TECHNICAL UNIVERSITY OF LIBEREC
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# Process optimization by proper selection of batch sizes.

## Master Thesis

*Study programme:* N2301 Mechanical Engineering
*Study branch:* Manufacturing Systems and Processes

*Author:* **Lakshmanraj Ramalingam Ramesh**
*Thesis Supervisors:* Ing. František Koblasa, Ph.D.
Department of Manufacturing Systems and Automation

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TECHNICAL UNIVERSITY OF LIBEREC
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## Master Thesis Assignment Form

# Process optimization by proper selection of batch sizes.

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|---|---|
| *Name and surname:* | **Lakshmanraj Ramalingam Ramesh** |
| *Identification number:* | S18000452 |
| *Study programme:* | N2301 Mechanical Engineering |
| *Study branch:* | Manufacturing Systems and Processes |
| *Assigning department:* | Department of Manufacturing Systems and Automation |
| *Academic year:* | **2019/2020** |

**Rules for Elaboration:**

The aim of this thesis is to optimize manufacturing system processes by selecting batch sizes at ordering, manufacturing or transportation.
Thesis will include:
1/ Literature review focused on manufacturing processes analysis tools, models used to select optimal ordering, manufacturing and transportation batch sizes. Review should include also simulation tools and other approaches of selecting mentioned batches.
2/ Production portfolio analysis and selection of representative products and processes.
3/ Analysis of current approaches to define before mentioned batch sizes. Data gathering, analysis and measurement of current processes which are necessary to model batch sizes.
4/ Define optimized approach to select batch sizes.
5/ Verify and validate optimized approach by other analytical tools or by simulation.
6/ Compare current state with newly defined one. Estimate economic benefits and expenses of new solution.

*Scope of Graphic Work:*
*Scope of Report:* 50-60
*Thesis Form:* printed/electronic
*Thesis Language:* English

**List of Specialised Literature:**

[1] ANDERSON, M.A., E. J. ANDERSON a G. PARKER. *Operations management for dummies*. Hoboken: John Wiley, 2013. For dummies. ISBN 978-1-118-55106-6.
[2] IVANOV, D., J. SCHÖNBERGER a A. TSIPOULANIDIS. *Global Supply Chain and Operations Management*. Springer, 2017. Springer Texts in Business and Economics. ISBN 978-3-319-24215-6.
[3] SALVENDY, G. ed.*Handbook of industrial engineering: technology and operations management*. 3rd ed., compl. rev. and updated. New York: John Wiley and Sons, 2001. ISBN 0-471-33057-4.
[4] GUPTA, P. K., D.S. HIRA. *Operations research: for engineering, computer science, commerce and management, economics, statistics, mathematics, CA, ICWA and CS : also useful for IAS and other competitive examinations*. Seventh edition. New Delhi: S. Chand and Company, 2014. ISBN 978-81-219-0281-6.
[5] LIANG, X., L. MA, H. WANG a H. YAN.*Inventory Management with Alternative Delivery Times*. Springer, 2017. SpringerBriefs in Operations Management. ISBN 978-3-319-48633-8.

*Thesis Supervisors:* Ing. František Koblasa, Ph.D.
Department of Manufacturing Systems and Automation

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L.S.

prof. Dr. Ing. Petr Lenfeld
Dean

Ing. Petr Zelený, Ph.D.
Head of Department

Liberec November 20, 2019

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April 20, 2021 Lakshmanraj Ramalingam Ramesh

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## ABSTRACT

The work presented in this thesis deals with process optimization by proper selection of manufacturing batch sizes for the company KAMAX, s.r.o. and the company's current production system is studied, and optimal manufacturing batch size is determined by computing the production parameters using various manufacturing batch optimizing methods.

An optimal manufacturing batch is selected by simulating and validating the analytically computed models in simulation software. In order to understand the practical work done in the analytical, simulation and validation process, a theoretic chapter is established as well.

In this thesis work, the results explain the idea of converting the company's current inventory facility into a production facility to increase the productivity and profit to area ratio of the company. And by running the production with the newly defined optimal manufacturing batch and reduced alpha value, the company's production system is optimized.

## KEYWORDS

Process optimization, Capacity equation, Models to select optimal manufacturing batch sizes, Production portfolio analysis, Lot sizing.

## ABSTRAKTNÍ

Tato diplomová práce se zabývá procesní optimalizací volby výrobních dávek ve společnosti KAMAX, s.r.o. pomocí analýzy současného stavu výrobního systému a aplikací různých modelů stanovování výrobních dávek. Optimalizované velikosti výrobních dávek jsou vybrány na základě simulace a validace výpočtových analytických modelů pomocí simulačního nástroje. Pro potřeby praktické části je však nejprve zpracována teoretická část obsahující analytické metody stanovování výrobních dávek a postup validace a simulace.

Validace simulace je založena na stanovení ceny za skladovací plochu jako plochu výrobní s ohledem na možný potenciál využití této plochy pro přidávání hodnoty, spíše než pro skladování. Na základě stanovení ruzného koeficientu alfa - poměru přidávajícího hodnotu, jsou navrženy různé výrobní dávky a tím optimalizován výrobní systém. Na závěr jsou doporučeny hodnoty výrobních dávek na základě vybraných modelů.

