

**Capacity Utilization of a Single Machine Multi
Product Case in Make to Order Manufacturing
Organization - A Case Study**

A Dissertation

Submitted in Partial Fulfillment of the Requirements
for the Degree of

Master of Engineering
in
Production Engineering

by

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July, 2014

CERTIFICATE

I hereby declare that the thesis entitled **Capacity Utilization of a Single Machine Multi Product Case in Make to Order Manufacturing Organization - A Case Study** is an authentic record of my study carried out as requirements for the award of the degree of **Master of Engineering in Production Engineering** at **Thapar University, Patiala** under the supervision of **Mr. Supreet Bhullar**, Associate Professor, Mechanical Engineering Department, Thapar University, Patiala during July, 2013 to July, 2014. The matter embodied in this report has not been submitted in partial or full to any other university or institute for the award of any degree.

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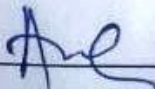
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It is certified that the above statement made by the student is correct to the best of my knowledge and belief.



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DEDICATED TO
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Acknowledgement

With deep sense of gratitude I express my sincere thanks to my guide **Mr. Supreet Bhullar**, Associate Professor for their valuable guidance, proper advice and constant encouragement during the period of work which help in completing my study.

I also feel very much obliged to **Dr. Ajay Batish**, Professor and Head of Mechanical Engineering Department.

My very special thanks go to all my family members. Their love, affection and patience made this work possible and the blessings and encouragement of my beloved parents greatly helped me in carrying out this research work.

Finally, but most importantly, I thank Almighty God, my Lord for giving me the willpower and strength to make it this far when I didn't see a light.



SHANKEY

Abstract

The purpose of the study was to determine the capacity utilization for a single machine multiple product case in make to order manufacturing organization. Firstly, the problem was identified in the manufacturing organization of Ludhiana. The problem was reported in the CNC department as the organization was not able to fulfill the orders by their due dates. The mathematical model proposed by [Kumru, 2011] was found to be the appropriate for solving this type of problem. Using information of the pre-requisites of model application, the data was collected. The data collected was analyzed with the mathematical model. The results not only validated the model but also showed that the utilization of the machine was found less than as per the specifications of the machine.

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Acronyms

MTO	Make to Order
MTS	Make to Stock
ATO	Assemble to Order
AH	Annualized Hours
WIP	Work in Process
BTO	Build to Order
CRP	Capacity Requirement Planning
PEDD	Pre-emptive Earliest Due Date
LP	Linear Programming
CU	Capacity Utilization
CG	Capacity Gap
CNC	Computer Numeric Control

CHAPTER – 1

Introduction

1.1 Introduction

This chapter put forward the introduction of capacity and capacity planning. The strategies and the objectives of capacity planning have been discussed in this chapter. It explains how capacity planning and capacity utilization benefit the industries.

1.2 Capacity

The capacity can be explained in the terms of the number of units produced per period in the manufacturing unit. Sometimes it is more complicated for the organizations who are manufacturing multiple products because in such conditions the capacity is given as man-hours or machine-hours. The relation between the capacity and the output is shown in the Fig.1.1.

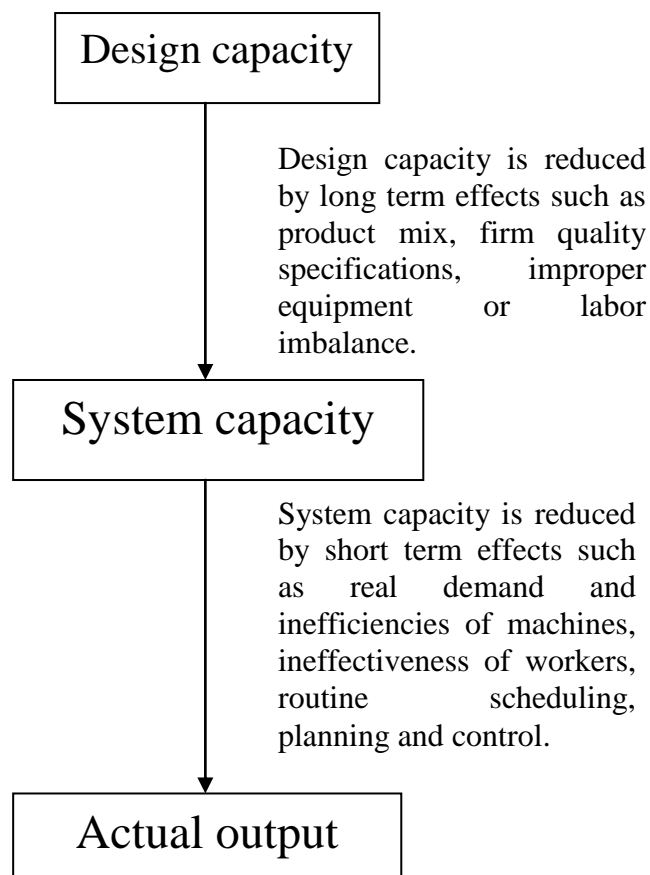


Figure 1.1: Capacity and output relationship [Kumar and Suresh, 2009]

- **Design Capacity**

Design capacity of a facility or organization is the premeditated rate of output of products or services under the normal conditions or at full-size operating conditions. The Organisation does not bother to plan for enough normal capacity so that they can assure all their urgent demands. Designing for a least demand would give higher utilisation but may result in lower service levels and disappointment of clients because of insufficient capacity. The management strategy for meeting the future demand should be replicated by the design capacity [Kumar and Suresh, 2009].

- **System Capacity**

System capacity is the maximum output of a product or product mix that a system of workers and machines can produce as an included total. System capacity is less than or may be equal to the design capacity because of the limitation of product mix, breakdowns and the quality specification. The actual capacity is even less than that of design and system capacity as many factors affect the output such as actual demand, unauthorised absenteeism and the downtime because of the machine or equipment failure. Because of long-range irrepressible factors the system capacity is less than the design capacity. The actual output is also reduced because of short-term effects. These short term effects are breakdown of equipment, inefficiency of labour. The system efficiency is usually expressed as ratio of actual output to the effective capacity [Kumar and Suresh, 2009].

There are two measures of system effectiveness:

- Efficiency
- Utilization

$$\text{Efficiency} = \frac{\text{Actual output}}{\text{Effective capacity}}$$

$$\text{Utilization} = \frac{\text{Actual output}}{\text{Design capacity}}$$

1.2.1 Capacity Constraints

- Many organisations deliberately operate lower than their maximum processing capacity either because of insufficient demand to completely fill their capacity or as an intentional policy so that they can rapidly react or respond to each new order.
- However, organisations find themselves with some parts of their operation operating below their capacity level while other parts are operating at their capacity maximum limit.
- It is the parts of the operation that are operating at their upper capacity limit which act as the capacity constraints for the whole operation.
- Unless extra resources are provided to increase the capacity of the micro operation it would constrain the capacity of all other operations.

1.3 Capacity Planning

The issue of managing capacity is neither new nor exceptional for manufacturing firms. Capacity and capacity related concepts, such as capacity determination, Capacity utilization, capacity planning, and capacity management, have been discussed widely in the past and still take part in current studies because of their considerable impact on resource management. Therefore, prior to concentrating on capacity determination and utilization, it would be necessary to clarify these concepts [Kumru, 2011]. The capability of a worker, work centre, organization or machine to generate yield per period is termed as capacity. The concept of plant capacity means the highest output that can be produced per unit of time with present plant and equipment but the ease of use of variable factors of production should not be limited. [Johansen, 1968]

The capacity planning also includes the capacitated facility location network design and capacity extension decisions. The first two are associated for selecting the time agenda for the installation of the resources at different locations to minimize the total discounted costs specified over a planning horizon for meeting the customer demands. [Erlenkotter, 1981]

The capacity planning depends upon two main decisions. The first decision is the expansion of the existing capacity. These decisions identify the technologies that are required for the manufacturing and their capacity levels that have to be actually expanded or outsourced through the planning period. The second decision is the capacity configuration

decision which determines that which type of facility has to be configured with which type of technology mix. [Karabuk and Wu, 2003]

The capacity planning should also take into consideration that how much capacity and what type of capacity should be installed so that it could have a major impact on all other production planning issues. [Lin et al., 2010]

Capacity planning plays an important role for the infrastructure and employment planning. Capacity planning also helps to identify and reduce inefficiencies related with either underutilization of resources or unmet customer demand. It helps to provide adequate service levels in a cost-efficient manner. It ensures that all infrastructure components are competent of performing all required functions, that component will perform as capably as possible, and contain reasonable growth without being excessively wasteful.

The definition of capacity should include the volume as well as the time over which the capacity is available. Thus the capacity may be defined as a measure of ability of organization to provide the customers with goods and the service in the requested quantity and within the time requested. Capacity decisions must be taken after identifying the capacity necessities and generate the alternative plans. Then the evaluation of the alternative plans that are generated should be done. The purpose of capacity planning is to give satisfactory service levels to users in a cost-effective way. Capacity planning and control is done for setting the effective capacity of the operation so that it can easily and quickly respond to the demands placed upon it. This is basically used for deciding that how the operation should react to fluctuations in demand. In case of stable demand it is very simple and easy to plan the capacity. But in real conditions the demand will hardly be steady. The fluctuations in the demand cause the problems in the fulfilment of the customer demand because of the procurement of resources. The Capacity is basically the rate of production ability of an organization. Capacity is usually articulated as the volume of output over a period of time. Capacity decisions are strategic in nature.

The capacity issues are taken into consideration by the production managers because of the following reasons.

- Adequate capacity is necessary to satisfy the consumers demand with in time.
- The cost effectiveness of operations is also affected by the capacity.
- Capacity affects the scheduling system.
- Investment is required for the capacity creation.

