to 5 min, then containers and space utilization reduces significantly. The thesis discussed one of the ways of changeover reduction model by proper sequencing decisions using changeover compatibility.

The production lot sizes can further be reduced, but there is a requirement in the lean model that all lot sizes should be rounded up to the nearest integer value to avoid partial containers. One of the reasons for partial containers is that high QPC values. If there is a pursuit for small lot manufacturing, then the higher QPC value will be another constraint in the future which will become an obstacle for JIT. Figure 6-1 showed the correlation between lot size and QPC value.

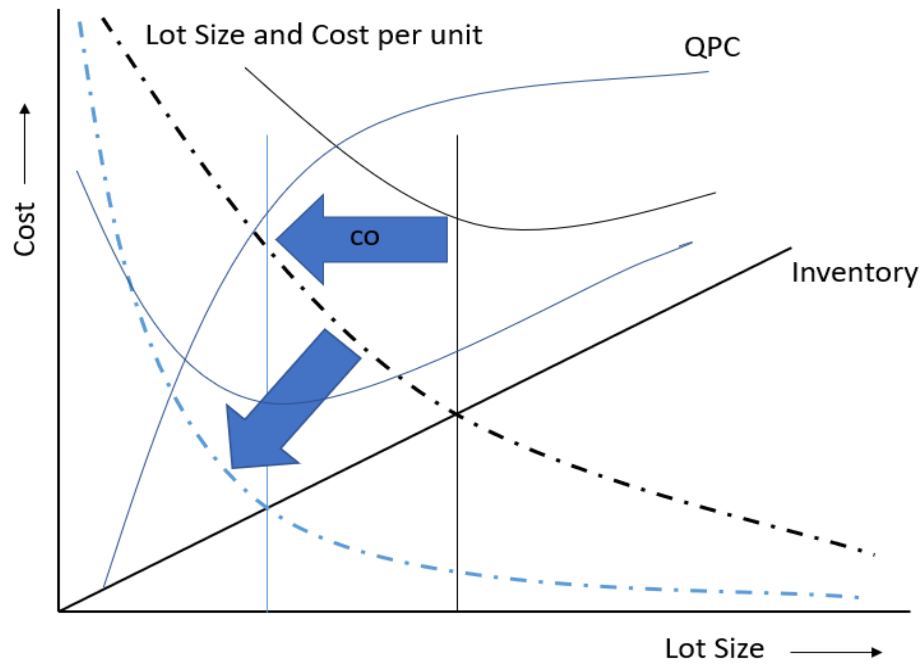

Figure 6-1 Relation of QPC and Lot Size

The main conclusions of this thesis are:

1. Conventional model do not consider high mix low volume environment and external changeover hence the model is less reliable and resulted in idling time which was not indicated in the model
2. Changeover time is a crucial factor in deciding the lot sizes and the first reason for the large production lots. It is reduced by finding optimal sequences and changeover kaizen activities

3. When production lot sizes are decreased, production hours reduce. It creates idling time for the workforce, hence lot sizes are increased. It is avoided by frequent changeovers.
4. In a low demand environment, the time-oriented approach can avoid idling caused by external changeovers. If low demand production carried frequently, it will reduce the lot sizes of FPVA parts since it also depends upon the FAVP production to avoid idling.
5. Large QPC sizes are one of the reasons for increased inventory. The decreased lot sizes create partial containers. These are avoided by rounding up the lot size to the nearest integer, thus increases overall inventory.

6.2 Future Work

This thesis addresses the key factors which affect the lot sizes. However, it also opens and discusses several avenues that require future research and analysis, especially the detailed lot sizing of multiple machines using the Yosedome method. The thesis presents the analysis of three models with a single machine in the HMLV environment. A similar understanding of multiple machines with HMLV environment and sequencing decisions needs to be undertaken

APPENDICES

Cycle Time for some parts

Part 1	6 sec
2	6.7
3	6.7
4	6.7
6	5
10	6.5
12	5
14	6.5

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