## KLÍČOVÁ SLOVA

Optimalizace procesů, kapacitní výpočty, modely stanovování velikosti výrobních dávek, analýza produktového portfolia, optimalizace výrobních dávek.

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# 1. INTRODUCTION

All manufacturing companies face the most common challenge of investing less while increasing throughput and/or performance. Process optimization is the process of fine-tuning a process to optimize a set of parameters while staying within a set of constraints. One of the most important quantitative methods in industrial decision-making is this. The aim of process optimization is to improve one or more process requirements while remaining within the constrains of the others.

The company KAMAX, s.r.o. is a part of the hardware & fasteners manufacturing industry. It produces about 1400 different products. For optimization of batch sizes, six different products are selected as they are representatives for six different part families which are major contributors of production and related activities. The reason behind the selection of those six products is because it represents pretty much the entire portfolio of the company which is delivered to its customers.

The company's current production system is studied, and optimal manufacturing batch size is determined by computing the production parameters using various manufacturing batch optimizing models, and a suitable manufacturing batch size is selected by simulating and validating the analytically computed models in simulation software.

The aim of this thesis is to optimize manufacturing system processes by selecting proper manufacturing batch sizes. Thesis work includes:

- Production portfolio analysis and selection of representative products and processes.
- Analysing of current approaches to define manufacturing batch sizes.
- Data gathering, analysis and measurement of current processes which are necessary to model batch sizes.
- Defined optimized approach to select batch sizes.
- Verifying and validating optimized approach by simulation.
- Comparing current state with newly defined one.

# 2. LITERATURE REVIEW

This chapter addresses all the details required to understand theoretically the practical work and the conclusion of this thesis work. The explanation on all manufacturing process analysis tools, models used to select optimal manufacturing batch sizes which could optimize the company processes has been explained in theory.

## 2.1 MANUFACTURING PROCESS ANALYSIS

Analysis of process is important not only in production management or operation but also in running and managing a business. When managers and workers do not understand an organization or value adding process, it is very difficult to control and operate them in efficient level.

Knowing a process well helps the Business owners and managers a clear idea of

- Manufacturing costs.
- Inventory costs.
- Use of company assets.
- Capacity utilization.
- Different processes currently in place to produce the required outputs.

## 2.2 PROCESS ANALYSIS STEPS

Understand the process – This is the first step in order to understand what are the inputs, outputs, Steps and tasks that comprise the productive process. Observation and visual inspection will always provide a better than a process diagram or theory alone.

Collect data – The following information can contain useful data for analysis such as observation, production data collection, customer surveys, sales and marketing information.

Analyse/ Process data – In process analysis, this is the biggest and important step. This can be done in several ways depending on data available, the complexity of the process and resources available to perform the analysis [1]

## 2.3 MANUFACTURING PROCESS ANALYSIS TOOL

- Pareto analysis
- ABC analysis
- Bottleneck analysis
- VSM
- Muda
- SIPOC

### 2.3.1 PARETO ANALYSIS

It is a methodology used on the basis of 80/20 rule for business decision making. It is a technique of decision-making, which statistically distinguishes a small number of input variables as having the greatest effect on an outcome, whether desired or unwanted.

- Pareto analysis is based on the assumption that 80% of profit is obtained by doing 20% of the work in a project
- Conversely 80% of the issues is tracked by 20% of the causes.

A numerical score is given for each problem or benefit, based on the level of impact on the company. The greater the value, the higher the impact.

By allocating resources to issues with higher scores, companies can more effectively solve problems by targeting those with a higher impact on the business.

### STEPS OF PARETO ANALYSIS

Depending on whether the issue affects profits, consumer concerns, technical issues, product defects, or delays and backlogs caused by missed deadlines, problems can be sorted using the 80/20 rule.

The following is a clear breakdown of the steps:

- Identify the problem or problems.
- Identify or list the cause of the issues or problems, keeping in mind that there may be several causes.
- Prioritize the problems by assigning a number to each one based on the magnitude of the negative effect on the business.

- Sort the issues into categories, including customer care or device issues.
- Create and implement an action plan to address the issues, focusing on the problems with the highest scores first.

Not all problems would have a high score, and some smaller problems may not initially be worth pursuing. By allocating resources to high impact problems or higher ratings, companies can tackle challenges more effectively by solving complaints that have a direct effect on income, revenue or their customers [2].