When an organisation decides to produce more or new products, capacity planning is the first step that an organisation should take. [Kumar and Suresh, 2009]

The process of capacity planning is shown in Fig. 1.2

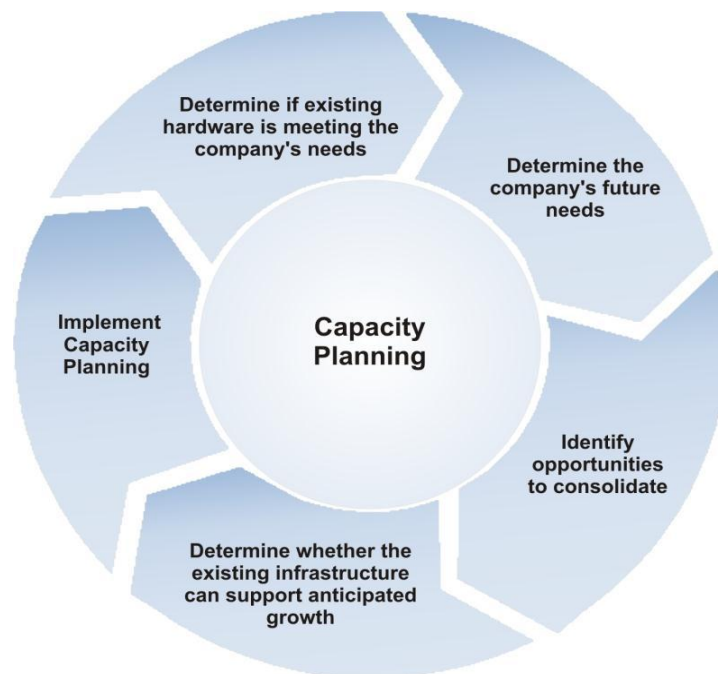


Figure 1.2 Process of capacity planning
[<http://www.edaratgroup.com/ar/Page/capacity-planning>]

1.3.1 Steps in Capacity Planning Process

The steps for capacity planning are as follows:

- Calculate approximately potential capacity needs.
- Estimate the present capacity and try to recognize gaps.
- Categorize the other options for meeting the necessities or needs.
- Economic analysis should be done for each options categorized for meeting the need.
- Evaluate important qualitative problems for each option.

- Select the option that seems to be finest in the long period.
- Execute the selected option.
- Observe the results.

1.3.2 Factors Affecting Capacity Planning

The following factors affect the capacity planning:

- The layout of plant and the location of plant.
- Product line or matrix
- The technology used for the production.
- Human assets (job design, compensation)
- Quality assurance and the routine scheduling used for the operations.
- The guidelines or the policy factors and the safety regulations given by the management.

1.3.3 Classification of Capacity Planning

The long-term and the short-term capacity requirements of an organization are concerned with the capacity planning and determining the customer requirements. The capacity planning decisions depend upon the consumer requirements and this is combined with the individual, material and economic funds of the organization. There are two strategies to calculate the capacity: (1) Long-term capacity decisions (2) Short-term capacity decisions.

- **Long-term capacity decisions**

Long term capacity decisions are decisions that are usually taken by the top management to build up new product lines, develop the present facilities, and create or phase out production plants which can have a significant impact on capacity. These decisions also take a long time for the implementation – often more than one year. Long-term capacity planning is done to accommodate the significant changes that can influence the overall output of the organization in the longer term. The major responsibilities of the top management are to assess the market environment and implement the long-term capacity plans in an orderly and effective ways. Long-term capacity requirements depend upon the marketing tactics, product improvement and life-cycle of the product. The Long-range capacity decisions are affected by the following parameters:

- **Multiple products:** The manufacturing organizations produce multiple products to increase the profit and try to reduce the risk of failure. The manufacturing of the multiple products help the capacity planners to perform a better job. It is easy to schedule the

products that are in different stages of their life cycles in order to get maximum capacity utilization.

- **Phasing in capacity:** The rate of obsolescence is high in the high technology industries. The industries are keen to bring the products into the market quickly. But the construction of the facility will take a long time and that much time is not available so as to compete in the market. Therefore the solution to this type of problem is the phase in capacity on the regular criteria. Thus, phasing in capacity is an effective method to capitalize on technical start.
- **Phasing out capacity:** The manufacturing facilities that are outdated cause too much plant closing and down time. These closings not only affect the fixed costs of the industry but also it affects the humans concerned with the facility. Thus, the phasing out is done with humanistic way so that it would not affect the community. This strategy makes the options of the substitute provisions for men like shifting them to new jobs or to new locations, compensating the employees, etc. [Kumar and Suresh, 2009]
- **Short term capacity decisions**

In the shorter term planning, the capacity involves the variations in demand caused by cyclic and financial factors. Short-term capacity planning is associated with responding to relatively immediate deviations in demand. Manufacturing and service-oriented firms adjust to the ups and downs of demand in many different ways. The issues of scheduling of the shifts of labor, and balancing the resources capacities are concerned with the short term capacity planning decisions. The objective of short-term capacity planning is to handle the unanticipated shifts in demand in the way that it can be efficiently economic. The time period for short-term planning can only a few days and can run as long as six months. Short-term capacity can be customized by operating the industry either more or less powerfully than usual. The short-term capacity can be changed in labor intensive processes by lying off or appointing the people or by giving the workers overtime. The capacity changing strategies also depend upon the factor that how long the product has to be stored in the inventory.

The short-term capacity strategies are:

- **Inventories:** Store the finished products during the floppy period and sale the products during the peak periods.
- **Backlog:** The eager customers are requested to wait for their order during the peak periods and their orders are satisfied after the peak demand period.

- **Employment level (hiring or firing):** During the crest demand period hire the extra employees and fire or adjust the employees as the demand decreases.
- **Employee training:** The training should be given to the employees to make them multi skilled so that they can be rotated in any department at any time. This type of approach helps as an option for hiring employees.
- **Subcontracting:** During high demand periods, subcontracting should be done and the capacity of the other organization should be hired provisionally to produce the element parts or products.
- **Process design:** Redesign the job and change the contents of the job.[Kumar and Suresh, 2009]

1.3.4 Strategies of Capacity Planning

The broad strategies of capacity planning are lead strategy, lag strategy and average capacity strategy.

- **Lead strategy:** In this strategy the capacity is added in the expectation of the increase in the demand. The goal of this strategy is to attract the customers from the competitors in the market by providing them with improved service level and also by reducing the lead time. This is an aggressive strategy but there is always risk of excessive inventory associated with this kind of approach. The capacity lead strategy is shown in Fig. 1.3.

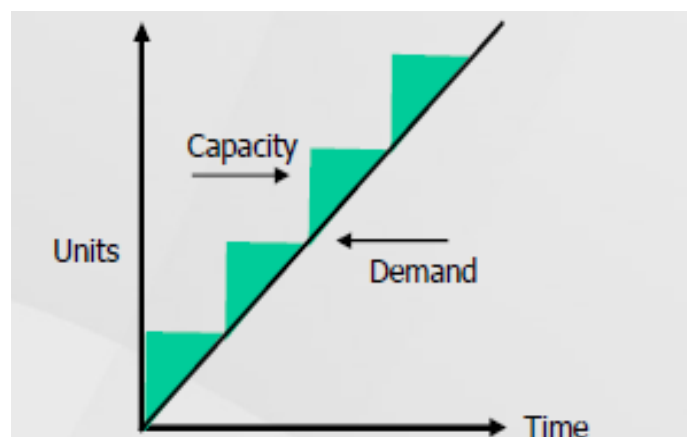


Figure 1.3: Capacity lead strategy [Russell and Taylor, 2009]

- **Lag strategy:** In this strategy the capacity is added due to increase in demand only after the organization is running at full capacity or beyond the full capacity. This is a conservative strategy. It helps in reducing the cost of excessive inventory but the risk of

customer loss is associated with this strategy. The capacity lag strategy is shown in Fig. 1.4.

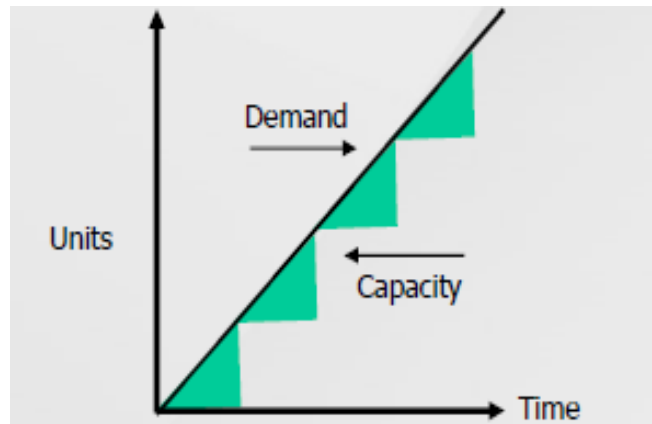


Figure 1.4: Capacity lag strategy [Russell and Taylor, 2009]

- **Average capacity strategy:** In this strategy capacity is added so that it can meet the average probable demand. This is a sensible strategy. In this strategy half of the period the capacity leads the demand and half of the time the capacity lags the demand. In this the capacity managers are confident that at least a little fraction of the output will be sold and suffer some periods of excessive demand. The average capacity strategy is shown in Fig. 1.5.

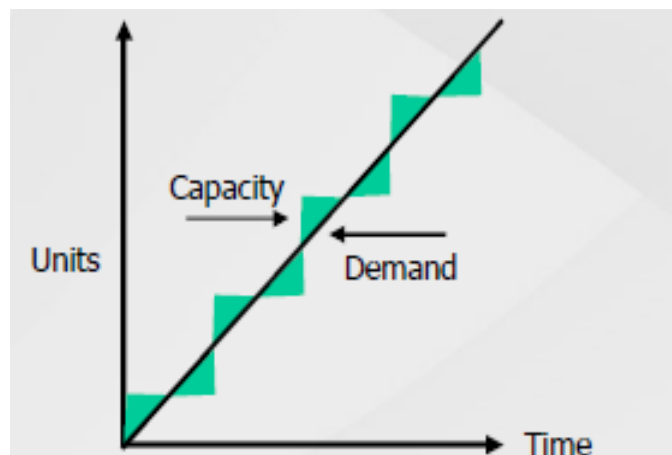


Figure 1.5: Average capacity strategy [Russell and Taylor, 2009]

1.3.5 Determinants of Capacity Planning

The determinants of capacity planning are as follows:

- **Facilities:** While designing of facilities the key factors are the size and provision for expansions and the other facility factors such as location factors, cost of transportation, and distance from the market, labour supply, and energy sources should also be considered. The layout of the facility can decide how effortlessly the work can be performed in the organization.
- **Product and Service Factors:** The output of the organization should be uniform to create more opportunities for standardization of methods and materials. This would lead to better capacity.
- **Process Factors:** The quantity capability and the output quality are the important determinants of capacity. The output rate would decrease if the quality of the product is not satisfying. This would increase the rework and the quality inspection activities and the productivity would deteriorate. The improved process factors can result in the increased capacity. Another process factor that has to be considered is the time that takes to change over equipment settings for different products or services.
- **Human Factors:** The skills and the experience of the employee affect the potential as well as the actual output of the organization. The training should be given to the workers and also motivation should be given to them to improve their skills. Employee motivation, training and labour turnover all these would affect the output rate.
- **Policy Factors:** Management guidelines or policy can also affect capacity whether the management permitting or not permitting the capacity options such as overtime, second or third shifts etc.
- **Operational Factors:** When an organization has differences in apparatus capabilities among different pieces of equipment and the differences in job requirements then the scheduling problems may occur. The inventory stock, purchasing of the requirement, quality inspection and the late deliveries are the other areas that also impact the effective capacity.
- **Supply Chain Factors:** The impact of the change on the suppliers, transportation and the distributors has to be considered. The issue is that can these elements of the supply chain be able to control the increase, if the capacity of the organization is increased. Also the impact on the loss of business of these elements of supply chain has to be considered if capacity has to be decreased.
- **External Factors:** inferior quality and performance standards could hurdle the options for the management to increase the capacity.