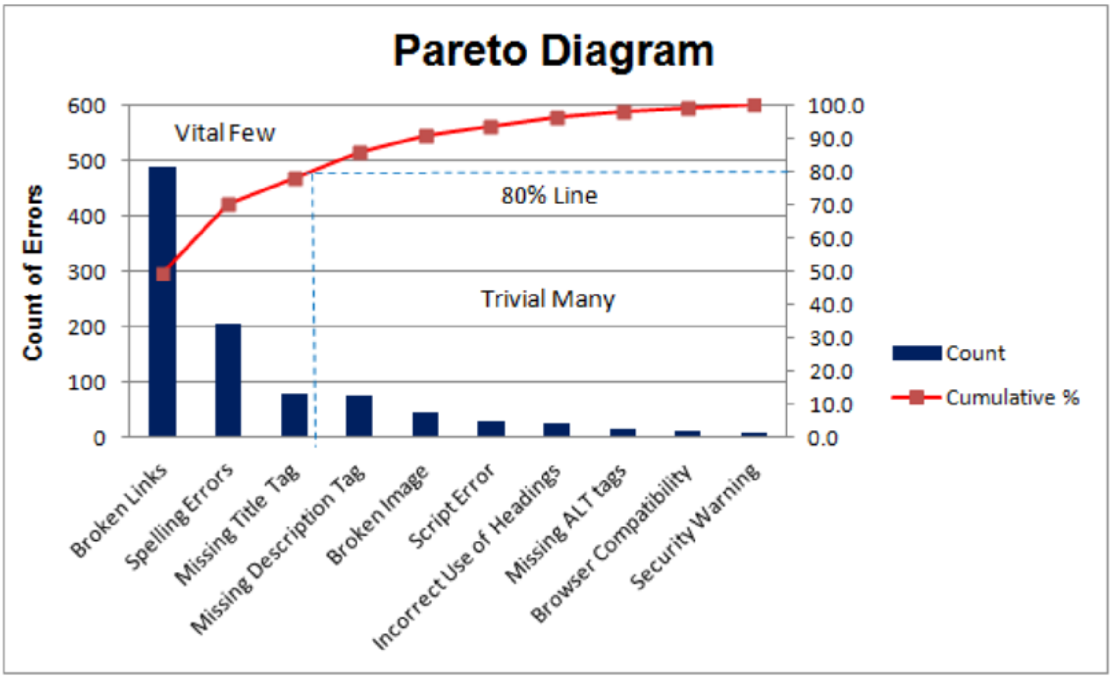


*Figure 1: Pareto Analysis* [3]

### 2.3.2 ABC ANALYSIS

It is a method of analysis that is categorised in three types: A, B and C.

**Category A** represents the most important products or customers that we have. These are the products that contribute heavily to our overall profit without spending up too much of our resources. These are products with high level of annual expenditures or high in costs.

**Category B** represents the average important products or customer that we have. These are the products with the low value of the average level of stocking. The stocktaking scale will be weekly-monthly and these are the products with the low volume of work connected with the purchasing. It's the category that we need to continue to simplify sales as soon as possible to save costs.

**Category C** is all about the hundreds of tiny transactions that are important to income but do not bring much value to the company individually. It is the group that would make most of the goods or customers live in. It's also the area where you have to try to optimize revenue and bring down operating costs as much as possible.

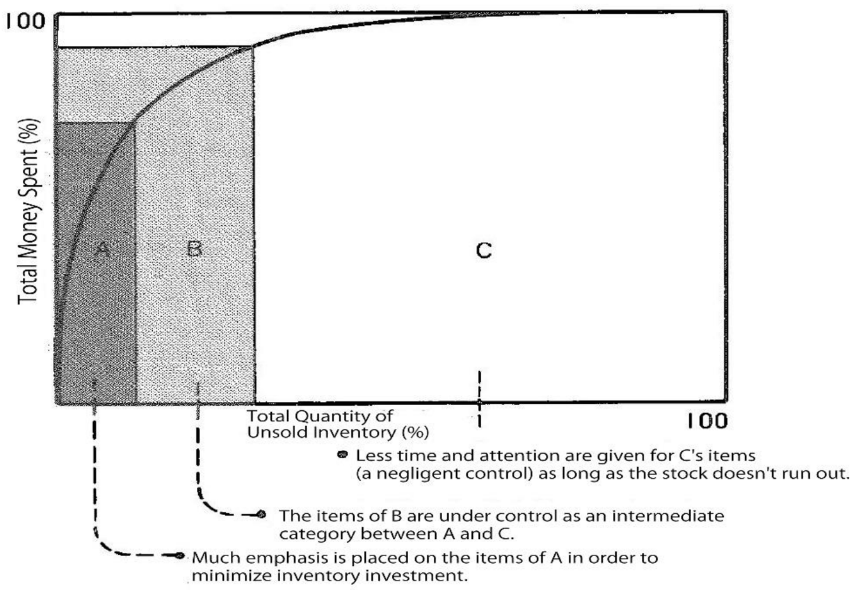


*Figure 2: ABC Analysis* [22]

ABC analysis is primarily used to enhance the ability to manage large and complex data sets by breaking them down into three parts. These segments identify the data priorities for the field in which we use them.

When the data is broken down into pieces, focusing on the data and using it meaningfully becomes simpler. By breaking down data into these parts, unique problems in the data become more evident. This also helps to have the various segments prioritized.

ABC analysis can be used to segment the consumers and break down relevant consumer data. First, we can split the customers into one of the three groups based on the amount of revenue the consumer makes available. Then, consider how that volume relates to our margin contribution.

If we effectively classify customers, customers with the highest interest should be put in the highest priority category A, while less relevant customers are put in the lowest category C. Customers anywhere in between must remain in Group B.

Segmentation helps us to identify our most valuable customers. It then helps us to look at them individually so we can shape a plan of action. If we are forced to look at things in three different categories, it is better to distribute the money in a more

Strategic way than if we are flitting back and forth through charts or only trying to make sense of raw data heaps. The downside of doing this extra step is that it makes evaluating the data practically easier, which in effect makes optimizing the profits easier [4].

### 2.3.3 BOTTLENECK ANALYSIS

A process bottleneck, in the simplest sense, is a stage of operation that gets more demands for operation than it can handle at its full efficiency. That creates a workflow interruption and delays in the production process. In other words, even if this level of work runs at its full potential, it also cannot handle all the work items fast enough to move them to the next levels without causing a delay. The bottleneck workflow can be a computer, a person, a department or a whole stage of the work. The software testing and quality control procedures are common sources of bottlenecks in the technology sector. Unfortunately, a bottleneck is still only identified after it has caused workflow blockage.

#### 2.3.3.1 METHODS TO DETECT WORKFLOW BOTTLENECK

When finding the system operates in bursts and unpredictable, there is a bottleneck somewhere, instead of a smooth flow. The main challenge is defining it and establishing an appropriate countermeasure. In Lean Management you can use many Kanban bottleneck analytics tools to find a bottleneck.

#### 2.3.3.2 IDENTIFYING BOTTLENECK

- **Visualize.** Having track of the job on a Kanban board in the form of task cards makes it very easy to see where the job things are piling up, which is a sure indication of a problem, most definitely a bottleneck.
- **Map Queues and Activities.** When sorting queues and activities and displaying them on the Kanban board, we will see how long our work sits waiting in a queue before a certain task takes place. If this queue is growing considerably faster than the processes in the activity stage work, that we have found our bottleneck.

- **Measure Cycle Time per Stage.** Measuring cycle time at each point helps us to create a diagram of the cycle time heat map. Just a glance at this map shows the stages where the most time cards spend. If these workflow stages are queues, the bottlenecks would definitely be these [5].

### 2.3.4 VSM (VALUE STREAM MAPPING)

The Value stream mapping process helps us to create a detailed visualization of all the steps in your work. This is a representation of the flow of goods through the company, from manufacturer to customer. A value stream map displays all the essential steps required for generating value from beginning to end of the work process. It helps us to imagine which task the team is working on and give reports on the progress of each assignment at a single glance.

It's important to clarify that Lean says value is what the customer would pay for.
However, when it comes to modelling a value stream, there are measures that do not add direct value to our customer but help ensure the final product / service can be provided.

Quality inspections are a simple example of these steps and are an irreplaceable phase in any production cycle. A customer doesn't pay for these inspections, so if a finished product doesn't meet the quality standards or expectations, that the customers will be less willing to buy back from the company.

#### 2.3.4.1 PURPOSE OF VSM

The primary purpose of developing a value stream map is to show us where
we can enhance the method by showing its added value as well as unnecessary measures.
Just put every important phase of our workflow on display and analyze how it brings value to our customers. It helps us to analyse the method in detail and gives us insight as to where improvements can be made to enhance the way of working [6].

### 2.3.5 MUDA

Muda is a Japanese word meaning uselessness, wastefulness or futility. Muda is a core concept in Lean production, as one of three forms of waste (muda, mura and muri) defined by the Toyota Production System. Muda refers to the seven wastes frequently found by Taiichi Ohno in Lean manufacturing:

- Transportation: Unnecessary product movement. Products are more likely to be damaged or lost during shipping, and do not add value to the product or to the customer if it is not necessary.
- Inventory: Raw materials, work-in-progress, and finished products are all included in inventory. The more time a product spends in one of these states, the more waste it produces. It disrupts the plant's workflow without adding value, causes longer lead times, and can result in damaged or defective or damaged products.
- Motion: It is not the movement of the commodity that is inefficient or dangerous, but the excessive movement of workers. It may result in worker strain injuries, downtime, or equipment failure due to normal wear and tear.
- Waiting: a product that is not processed or is not being transported is known to be "waiting." While waiting, the operation is interrupted and the product's value decreases.
- Overproduction: one of the worst kinds of waste is producing more than what is needed. While taking up important storage space, it can hide product defects and make it more difficult to manage.
- Over-processing: the delivery of a product or service that exceeds the customer's requirements can be considered as over-processing. It takes longer and demands more resources than required, making it wasteful.
- Defects: Products that do not meet (defective) company standards will likely need to be reworked or scrapped, thereby wasting the resources that have been used up until now. This increases operating costs but does not add value for the consumer [7].