1.3.6 Objectives of Capacity Planning

The objectives of capacity planning are:

- Capacity planning can enhance the speed of response to customer demand either by the build-up of inventories or by adding the capacity to avoid the queuing.
- Capacity planning also affects the dependability of supply. As close the demand levels are to capacity dependability of the supply is more affected. The nearer demand reaches to the operations capacity upper limit, the less capable it is to deal with with any unpredicted fluctuations.
- It helps in enhancing the flexibility especially the volume flexibility of the capacity. If demand and capacity are not balanced, the operation system will not be able to react or fulfill any unexpected increases in demand.
- Capacity planning is done to satisfy the future requirements or demands of the customer and also avoid the shortage of the product.
- Capacity planning is done to avoid the extra cost because of the under utilization of capacity. Also the over capacity is kept minimum.
- Capacity planning is done to attain a much lower break-even volume by keeping the initial investment at lower point.
- Proper capacity planning is essential because the investments in increase of the capacity of the facility are long-standing & cannot be inverted easily.

1.3.7 Issues related with Capacity Planning

[Schiesser, 2004] described some of the issues of capacity planning. These are summarized below:

- Lack of time: The top management is not able to give time to the capacity planning as they are so involved with other activities such as maintenance, installations etc. so the proper time for capacity planning is not given in many organizations.
- Lack of interest: the most important issue related with the capacity planning is lack of interest of the top management. More importance is given to current activities and the maintenance but capacity planning is not considered as an important task.
- Inaccurate forecasting: capacity planning heavily relies on the accuracy of the demand forecast. Sometimes the forecasting can be inaccurate due to inadequate tools, skills and

lack of experience and training, and hence could result in inaccurate future predictions of demand.

- Use of conventional methods: Many analysts rely on the traditional techniques only and are not willing to try out use new methods and hence are unknown of more effective and efficient tools.
- Change in corporate model: The capacity planning model should be changed regularly and frequently so that the changes in the strategies within the organization can be incorporated easily.
- Lack of man-power: the organizations give very little importance to capacity planning because of the cost constraints and limited manpower [Vasudevan and Parthasarathy, 2007].

1.4 Capacity Utilisation

Capacity planning requires knowledge of current capacity and utilization. Capacity utilization is expressed in the percentage of the total production capacity that is actually used in the organization. It is the ratio of the average output produced to the maximum capacity that can be produced from a facility. Utilization is the degree to which any equipment or labor is presently being used.

$$\text{Utilization} = 100 \% \times \frac{\text{Average output}}{\text{Maximum Capacity}}$$

For calculating the utilization, the average output rate and the capacity must be measured in the same terms (time, customers, units, or dollars). Whether there is need of adding the extra capacity or there is need of reducing the extra capacity, this is indicated by the capacity utilization rates. There are two measures of the capacity utilization: peak capacity and effective capacity.

1.4.1 Peak Capacity

Peak capacity is defined as the greatest output that can be achieved under the ideal conditions. Peak capacity can be achieved only for a short period of time, such as a few hours in a day or a few days in a month. An organization can achieve this by overtime, extra shifts, and provisionally reduced maintenance actions, overstaffing and subcontracting. The peak capacity will be temporarily increased and would not be sustained for a long time because the

employees don't want to work for overtime for the extended periods. This may lead to the extra cost and the quality drop.

1.4.2 Effective Capacity

Effective capacity may be defined as the maximum output that can be achieved by an organization or facility under the normal conditions. The effective capacity is less than that of the design capacity because of certain limitations or constraints. These constraints are the constraint of product mix, breakdowns and the quality inspections. The actual capacity is even fewer because of many other factors disturbing the output like real demand, machine or equipment failure. Because of long-range uncontrollable factors the system capacity is less than the design capacity. The actual output is lower than the system capacity because of breakdown of equipment known as short term effects.

1.4.3 Financial Implications

The capacity utilization level of an organization determines that how much fixed cost should be spent per unit so that the capacity utilization can be increased and the fixed cost per unit should be decreased. An organization should be more efficient if it is running at 100% capacity utilization level. However, there are some disadvantages of running at 100% utilization level:

- Routine maintenance will be affected. The orders would be delayed if the machine breakdowns occur frequently.
- The unexpected or new orders may not be possible to complete, so the business cannot grow without expanding the level of production.
- There would be pressure on the labour and the staff which may lead to the increase in the mistakes and the labour absenteeism.
- The working conditions would become messy and quality of work may decrease.
- The overtime of the staff would be needed to satisfy the orders which would increase the labour costs.

1.4.4 Causes of Under-Utilisation of Capacity

An organization might be experiencing low capacity utilisation, because of the following reasons:

- Over-supply in the market as new competitors taking market share.

- Customer taste changes very frequently. This causes the fall of demand in the market.
- Unsuccessful marketing is another important cause of low capacity utilization.
- The seasonal demand is especially obvious in some industries like the holiday-maker industry where firms like hotels, motels and leisure parks in summer season attain full utilization but the utilization is at much lower side during the other seasons.

1.4.5 Problems Arising from Low Capacity Utilisation

- The cost per unit is increased because of the low capacity utilization which results in the reduced profitability. If these fixed costs per unit are covered by raising the price this would probably lead to the reduction in sale.
- Low capacity utilization would generate negative image of the organization in the market which would lead to the loss in the business.
- Because of the low capacity utilization the staff of the organization would become demoralised as they don't have much to do and become inefficient. The staff would always feel the risk of losing their jobs.

1.4.6 Benefits of Low Capacity Utilisation

The low capacity utilisation is undesirable in the organization as the higher per unit costs will make it difficult to fight in the market but it has some possible short term benefits:

- There would be enough time for the regular maintenance and the repairs.
- There would be enough time for the training of the staff so that they would become more skilful.
- The organization can easily accept and cope with new orders and build their sales.

1.5 Production System

The system that is used for producing the goods of an organization is known as the production system of that organization. It is that action in which the resources, curving within a specific system, are joined and malformed to add value in a very controlled manner in agreement with the guidelines given by management [Kumar and Suresh, 2009].

The production system is characterized by the following:

- Every production system has an objective because the production is an organised and controlled activity.

- The various inputs are transformed into the useful outputs by the production systems.
- It does not operate in separately from the other organisation system.
- Feedback is an essential part of the production system to manage and to improve system performance.

1.5.1 Classification of Production System

Production systems can be classified as:

- Job-shop production system
- Batch production system
- Mass production system
- Continuous production system

The classification of production systems is shown in Fig. 1.6.

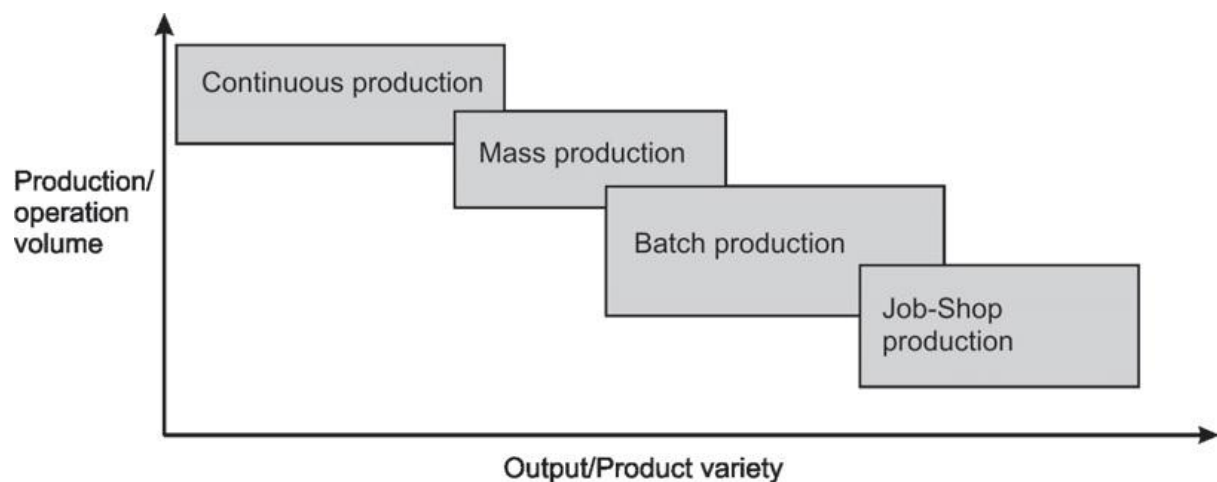


Figure 1.6: Classifications of production systems [Kumar and Suresh, 2009]

1.5.2 Job-Shop Production System

In Job-shop production system is the system in which one or little quantity of products is manufactured and designed as per the specifications of clients within predetermined time and cost. In this system the volume of production is low but there is high mixture of products.

The general-purpose machines are used in this type of system and are settled into the dissimilar departments. Every job demands for the exceptional technology, demands processing on machines in a definite order.

The characteristics of job shop production system are:

- Low production volume but with high variety of products.

- General purpose machines are used in this system.
- Because of the uniqueness of each job highly skilled operators and highly skilled labour is required.
- The inventory is kept large for all materials and tools.
- Complete planning is crucial for sequencing the needs of each product, capacities for every work centre and for setting the priorities for the orders.

Advantages of Job-Shop Production System

Following are the advantages of Job-shop Production system:

- High mixture of products can be manufactured with the use of general purpose machines and equipments.
- Uniqueness of each job provides the opportunities for the Operators to become more skilled and competent.
- Better utilization of the potential of operators.
- The Opportunity for Creative methods and innovative ideas exist in this system.

Limitations of Job Shop Production System

The limitations of Job-shop Production system are:

- Elevated cost due to regular changeover in the set up.
- Higher inventory cost because of higher levels inventory.
- Production planning and control is a complicated task.
- Large space is required for this type of system.