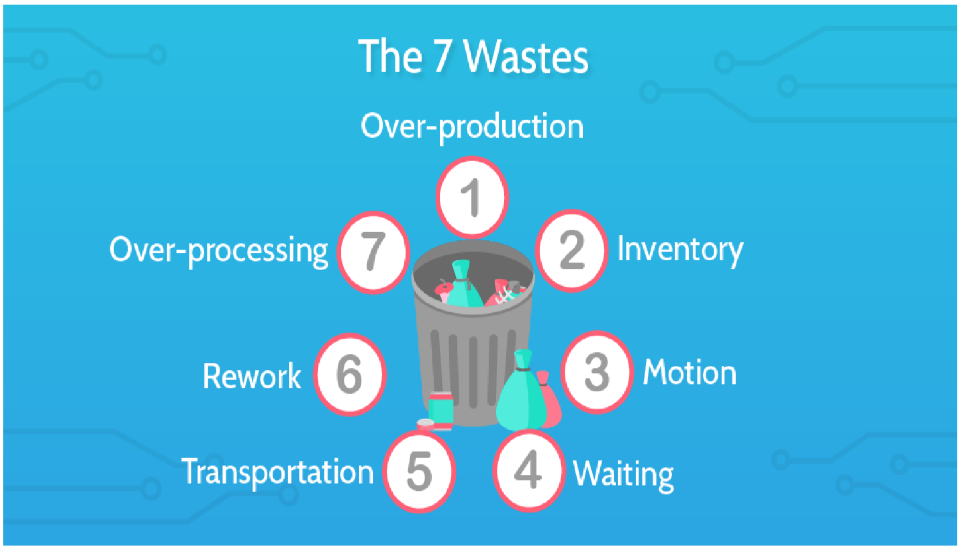


*Figure 3: 7 Types of Wastes* [7]

### 2.3.6 SIPOC

SIPOC is a tool that lists the inputs and outputs of one or more processes in a tabular form. It's an acronym for Customers, Outputs, Process, Inputs and Suppliers. Many organizations use the opposite acronym COPIS, which places the customer first and shows the organization's value to the company.

The term SIPOC originated in the 1980s and is part of the movement toward total quality. Today you will consider SIPOC as one of the fields of Six Sigma, lean design and business process management [8].

| | |
|---|---|
| Process or Function Name: AUTOMOTIVE DIVISION CUSTOMER SERVICE | Date: 2/4/16 |
| Scope: ALL U.S. CUSTOMER SERVICE FOR AUTOMOTIVE DIVISION. CANADA AND MEXICO OUT OF SCOPE. | Notes: EDI ORDER MAINTENANCE WILL BE ADDED ON 5/1/17 |

**SIPOC Diagram**

| Suppliers | Inputs | Processes | Outputs | Customers |
|---|---|---|---|---|
| Who supplies the process inputs? | What inputs are required? | What are the major steps in the process? | What are the process outputs? | Who receives the outputs? |
| CONSUMERS | PHONE ORDERS | (1) ENTER PHONE AND FAX ORDERS | ORDERS ENTERED | CONSUMERS |
| RETAIL CUSTOMERS | FAX ORDERS | (2) RESPOND TO TECHNICAL SUPPORT CALLS | CLOSED CUSTOMER INQUIRIES | RETAIL CUSTOMERS |
| SAP CRM SYSTEM | CUSTOMER CALLS AND EMAILS | (3) RESPOND TO ORDER STATUS INQUIRIES | RAPID-ALERTS DISTRIBUTED | MATURE-PRODUCT ENGINEERING |
| FIELD SALES TEAM | CUSTOMER PORTAL INQUIRIES | (4) MAINTAIN RAPID-ALERT SYSTEM FOR PRODUCT ISSUES | MONTHLY CS METRIC REPORT | EXECUTIVE MANAGEMENT |
| TECHNCIAL PRODUCT DATABASE | DATA FOR MONTHLY METRICS | (5) PUBLISH MONTHLY CS METRICS | | MANUFACTURING QUALITY |
| SAP ERP SYSTEM | PRODUCT APPLICATION DETAILS | | | FIELD SALES TEAM |
| | ORDER STATUS | | | |

*Figure 4: SIPOC Diagram* [9]

## 2.4 PRODUCTION PLANNING

Production planning is an activity that considers the best use of production resources to meet production goals (satisfying manufacturing requirements and anticipating sales opportunities) over a certain period called the planning horizon [10].

Lot-sizing and scheduling are the essential tasks for planning and controlling the production. Lot-sizing deals with determining the quantity of each product to be manufactured at each time, while scheduling is to determine the sequence of production in which the products are produced on a machine [11].

The complexity of the problems with lot sizing depends on the features the model takes into account. The following are some of the characteristics which affect modelling, classifying and the complexity of lot sizing decisions.

### 2.4.1 PLANNING HORIZON

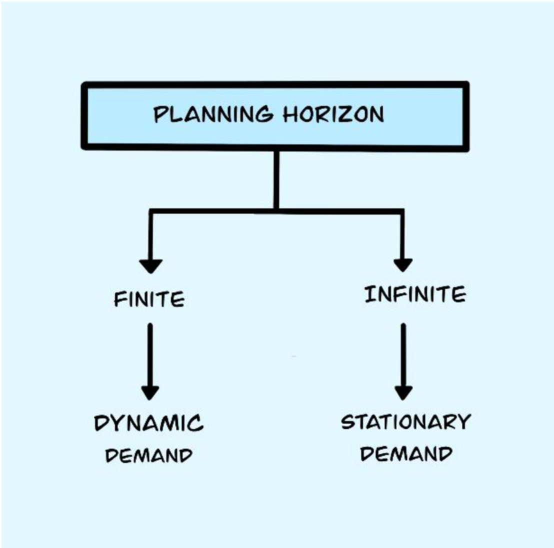


*Figure 5: Planning Horizon [source: own]*

The planning horizon is the time period at which the master schedule of production extends into the future. The horizon of planning can be finite or infinite. Dynamic demand usually follows a finite planning horizon, while stationary demand follows an infinite planning horizon. Moreover, the system can be monitored continuously or at discrete time points and then classify the system as a continuous or discrete type system.