1.5.3 Batch Production System

In batch production system the products are manufactured and go to the various departments in batches or in the lots. Every batch or lot might have a dissimilar sequence. The limited number of products are processed at usual intervals in this type of production system and stocked in the inventory in the anticipation of sales.

The characteristics of batch production system are:

- Production runs are relatively shorter.
- Flexibility in the plant and the machinery.
- The set up of the plant and the machinery is done in such a way that it can be easily used for the production of items in a batch and change of set up can be easily done for the processing of the next batch.
- Manufacturing lead-time and costs are lesser relative to job order production system.

Advantages of Batch Production System

The advantages of Batch Production system are:

- The plant and the machinery can be utilized in a better way.
- Practical specialisation is enhanced.
- The cost per unit is lower relative to job order production system.
- Machinery and plant requires lower investment.
- More flexibility to accommodate and process the variety of products.
- Operators are satisfied by the job.

Limitations of Batch Production System

Following are the limitations of Batch Production:

- Material handling is difficult because of uneven and longer flows.
- Production planning and control is difficult task in this production system.
- The cost of work in process inventory is higher as compared to continuous production system.
- Set up costs are high because of regular or repeated changes in the set up.

1.5.4 Mass Production System

In the mass production system discrete parts or assemblies are manufactured by using the continuous processes. The large volume of production justifies this type of production system. The machines are arranged in a line layout or product layout. The standardisation of products and process exist in this system and all outputs follow the same path.

This system is characterised by:

- Product and process order is standardized.
- In this system dedicated special purpose machines are used which provide superior production capacities and elevated output rates.
- The production volume is at higher.
- The cycle time of the production is less.
- In process inventory is low.
- The production lines are perfectly balanced in this system.
- There is no back tracking of the products and the flow of materials, components and parts is continuous process.
- Production planning and control is an easy task in this system.

Advantages of Mass Production System

Following are the advantages of Mass Production:

- Production rate is higher because of reduced cycle time.
- Due to line balancing the capacity utilisation is also high.
- Less experienced operators are required.
- In process inventory is low.
- Manufacturing cost per unit is low.

Limitations of Mass Production System

Following are the limitations of Mass Production:

- The entire production line will be stopped even with the breakdown of a single machine.
- If there is a change in the product design the major changes will be required in the line layout.
- Production facilities need higher investments.
- The slowest operation determine the cycle time of the product.

1.5.5 Continuous Production System

In the continuous production system the production facilities are arranged according to the sequence of production operations i.e. starting from the first operation to the final operation or the finished product. This type of system is fully automated and the products are produced to flow through the order of operations with the use of material handling procedures such as conveyors, transfer devices, etc.

This type of system has following characteristics:

- This system requires a dedicated production plant and equipments with zero flexibility.
- Fully automated material handling system.
- Predetermined sequence of operations is followed by the process.
- It is difficult to identify the component materials final product.
- Planning and scheduling is a regular activity.

Advantages of Continuous Production System

Following are the advantages of Continuous Production:

- Product and process sequence can be standardized.
- Production rate is higher with reduced cycle time.
- Due to line balancing the capacity utilisation is also high.

- This type of system is fully automatic and the manpower is not required for the material handling purposes.
- Labour having limited skills can be used on the production line.
- Because of the high volume of production the per unit cost is lower.

Limitations of Continuous Production System

Following are the limitations of Continuous Production:

- Less Flexibility and processing of number of parts is not possible.
- Investment is quite high even for the setting of flow lines.
- Segregation of the product is limited in this system [Kumar and Suresh, 2009].

1.6 Make to Order (MTO)

In make to order strategy the manufacturing organizations manufacture the products only after the customer order is documented. In this strategy the consumer has to wait for some additional time to receive the product but it allows the consumer to buy the products according to their specification. The make to order (MTO) strategy reduces the problems of unnecessary inventory. The MTO manufacturing organization delivers an extensive variety of products, ranging from a set of standard ones to all orders requiring a customized one. The degree of product customization and the amount of product variety expand in the MTO companies. The organizations offering costly standard products to meet irregular low demands do not keep the products in stock but only produce them after the customer order. The receiving of customer orders is stochastic process over a period of time. Each probable order from the query tends to be for a inconsistent number of units and needs varying routings and processing times through the production system.

MTO systems are not suitable for all type of products. Some factors have to be considered when evaluating the aspect of make-to-order.

- **Value of custom product:** It should be considered that whether the clients are ready to pay more for the customization or not.
- **Customer patience:** The risk of losing the customer is there if customer is not ready to wait for the product to be manufactured and delivered. Then the customer would attract towards the competitor in the market. This would also result in the loss of the goodwill of the organization in the market.
- **Cost of stock outs:** If the customer is willing to wait for the product that has to be manufactured and delivered, the make to order strategy becomes more effective and

attractive as it eliminates the problems of stock outs. If the cost of stock outs associated is relatively large, MTO becomes more attractive.

- **Modularity:** In this strategy less safety stock is required so the inventory cost of the component can be reduced even if the product is modular.
- **Manufacturing lead time:** Make to order system becomes infeasible because of the long manufacturing lead time and if the customers are not willing to wait.
- **Manufacturing setup costs:** If setup costs are too high then the penalty cost might be too large than the benefits of the customization in make to order organization. Automated flexible manufacturing system helps to reduce the setup costs [http://www.oxbridgenotes.co.uk].

1.7 Made to Stock (MTS)

Make to stock (MTS) is a traditional type of strategy. In this type of strategy the manufacturing organizations manufacture the product on the basis of the demand forecast. The organizations manufacture the products and store them into the inventory and then products are retrieved from the inventory according to the demand. In this method the demand forecast determines the quantity of the products to be produced. The efficiency of this strategy depends upon the accuracy of the demand forecast. If the demand is accurately forecasted, MTS strategy could be an efficient choice for the manufacturing organization [Kumru, 2011].

The main disadvantage of the make-to-stock (MTS) method is that it depends heavily on the accuracy of demand forecasts. The risk of losses due to the stock outs or losses due to the excessive inventory are always associated with MTS strategy if the demand forecast is not accurate.

CHAPTER – 2

Literature Review

2.1 Introduction

This chapter presents the summary of work carried out by the different researchers on the capacity planning and its utilization level in the different industries and proposed different models and approaches to improve capacity planning.

2.2 Literature Review

Occhino [2000] discussed that as the demand for semiconductor product was increased, the objective of a high capacity manufacturing industries were to fulfill the customer requirements so that they could stay reasonably competitive in the market. To fulfill that, whole factory utilization and well-organized product mixing was desirable. The outputs and goals were possible with watchful capacity planning of equipment, proper utilization of the equipment, and uninterrupted confirmation of attained throughput versus intended throughput. The paper described the formation of the capacity planning model and how it would be a vital part of the success in the growth of a large quantity manufacturing industry of the semiconductor. The capacity planning model helped to achieve the White Oak Semiconductor output goals. If a probable decline in throughput was needed, the model showed whether new the purchase of new tool was desirable or the additional time was there so that the improvements should be done in order to recover the capacity. The model could be used by the management to get an impression of their area and be conscious of future capacity problems. The model could be used as a operational document and the capacity effect of an improvement project and the results showed that the new tools were saved.

Balakrishnan and Sivaramakrishnan [2001] discussed that a firm might plan capacity using limited demand information and revise prices after once additional demand information was available. The loss was identified due to this type of sequential planning. It used simulation experiments to evaluate the size of the loss in more intricate settings. It was found that there was comparatively small loss when the firm planned for capacity using narrow demand information and then adjusted product prices to replicate realized market circumstances. The simulation experiments results suggested that by using the full-cost-plus

pricing approach for planning was not very expensive to the firm if the firm adjusted short-run prices to recognized market situations.

Filho and Marcola [2001] studied that the capacity planning was very important to carry out sales requirements for make to order or assemble to order manufacturing and the available capacity should be flexible to meet the sales requirements. The annualized hours (AH) could help in increasing the flexibility in the production system. The paper proposed a linear programming model for the planning of operations using AH. The objective of the model was to introduce the AH as a tool of the rough cut capacity planning to compare the production capacity with AH and the demand during a certain planning horizon. The model was implemented on the data of company that produce agriculture products. The results showed that the model helped in the reduction of the overtime and the use of the temporary labor was also minimized. The model increased the flexibility of the system to attend the demand and became a beneficial tool to balance demand and capacity for the small capacity increments.

Grando and Turco [2005] contributed to the development of a method that could be used to examine and determine parameters such as capacity, throughput rate of production, level of utilisation, saturation, availability and yield. The paper focused on the recognition and computation of these factors in order to define a productivity employment system and to explain different production capacity ideas. The proposed approach was applied in some manufacturing production units where single machines were monitored in different industries. The approach was targeted for diagnostic purposes and were proved useful during the execution of improvement projects designed for removing losses causes and thus increased the efficiency and productivity;. The results showed that the approach gave the opportunities to establish appropriate production capabilities by focusing on bottleneck machines so that the actual system throughput could be controlled.

Deif and Eimaraghy [2006] presented a dynamic model and analysis for capacity scalability. They examined also the problem of how to supply exact capacity in response to market changes by solving the dynamic problem, and finally proposed a general capacity scalability controller in response to sudden demand changes. The proposed controller considered the different activities associated with the capacity scalability process. A numerical example was also presented to highlight the applicability of the approach. The results showed the superiority of the proposed controlled capacity scalability system over the uncontrolled system in terms of time required to eliminate backlog and to reach the required work in process (WIP) level.

Vasudevan and Parthasarathy [2007] compared the traditional statistical based methods with neural networks based methods. The training set for the neural network was done which was consisted of historical values of a metric for which the forecast was to be done. The advantages of neural network based method were discussed over the other methods. This paper studied the performance of an organization by using the artificial neural network method as a framework. The behavior of neural network was compared with the conventional methods for a typical case. The results showed that the neural network was a better model than statistical methods to predict the CPU utilization for any organization.

Eckert et al. [2008] described that queuing theory could be used to examine the execution capacity of web service workflows and to plan the workflow control. Capacity planning and performance measurement were important to avoid the violation of service level agreement due to overload. The paper put forward a capacity planning approach which was based on the queuing theory for web service workflows to support capacity planning decisions. It described that the optimization algorithm could attain best achievable utilization of the invoked web services at minimum costs. The basic principle of the model was to apply results from queuing theory to web service workflows. The concept of Poisson arrivals was used to explain the arrivals of requests. The results showed that the execution capacity of web services of the entire workflow has been maximized by using an optimization algorithm.