The lot sizing problems are categorized as either big batches or small batches problems according to the terms of time period terminology. Big batches problems are ones where the period of time is too long to produce multiple items (in multi-item problem cases), whereas the period of time is so short for small batches problems that only one item can be produced in each time.

Another type of planning horizon is typically a rolling horizon Considered when data is uncertain. Under this assumption, optimal solutions act as heuristics for every horizon but cannot guarantee the optimal solution.

### 2.4.2 NUMBER OF LEVELS

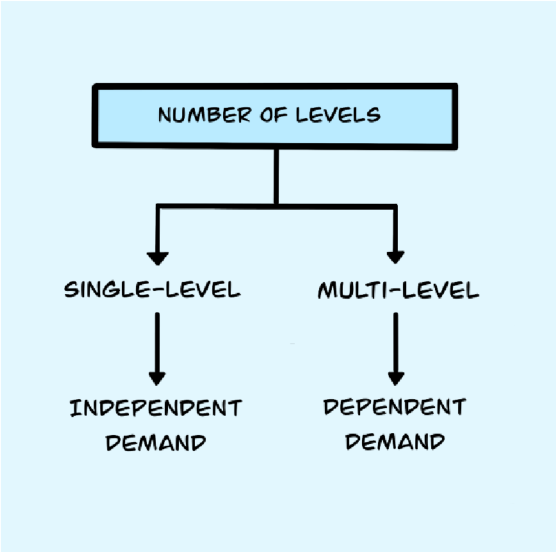


*Figure 6: Numbers of Levels [source: own]*

Production systems may be either single or multi-level. In single-level systems, the end product is usually simple. Raw materials are converted to finished product after processing by a single operation, such as forging or casting. In other words, the end item is produced directly from raw materials or materials purchased that have no intermediary sub-assemblies.

The demands of the products are determined directly from customer orders or market forecasts. This kind of demand is known as independent demand. In multi-level systems, there's a parent – component relationship among the items. Raw materials change as end products after processing by several operations.

In another operation, the output of an operation (level) is input. The demand at one level, therefore, depends on the level of demand for its parents. This kind of demand is known as dependent demand. Multi-level problem solving is more difficult than single-level problem solving.

### 2.4.3 NUMBER OF PRODUCTS

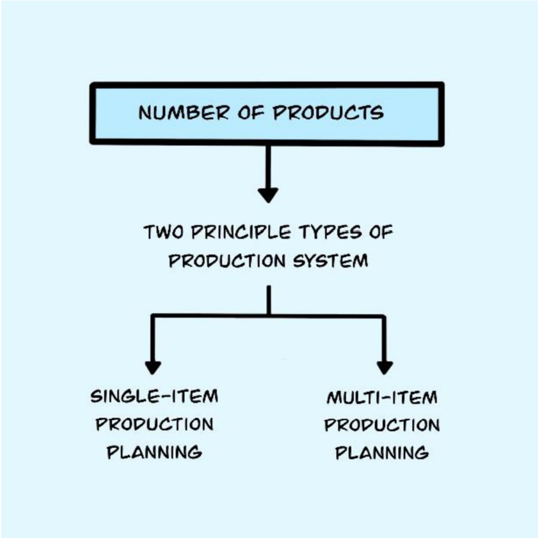


*Figure 7: Number of Products [source: own]*

One important feature that affects the modelling and complexity of production planning issues is the number of end items or final products in a production system. In terms of a number of products, there are two principal types of the production system. There is only one end item (final product) about which the planning activity needs to be planned in single-item production planning, whereas there are several end items in multi-item production planning. Multi-item problems are much more complicated than single-item problems.

### 2.4.4 CAPACITY OR RESOURCE CONSTRAINTS

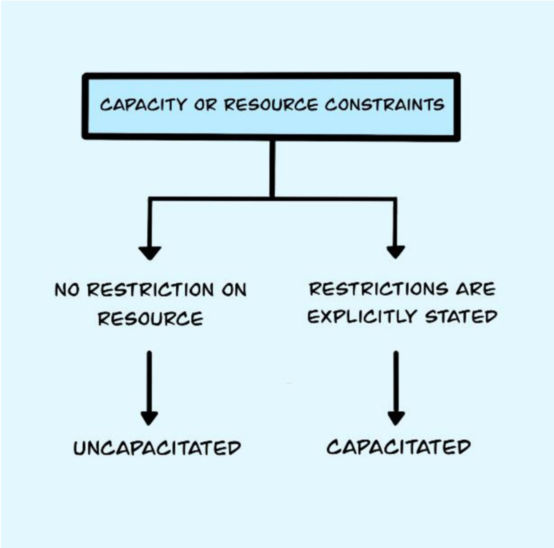


*Figure 8: Capacity of Resource Constrains [source: own]*

In a production system the resource or capacities include budget, machines, equipment, manpower, etc. When there's no resource restriction, the problem is said to be uncapacitated and when capacity constraints are explicitly imposed the problem is reported to be named capacitated. Restriction in capacity is important and it directly affects the complexity of the problem. Problem solving is more difficult when there are capacity constraints.