Bihlmaier et al. [2008] presented a deterministic and a stochastic model, which extended present approaches, particularly by an expectation method for tactical workforce planning. The method was compared to an extensive formulation of the deterministic model, which incorporated workforce planning by means of comprehensive shift models. The stochastic model was solved by an accelerated decomposition approach efficiently. The mathematical formulations of strategic network design problems were taken into the consideration under doubtful demands for the automotive industry from a capacity planning and the production planning point of view. The tactical aspects such as workforce planning were included in the formulations to emphasize the requirement of anticipating successive stages in a hierarchical planning process. Based on Benders' Decomposition, the customized solution approaches were implemented. The numerical results showed that the approach of the solution greatly reduced the solution time as compared to standard methods. The paper demonstrated that by using these methods the automotive industry could tackle large-scale and real-world problems quite easily and helped for better decisions than widely accepted methods for actual planning problems in the automotive industry.

Yong-hui and Yuan [2009] suggested that the capacity planning of the supply chain should be done to increase the overall interests of supply chain. A whole framework of capacity planning of supply-chain based on multi agent was proposed. Then the difference between multi-site capacity planning and traditional capacity planning was discussed. Then a three-level capacity planning system was constructed. The first level consisted of planning unit agent who carried out capacity planning of supply chain. The second level was member enterprise agent and the third level was coordinator agent. Then the operating model of capacity planning was discussed as shown in Fig 2.1. Finally, the practical case was given to verify the validation of the proposed model. The results showed that the multi-site capacity planning system had more advantages of knowledge sharing and exchange which could immediately respond to the market demand change.

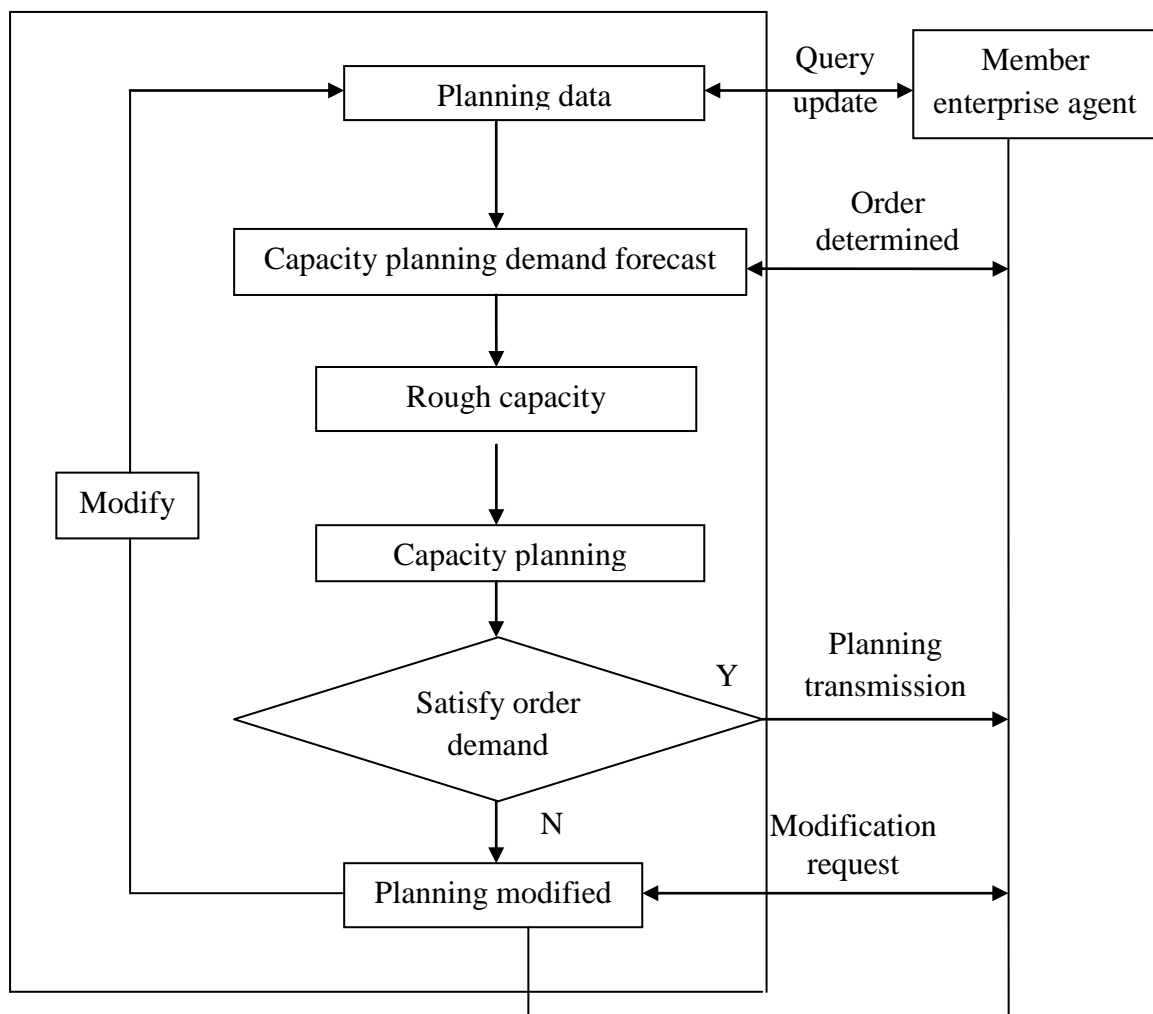


Figure 2.1: Operation model of capacity planning [Yong-hui and Yuan, 2009]

Shengchen et al. [2009] addressed the problem regarding the capacity planning in the short-term horizon in a make-to-order (MTO) production environment. A mathematical model was put forward to help an operations manager in selecting a range of probable customer orders in an MTO environment so that the profit from the operational functions can be maximized and also the orders that were selected could be fulfilled by their deadline. The proposed model considered regular time, overtime, and outsourcing as the sources for each resource type. The model was validated by solving it with the use of the mixed-integer program solver CPLEX. The working of the model was explained by taking many examples with the objective that it could benefit a manager in an MTO environment. The computational result showed that the commercial system could only solve the proposed capacity planning model for small problems.

Wang [2009] concluded that the decisions for which customer orders to be accepted were important to get the maximum profit within the due time. The author addressed an order selection decision model in make to order manufacturing environment. A mathematical model was proposed in the paper. The objective of the model was to help the managers to accept or reject an order, considering the resource capacity and meeting the due date commitment so that the operational profit should be maximized. The model was solved by using a mixed integer programme solver CPLEX. Several examples were used for the working of the model and it was found that it was useful for the managers in the order selection decisions.

Lin et al. [2010] considered the issues of mid-term capacity planning in the foundry. The paper first categorized the issues related with capacity planning of the foundry and then proposed an increment strategy for the number of the accessory tool-"photo mask" to increase the flexibility of production as the cost of mask was very much lower than the semiconductor equipment. The problem associated with the capacity planning was that the demand changes were very fast and the flexibility of the production was very poor. To overcome the problem the mathematical programming model of capacity planning was constructed whose objective function was to improve the capacity utilization within the planned time. The results showed that the rates of capacity utilization and customer order fulfillment were successfully improved by adding new masks and the flexibility of the production was increased. The improved capacity planning helped the decision makers to remind the future bottleneck in capacity and they could easily purchase the new masks within time to improve the capacity utilization and also the rate of customer order fulfillment could be increased effectively.

Pimentel et al. [2011] proposed a multi-stage stochastic programming approach so that the problem of capacity planning in a realistic global mining supply chain could be handled. A discrete probability scenario tree was difficult to solve even for the modern optimization software. Specific software configurations were analyzed which indicated a series of different solution advances from exact methods such as cutting planes to approximate methods. This paper, addressed the problem of stochastic capacity planning problem in global mining supply chain. The model used incorporated the decisions of capacity extensions, capacitated facility location and network design in a supply chain planning framework. The significant challenges were posed by the size and complexity of the model, especially for a large number of scenarios to general-purpose optimization solvers. Many analyses were performed to the optimization procedure and good estimated results were yielded by a specific combination of parameters. The results, however, were associated with a network and scenario tree of restricted size.

Kumru [2011] concluded that when the demand increased more than the available capacity, the capacity should be determined firstly and then the available capacity should be allocated to maximize the profit. The paper introduced a simple deterministic model to determine the capacity and its level of utilization for a single specific machine in make-to-order manufacturing industry. The processing time, set-up time, product defective rate, and maintenance downtime were considered as variables and the critical determinants were the number of product types and the number of lots per product. The machine assumed to be bottleneck in the production process and it was difficult for the management to take the decision about the marginal customer orders. The model proposed model determined the capacity and its utilization level of a specific machine for a given products. Firstly, the net production quantities per unit of time for each product type and for the product mixtures were calculated and then capacity utilization values were derived. The model was applied to the data of an injection press and the capacity utilization level was determined. The results showed that the model was highly practical for the small and medium size companies. The results helped the management to support the decision making and to handle a number of different customer orders.

Li and Chen [2011] studied that the customers should be segmented into different classes based on service level or priority to get more efficient production system and also to achieve better match between supply and demand in build to order manufacturing (BTO). The paper studied the two different customer classes in BTO manufacturing firm where one class had

higher priority of fulfillment than other. The paper formulated a model of priority differentiation with consideration to substitution. The model of differentiation and the proposed model were compared. The numerical examples were given to carry out the study and the results were derived by the software of LINGO. The results proved that the differentiation strategy and consideration to cross elasticity could improve the firm profit.

Dorsch and Hackel [2012] discussed that the capacity planning is an important task and also a big challenge for the business organizations. The technology could help the combination of the demand to handle the maximum load at very short time notice. The paper put forward a three stage supply chain model having a service provider which could receive the demand from the customers. Also the external business partners could handle the demand. The paper examined the problem regarding the capacity planning of the service provider. The problem arose that how the demand combination capability could influence the best possible level of the in house capacity. The model was consisted of two different methods of queuing system i.e. in house unit and external business partners. The cost functions of both the methods were taken into the consideration. Then after a routing algorithm was developed which helped in deciding the best method between the two methods by evaluating both the systems. A case study was done and the results were derived from simulation software. The results showed a significant fall in the optimal capacity and the huge amount of overcapacity could be reduced to the large extent.

Hung et al. [2013] developed an effective approach of capacity requirement planning (CRP) that considered orders with inconsistent time windows. By applying the pre-emptive earliest due date (PEDD) rule to a single machine problem the possibility of real-time capacity could be analysed on both the corporate planning and detailed operational scheduling levels. Each time when the order was received, the impact on the capacity consumption can be easily assessed with the simple and efficient dispatching rule. By using a continuous time axis the capacity representation for intermediate-term planning was enhanced. The main question for MTO organization was that whether all orders could be possible to produce with differing time windows. The paper bypassed the difficulty of formulating and solving an optimization problem of LP by using a simple dispatching rule.