### 2.4.5 DEMAND

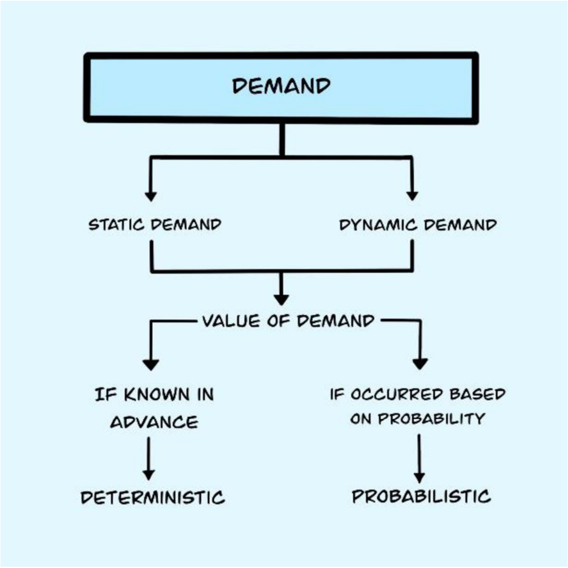


*Figure 9: Demand [source: own]*

Demand type is considered to be an input to the problem model. Static demand means that its value is stable or even constant over time, whereas dynamic demand means that its value varies over time. If the demand value is known in advance (static or dynamic), it is called deterministic, but unless it is known exactly and the demand values that occur are based on several probabilities and are then considered probabilistic. In cases of independent demand, the requirements of an item don't depend on decisions about the lot size of another item. In single-level production systems this kind of demand can be seen.

For multi-level lot sizing, where there is a parent-component relationship between items, because one-level demand depends on the demand for their parents (previous level), it is called dependent. Dynamic and dependent demand problems are much more complex than static and/or independent demand problems. In general, probabilistic demand problems may be more complex than deterministic demand problems.

### 2.4.6 SETUP STRUCTURE

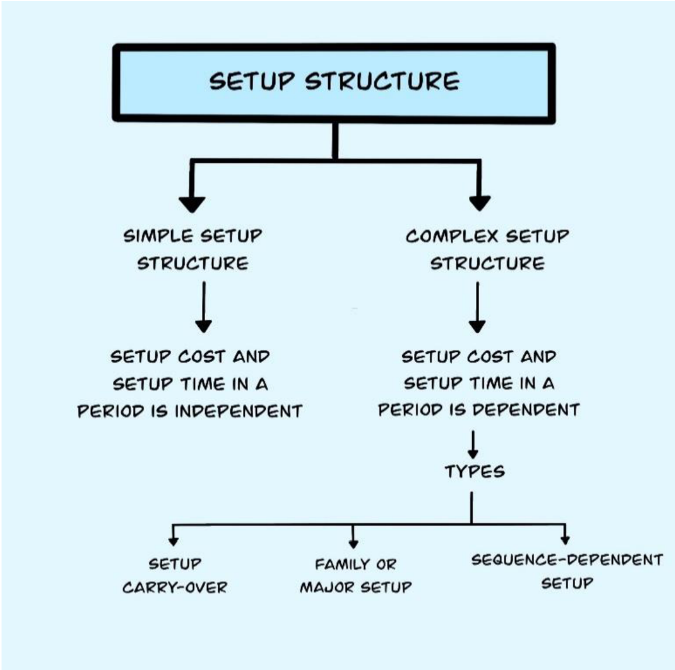


*Figure 10: Setup Structure [source: own]*

Another essential feature that directly affects the complexity of problems is the setup structure. Setup costs and/or setup times are typically modelled by introducing zero-one variables into the problem's mathematical model and cause more difficult to solve problems. Production changes between different products can usually take setup time and setup cost. Simple setup structure and Complex setup structure are the two types of setup structure. If the setup time and cost are independent of the sequence and the decisions in previous periods, it is called a simple setup structure, but it is called a complex setup when it depends on the sequence or previous periods. Now we could define three types of complex setups.

First, if the production run from the previous period into the current period can be continued without the need for additional setup, thus reducing setup costs and time, the structure is called setup carry-over. We may also define a second type of complex setup, family or major setup, caused by similarities in the process of making and designing a group of items. Often an item setup or a minor setup occurs when the production among items within the same family changes. When we have sequence-dependent setup, the cost of setting up items and the time depends on the sequence of production; this is the third type of complex setup structure. Obviously, the complex structures are more difficult in both modelling and solving the problems of lot sizing [10].