Georgiadis [2013] demonstrated that the recycling activities were increased over the past ten years because of the economic and environmental dimensions of sustainability. Capacity planning became an important key for the profitability of recycling industry. The study proposed a system dynamics model for the strategic capacity planning in the recycling

industry. When the model was used as an experimental tool it tested alternative capacity planning policies and demonstrated policy suggestions for the forward and reverse channels that maximized the profitability over a strategic planning horizon. The model was implemented on the data of a paper producer with recycling activities. The simulation results showed the efficiency of a wide range capacity achievement decisions by using total company profit as the measure of performance.

Lee and Shahidul [2013] developed a framework for the measuring and analysis of machinery Capacity Utilization (CU) and Capacity Gap (CG). The framework was developed on the theory of short-run production and the concept of capacity utilization. The investigation of CU and CG enabled managers to check various capacity management options in controlled manufacturing environment. The proposed model was implemented on the garment manufacturing firms and tested by using input-output data of year 2007-2012. The model was found successful as it was enabled us to identify capacity gaps. The results showed that the capacity was not fully utilized and there was capacity in the production process. The actual and potential outputs were derived by the model from the short run theory of production. The results which were in the form of CU and CG of machinery showed that it was based on the engineering concept of capacity and appeared to be biased to operations management and no influence of changes in the economic variables. The proposed method has been a useful tool for the production managers to calculate CU and CG of machinery used in the production process. The advantage of using the method was that it helped the managers to develop well-organized production plan and contributed to improve manufacturing performance.

Altendorfer et al. [2014] presented different periodic capacity setting methods for make-to-order, multi-machine production systems in order to improve the service level and delay. The methods were developed for the decision support where there was the flexibility in the capacity. All the methods were based on the integrated capacity demand at every machine but they were different on the basis of the amount of information used by them. The information about process improbability and client behavior were implemented in the different methods. The impact of methods on service level and delay was weigh against to a constant provided capacity for a single and a multi-machine setting by simulation. The simulation results showed that the methods in which the information about both the processing time distribution and the customer required lead time distribution was used provided the best results. It was found that the proposed methods increased the service level as wall as there was a decrease in

the delay as compared to the regular provided capacity. In single machine the service level increase and the delay decrease was found better than the multi-machine production system. The capacity flexibility could be efficiently used by the proposed methods.

2.3 Summary of Literature Review

The following observations were made in the literature review:

- Capacity planning model used for high volume manufacturing facility to more effectively managing the new tools and other accessory equipment.
- Capacity planning process can be initiated even with restricted demand information and afterward adjusting product prices to imitate real market conditions without incurring heavy losses.
- Capacity planning approach finds its application in the service industry where it is used for web service workflows based on queuing theory to support capacity planning decisions.
- The capacity and production planning point of view help in deconstructing the problems of strategic network design under unsure demands for the automotive industry.
- The mathematical programming model of capacity planning help to enhance the rates of capacity utilization and customer order completion by adding new masks. This would further help to boost the production elasticity.
- The simple deterministic capacity planning model can help to determine anytime the capacity and its utilization level of a specific machine for given products.

CHAPTER 3

Problem Statement

3.1 Introduction

This chapter brings forward the capacity planning and its utilization level problem for the single-machine multiple-product in make-to-order manufacturing organization.

Make-to-order manufacturing industry (MTO) manufacture only in response to the customers' orders. The MTO organization has to supply the large variety of products. This includes the standard products as well as the customized products. The degree of product customization; which covers pure customization, tailored customization, standard customization and non-customization, and the amount of product variety diversify MTO companies. Those offering expensive standard products to satisfy irregular low demands do not keep them in stock but only produce to order.

The main problem associated with MTO organization is that the organization has to satisfy the demand for both the short term and the long term and the organization has to ensure that there is enough capacity to satisfy the demand. The main function of the demand management is to set the aggregate sales levels and individual product target sales levels so that the capacity is successfully and efficiently be utilized. If the expected aggregate demand is less than the capacity, in such situations there is no problem with demand management. But when the total demand is much greater than the capacity, then the problem arises with the capacity planning. Now the managers have to do the difficult task of allocating the capacity among competing classes of products and customers. However this can be solved by expanding the capacity but it would be a long term option and is not possible for the short term options. Therefore when the demand is greater than the capacity the MTO firms require to launch capacity management policies so that the short term capacity problems can be solved. The main issue for an MTO organization is to ensure that the utilization of the capacity is efficient and effective to satisfy the current demand. It is seen that often the MTO companies handle the capacity management problem as a matter of capacity allocation rather than a capacity determination. If both the factors are considered together the best results can be achieved.

3.2 Problem Definition

The case study would be carried out in a manufacturing organization of Ludhiana. This organization is the manufacturer of scaffoldings, form work systems and accessories and work on the basis of make to order or when the order has been documented. It was established in 1995. It is an ISO 9001:2008 and TS 16949 certified company. It has 4 production plants spread on a total area of 10000 sq. meters and 800 strong work force. It has in-house testing facility for all mechanical and chemical tests. This is a medium scale manufacturing organization as the company has invested INR 5-10 crore on the machinery. The turnover of the organization is about INR 50-55 crore per annum. The organisation unit has invested significantly in modern infrastructure for improving the operational efficiency. The infrastructure includes the machinery like power presses, drilling machines, riveting machines, cutting machines and CNC machines. By investigating the operational aspects of the organization, some very glaring facts regarding the capacity utilization came to light. On the discussions that pursued with the management, a thorough analysis of the functioning of the CNC department was proposed as the orders were not fulfilled by their due dates. Extensive literature was studied and a mathematical model was identified to be appropriate for this type of problem.

3.3 Objectives of the Study

Using the organizational requirements and the model pre-requisites, the objectives of the study were finalized. The objectives include the validation of the mathematical model on CNC proposed by [Kumru, 2011] on CNC machine in the CNC department of the manufacturing organization of Ludhiana. The objectives of the study are as follows.

- To determine the capacity and its utilization when the demand is deterministic with same type of product and same number of batches.
- To determine the capacity and its utilization when the demand is deterministic with the same type of products but the number of batches changing.
- To determine the capacity and its utilization when the demand is deterministic with the same number of batches but different type of products.
- To determine the capacity and its utilization when the demand is non-deterministic i.e. with different type of products and different number of batches.

CHAPTER 4

Methodology

4.1 Methodology

- Data collection
- Application of mathematical model to the collected data
- Validation of results

Assumptions of the Mathematical Model

There are a number of assumptions and approximations on which the mathematical model is based. Optimization is the basic criteria considered for the maximum utilization of the machine concerned.

- The machine is assumed to be a bottleneck in the production process. Due to this management face many difficulties in decision making on workload and this creates the doubt for the management whether they accept the outlying or marginal customer orders or not.
- The model is in static nature. The variables like set-up time, processing time and defective rate, mechanical and electrical maintenance duration of the machine for each type of product is included.
- The important determinants of the model are the number of product types and the number of lots per product.
- The number of product types determines the size of the problem, the number of lots per product, however, affects directly the total setup time of the product concerned.

When the necessary parameters are given to the model, it easily calculates the net production quantities per minute, the inverse coefficients and net quantities per planned time for each type of product and then calculates the capacity utilization figures for various demand levels of different product mixtures. By doing so, it makes available the optimal use of the resources.

The Notations Used in the Model

NQ_i is determined to be the total net number of units ordered for product i for which

$$NQ_i = \sum_{j=1}^{K_i} q_{ij} \quad (1)$$

Where

q_{ij} = quantity ordered for product i and batch number j for a specific period of time.

For i = different products from 1. . . . n , and j = different number of batches from 1. . . . k_i .

GQ_i represents the total gross number of units produced for product i , and is calculated to be

$$GQ_i = (1 + p_i)NQ_i \quad (2)$$

Where

p_i = defective rate for product i .

TP_i denotes the total processing time for product i , and is given by

$$TP_i = t_i GQ_i \quad (3)$$

Where

t_i = processing time for product i .

TS_i is defined as the total set-up time for product i and assumed constant for all type of products. It includes time for tool/fixture/die change & trial run as well, and is obtained as given by

$$TS_i = k_i t_s \quad (4)$$

Where

k_i = number of batches for product i

t_s = set-up time for a batch of any product.

Total shut-down rate s_t is derived from past records, or technical catalogs as percent of operation time (time for processing and trial run). It is the sum of failure and planned maintenance rates and determined by

$$s_t = f_e + f_m + m_p \quad (5)$$

Where

f_e = electrical failures rate

f_m = mechanical failure rate

m_p = planned maintenance rate.

Hence, the total time for delay due to break-downs for product i , TD_i , is attained as

$$TD_i = s_t(TP_i + rTS_i) \quad (6)$$

Where

r = rate of trial running time to set-up time.

Thus, the total operation time for product i , TO_i , is simply the sum of total processing, set-up, and delay times as follows:

$$TO_i = TP_i + TS_i + TD_i \quad (7)$$

Substituting Eqs. (3), (4) and (6) for Eq. (7) produce the following.

$$TO_i = t_i GQ_i + k_i t_s + s_t (t_i GQ_i + r(k_i t_s)) \quad (8)$$

Replacing GQ_i with $(1 + p_i)NQ_i$, we get the below equation

$$TO_i = t_i(1 + p_i)NQ_i + k_i t_s + s_t (t_i(1 + p_i)NQ_i + r(k_i t_s)) \quad (9)$$

After carrying out the necessary simplifications, Eq. (9) can be rewritten as

$$TO_i = (1 + s_t)t_i(1 + p_i)NQ_i + (1 + s_t r)k_i t_s \quad (10)$$

Where

$(1 + s_t)$ and $(1 + s_t r)$ are constants for all type of products.

Finally, in order to find out the net production capacity per unit of time for product i , NPC_i , which is to be used in production and capacity planning, we just take the ratio of NQ_i to TO_i , that is

$$NPC_i = \frac{NQ_i}{TO_i} \quad (11)$$

By substituting Eqs. (1) and (10) for Eq. (11), NPC_i is computed to be

$$NPC_i = \sum_{j=1}^{K_i} q_{ij} / (1 + s_t)t_i(1 + p_i) \sum_{j=1}^{K_i} q_{ij} + (1 + s_t r)k_i t_s \quad (12)$$

By the same argument, we can calculate the grand total net quantity ordered (grand total demand) for the current product mixture, GNQ , given by

$$GNQ = \sum_{i=1}^n NQ_i \quad (13)$$

Apparently, the grand total operation time for the current product mixture, GTO , is attained as shown below

$$GTO = \sum_{i=1}^n TO_i \quad (14)$$

Thus, the net production capacity per unit of time for the weighted average (standard) unit of current product mixture, NPC*, is simply determined by analogy, as the ratio of GNQ to GTO, which is

$$NPC^* = \frac{GNQ}{GTO} \quad (15)$$

The most demanded/produced product may also be used as the representative of the product set if appropriate. By substituting Eqs. (13) and (14) for Eq. (15), NPC* is determined as follows:

$$NPC^* = \sum_{i=1}^n NQ_i (1 + s_t) \sum_{i=1}^n t_i (1 + p_i) NQ_i + (1 + s_t r) \sum_{i=1}^n k_i t_s \quad (16)$$

Based on the machine's availability assumption of 24 h (3 shifts) per day along the whole year, the time dimension of the period, C, which means the installed capacity in time for the planning period, is simply determined by multiplying the number of days of the planning period with 24. The capacity utilization for product i, CU_i, is then calculated by:-

$$CU_i = \frac{TO_i}{C} \quad (17)$$

If we redefine TO_i by use of Eq. (11), then Eq. (17) can be trans-formed in the following way:-

$$CU_i = \frac{NQ_i/NPC_i}{C} = \frac{NQ_i}{NPC_i \times C} = \frac{1}{NPC_i} \times \frac{NQ_i}{C} \quad (18)$$

Where 1/NPC_i and NQ_i/C, as two separate constituents of CU_i, are called net capacity inverse coefficient for product i and net quantity per planned time unit for product i, respectively.

Once the capacity utilization figures of the products are known, then the total capacity utilization for the period, for the given product mixture, TCU, is found to be

$$TCU = \sum_{i=1}^n CU_i \quad (19)$$

or, considering Eq. (15), it can be attained in the way similar to Eq. (18) so that

$$TCU = \frac{1}{NPC} \times \frac{GNQ}{C} \quad (20)$$

Where 1/NPC* and GNQ/C, as two separate components of TCU, are called net capacity inverse coefficient for the product mixture and net quantity per planned time unit for the product mixture, respectively.

The logical diagram of the mathematical model is shown in Fig. 4.1

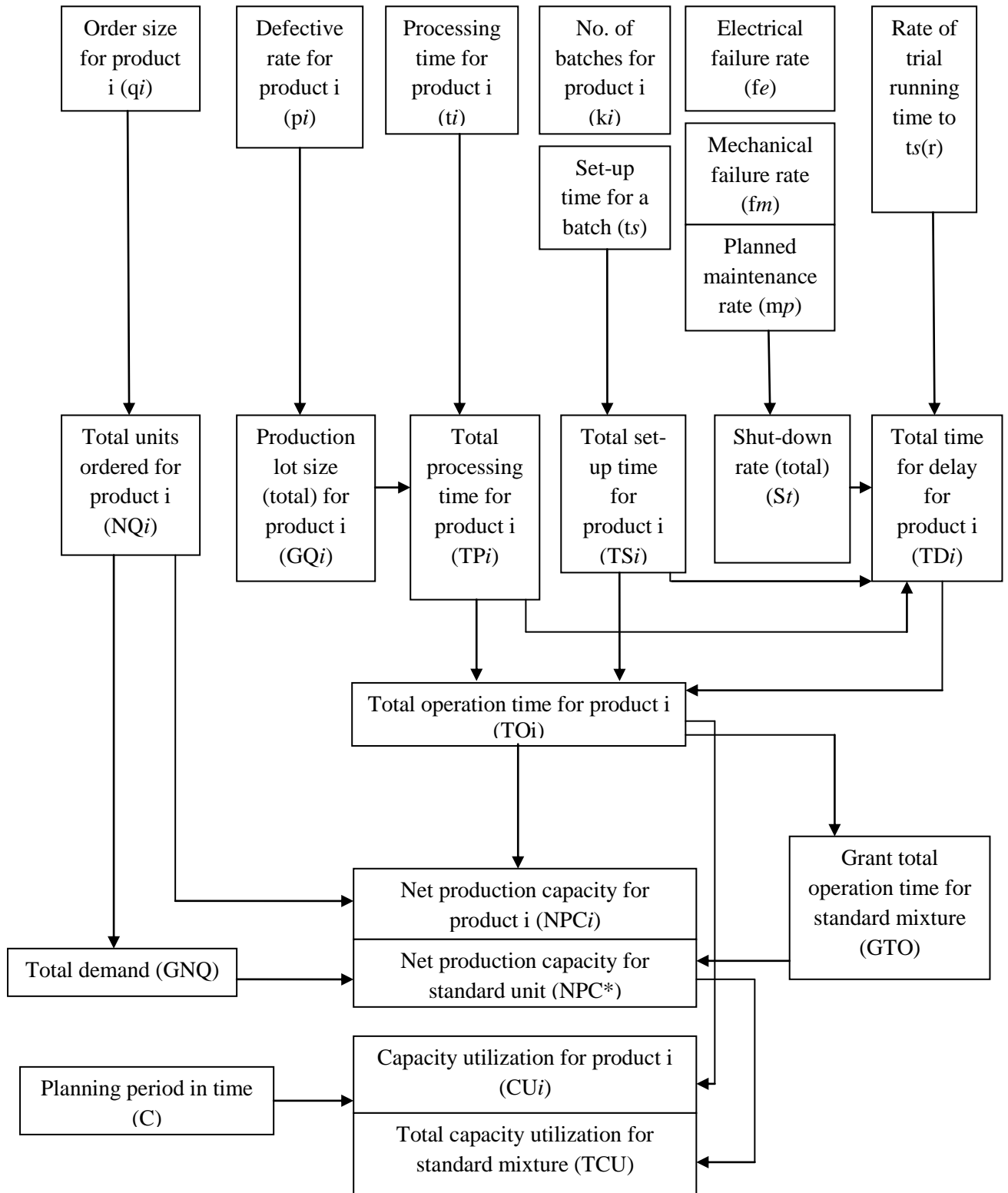


Figure 4.1: Logical diagram of the mathematical model [Kumru, 2011]

CHAPTER 5

Case Study

5.1 Industrial Application of the Model – A Case Study

A case study has been carried to validate the model. Using information of the pre-requisites of model application a manufacturing organization was identified and the operations and the work centres shortlisted as probable candidates for the study. Out of the three probable candidates, the work centre 2 was identified as the “understudy” as the model parameter requirements were completely satisfied. Using this work centre as the unit of analysis, the model was applied on CNC machine and data of the production of CNC machine was collected. The data regarding the total quantity ordered for the products that were manufactured on that CNC for last six months was taken. Also the total numbers of batches and the setup time for each batch for each product was taken. The total quantity produced was calculated by adding the defective rate or the non-conforming items to the total quantity ordered. The total breakdown delay was taken from the historical data of the organization and the total operation time was calculated that was the sum of setup time, processing time and the breakdown delay. The data collected was used to calculate the capacity utilization of the CNC machine.

Deconstructing the Case

From the data provided by the manufacturing organization, an exercise involving segregating of data had to be carried out so as to filter out irrelevant data. After data segregation, data related to a group of five products was selected among a range of products which included 90% of the total production, made during December 2013 – May 2014. The total number of batches for each product was taken. The defective rate was gleaned from the filtered data and represented as the percentage of the non-conforming items. The total quantity produced was calculated by adding the number of non-conforming items to the total quantity ordered. The total processing time was the time taken for the machining of the product. Setup time was defined as the time for fixing the appropriate tool to the machine plus the time for trial running of the machine. Based on the historical data, the proportions of these components were estimated to be 0.85 and 0.15, respectively. The proportion of total breakdown delay to operation time was 0.16. Total breakdown delay was involved in calculation which was derived as a function of operation time (processing time plus 15% of the setup time) with a multiplier of 0.16. Total operation time was calculated by the sum of the total processing

time, total setup time and the total breakdown delay. The net capacity (quantity/hour) was calculated for each product by simply dividing the total quantity order to the total operation time. Capacity and capacity utilization numbers were calculated for the specified group of products. Application results are given in Tables 5.1 and 5.2. The net capacity (quantity/hour) for each product is shown in Fig. 5.1.

Table 5.1: Capacity values determined for specified set of products

Sr. no.	Product name	Total no of batches (a)	Total quantity ordered (b)	Defective rate % (c)	Total quantity produced (d = b(1+c)/100)	Total processing time (hr) (e)	Total setup time (hr) (f)	Total delay time (hr) g = .16(e+.15f)	Total operation time (hr) (h = e + f+ g)	Net capacity (qty/hr) (i = b/h)
1	LPG Cylinder wan	10	65000	1.5	65975	751.38	20	120.70	892.08	72.86
2	Prop pipe	5	40000	2.1	40840	692.10	10	110.96	812.97	49.20
3	Prop pipe 2.1	5	40000	1.7	40680	870.10	10	139.45	1019.55	39.23
4	Anchor bolt	4	10000	1.85	10185	206.52	8	33.23	247.75	40.36
5	Tie rod	4	20000	2.3	20460	261.43	8	42.021	311.45	64.21
Total/weighted average		28	175000	1.89	178140	2781.44	56	446.37	3283.81	53.17

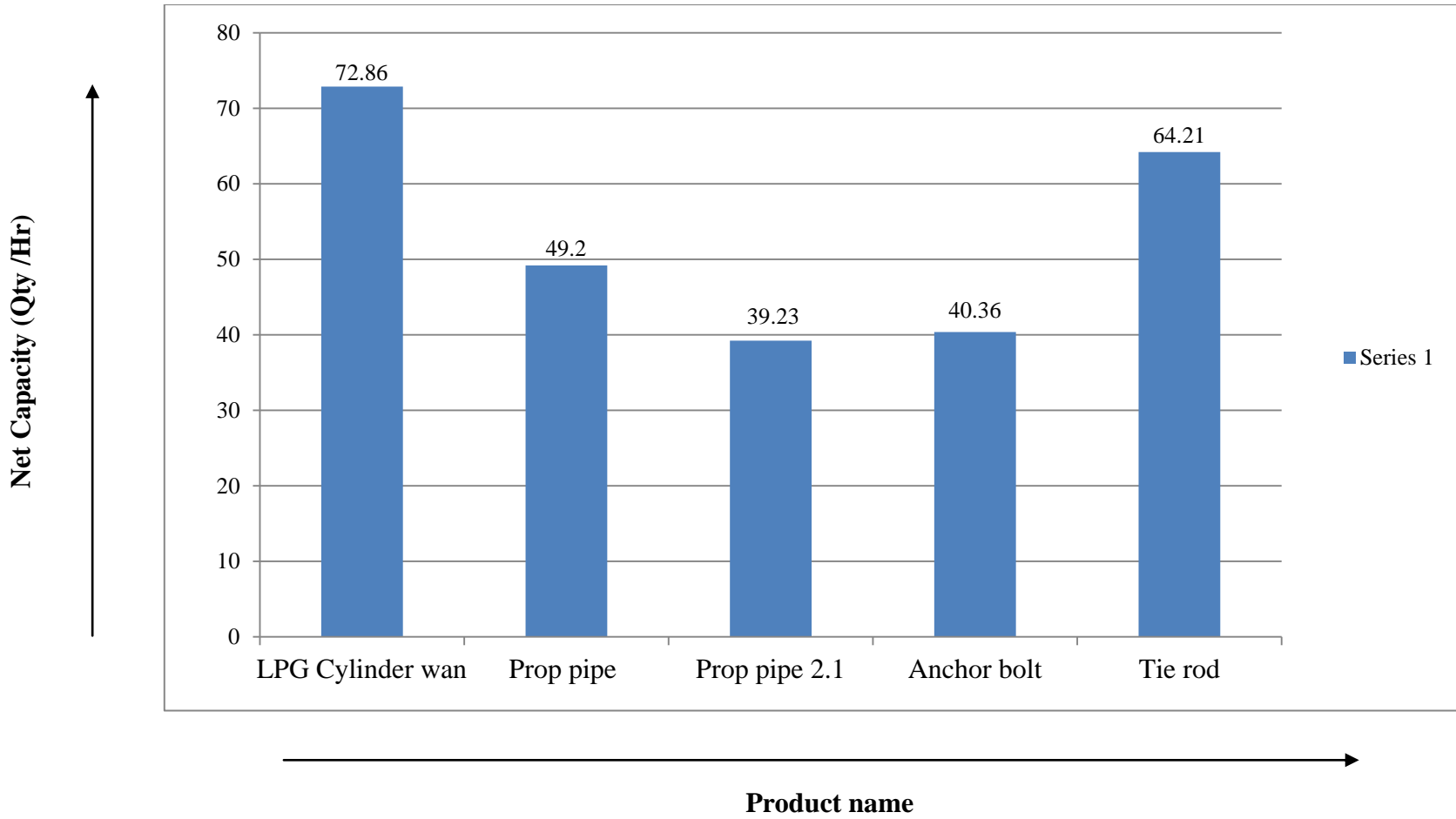


Figure 5.1: Net capacity for each product

5.2 Results and Discussions

The following results are derived from table 5.1.

- The range of capacity values as to each product type spans from a maximum value of 72.86units/hr to a minimum value of 39.23units/hr. The capacities of all other products lie within the above mentioned range of the net capacity values.
- For the given set of products the average capacity value is 53.17units/hr. (rounded off to 53)
- Since the percentage of total breakdown delay of operation time (total processing time + total setup time (number of batches \times setup time/product) \times 0.15)) is found to be 0.16, the effect of one setup/batch to the operation time is $0.15 \times 1.16 = 0.174$ hr. By multiplying this percentage with the number of batches for any type of product we can get the effect of sizing batch on the capacity values.
- The calculations carried out enable the creation of a data bank with regard to the products being processed on the CNC machine. Whenever any repeat order is received for these products, the calculated values can be used from the data bank created. Otherwise, it would be necessary to retrieve the data of the past performances of the products in order to get some leading indications about the capacity.
- If an order is placed for a product apart from the ones listed, then its similarity with one of the listed product could give us an opportunity to make estimation about its capacity.
- The application of the model generates the results related to capacity utilization which serves as a benchmark for the future orders.

The net capacity inverse coefficient for each product was calculated in table 2. The planned time was the total available time for the last six months. The net capacity/planned time was calculated by dividing total quantity ordered to planned time. Capacity utilization for each product was determined by multiplying the net capacity inverse coefficient to the net capacity/planned time. The total capacity utilization of the machine was calculated by adding the capacity utilization values of each product.

Table 5.2: Capacity utilization values for the specified set of products

Sr. No.	Product name	Total quantity ordered (a)	Net capacity (qty/hr) (b)	Net capacity inv. coeff. (c = 1/b)	Net capacity/planned time C = 182 days × 24h = 4368 (d = a/4368)	Capacity utilization (e = c × d)
1.	LPG Cylinder Wan	65000	72.86	0.014	14.881	0.204
2.	Prop pipe	40000	49.20	0.020	9.158	0.186
3.	Prop pipe 2.1	40000	39.23	0.025	9.158	0.233
4.	Anchor bolt	10000	40.36	0.025	2.289	0.057
5.	Tie rod	20000	64.21	0.016	4.579	0.071
Total/weighted average		175000	53.17	0.020	40.064	0.752

The capacity utilization of each product is shown in Fig. 5.2.

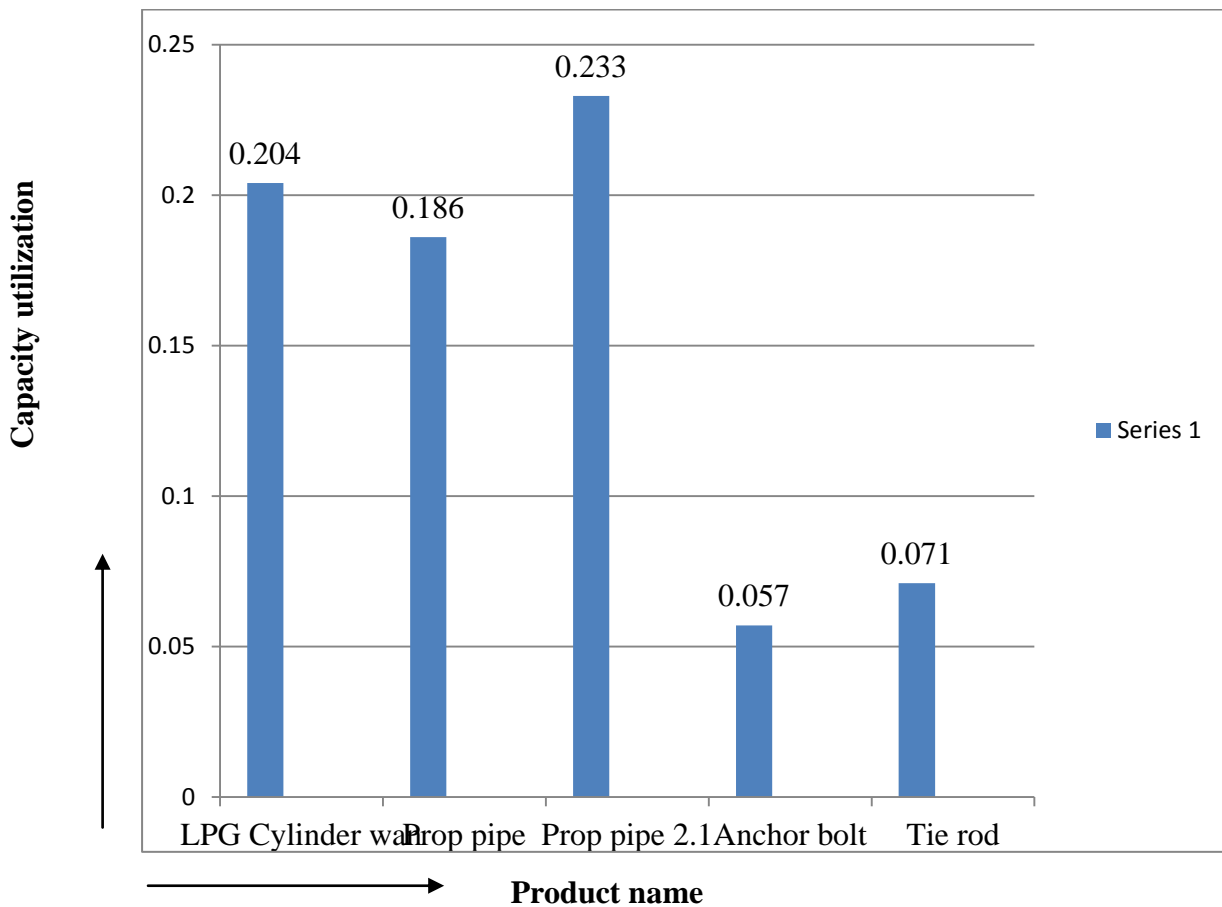


Figure 5.2: Capacity utilization for each product

The following results are derived from Table 5.2.

- The set of products under study generated an outcome which indicated that for the time period stretching from December-2013 to May-2014 the machine capacity utilization was 75.2% which is significantly lower as per the specifications of the machine under study.
- From the current set of products the product 1 has used 20.4% of the machine capacity. The product 2 has used 18.6%. The product 3 has used 23.3% machine capacity which is the maximum of all the listed products. The product 4 has used only 5.7% machine capacity which is the minimum of all. The product 5 has used 7.1% of the machine capacity.
- For the product 3, the operation time for one unit is about 0.025 h, and for 40000 units it is 1000 h (0.025×40000), and the capacity utilization rate is $0.233 \approx 1000/4368$. Or, in other words, total capacity for half a year for the first product is 174720 units

(4368/0.025) and 40000/174720 gives us again the capacity utilization rate of 0.233. In doing this way, we can estimate how many units to produce for each of the products.

- Similarly for the product 4, the maximum producible amount is 174,720 units for half of the year.

5.3 Conclusions and Future Scope of the Study

1. The model proposed can be implemented for the determination of the capacity utilization for a single machine multi-product case when the demand is deterministic and also when the demand is non deterministic.
2. The calculations made from the model can be used as a benchmark for the future capacity planning of any medium scale scaffolding manufacturing organization and to allocate the available capacity between the competing requirements so as to maximize profit and delivery reliability.

Future Scope

1. The work done relates to a single machine multiple product case in MTO. Comprehensive studies can be carried out involving multi machine multi product cases.
2. The study has been carried out assuming that the machine is a bottleneck in the production process and causes difficulties in decision making on work load. Such operational bottlenecks may be restricted to certain orders and cannot be assumed to be for all the different products that are processed on the CNC machine. Also, variations need to be accounted for, while processing different products. This area needs to be explored by selectively grouping products.
3. Future studies could also be carried out in an environment outside the MTO and with a dynamic planning horizon with varying length of the planning period.

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