## 2.5 LOT – SIZING PROBLEM

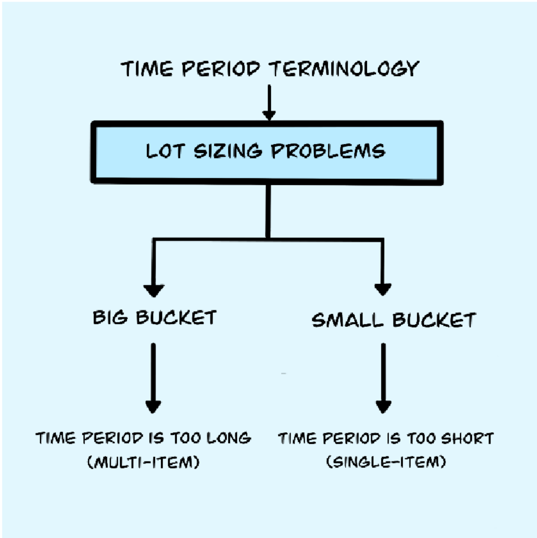


*Figure 11: Time Period Terminology [source: own]*

Lot sizing problems are the mathematical models with production planning with setups between production lots. Because of these setups, the production of a given product in every period is often too costly. At the other hand, generating fewer setups by producing large quantities to meet future demands leads to high cost of holding inventories. The goal is, thus, to determine the periods of production and the quantities to be produced in order to meet demand while reducing the cost of production, set-up and holding inventories [12].

The classification of problems with lot sizing is based on many criteria: number of machines, number of production stages (levels), capacity constraints and their existence (fixed or variable), length of production times, etc.

We may consider single-level and multi-level problems, based on production stages. But if we concentrate on the length of the period, we can talk about big time bucket Problems and small-time bucket problems. Small-time bucket issues have short production periods which are usually in the order of a few hours. Big time bucket problems consist of longer periods of time, usually a few days or weeks in order and which are characterized by the ability to produce more than one-unit item per period. Sometimes, they are called Discrete Lot Sizing Problems [12].

### 2.5.1 SINGLE LEVEL CAPACITATED LOT SIZING PROBLEM

In the context of production planning at single level, with Finite planning horizon and known dynamic demand without incurring backlogs, the classic capacitated lot sizing problem (CLSP), consists of determining the timing and amount of the planning horizon for the production of products. Restrictions on capacity constrain the quantity of production in each period. A fixed cost of setup and a linear cost of production are specified, and the cost of holding an inventory is proportional to the amount of inventory and the time carried.

In the classical CLSP, though setup costs can vary These are independent sequences for each product and for each time period. There are also some CLSP variants, where setups depend on sequence. As mentioned earlier, this kind of problem is called the complex setup structure. Classical CLSP's aim is to define a minimum cost production plan.

**Assumptions**

The following are the key assumptions for the multi-item capacitated lot-sizing problem in a flow-shop system with energy consideration:

- A flow-shop structure is used to manufacture a variety of products.
- Lot-sizing and scheduling decisions are made simultaneously.
- The capacity of each machine is restricted.
- The demands are known in advance.
- The demands are satisfied at each period.
- There is no lead time between the different production levels.
- Vertical interaction: If this quantity is not available at the previous buffer stock, a machine $m$ cannot start producing a quantity $x_j$, $m$, $t$ of product $j$ in period $t$.
- The machine cannot process more than one product simultaneously.
- For each machine, several setups are allowed at each period.
- The system's power consumption is proportional to the number of equipment operating in parallel (overlap between machines). It does not exceed a maximum power limit.

**Sets and Indices**

$T$ = Number of periods.

$N$ = Number of items.

$i$ = index of an item.

$t$ = index of a period.

**Parameters**

$d_{it}$ = demand (Where denominator $i$ represents the item and $t$ represents the period in all cases)

$C_t$ = available capacity.

$f_{it}$ = setup time.

$v_{it}$ = unitary resource consumption.

$\alpha_{it}$ = production unit cost.

$\beta_{it}$ = setup cost.

$\gamma_{it}$ = inventory unit cost.

**Variables**

$x_{it}$ = the quantity of item.

$y_{it}$ = binary setup variable.

$s_{it}$ = the inventory level.

### 2.5.2 AGGREGATE FORMULATION

The objective function minimizes the total cost that aggregates production, setup, inventory and shortage costs. The MCLS-LS model has the following aggregate formulation:

$$\sum_{i=1}^{N}\sum_{t=1}^{T}(\alpha_{it}\, x_{it} + \beta_{it} y_{it} + \gamma_{it} S_{it}) \tag{1}$$

### 2.5.3 DISAGGREGATE FORMULATION

In this formulation a strong lower bound for capacitated lot sizing problems is provided. It is opposite to the previous formulation; the production period and delivery period helps to define the production variable. Here new production variable is defined $z_{itt'}$ that corresponds to the quantity of item *i* produced at time period *t* and to satisfy demand at period $t'$. Inventory variables might be eliminated using these new variables. This formulation has more production variable that the aggregate model and generally better lower bound is provided [13].

Let us define $\alpha'_{itt'}$ , the cost of production per unit of item *i* at period *t* to satisfy a unit demand at period $t'$.The MCLS-LS model has the following disaggregate formulation:

$$\min \sum_{i=1}^{N} \sum_{t=1}^{T} \left( \sum_{t'=t}^{T} \alpha'_{itt'} \, z_{itt'} + \beta_{it} y_{it} \right) \tag{2}$$

### 2.5.4 LAGRANGIAN RELAXATION OF CAPACITY CONSTRAINS

The key concept behind the method is to decompose a Multi-item Capacitated lot-sizing problem into *N* single-item uncapacitated lot-sizing problems by relaxing the linking constraints (in this case the capacity constraints). In the objective, the violation of capacity is penalized Function $\pi_t \geq 0$ with Lagrange multipliers.

When using Lagrangian relaxation on capacity constraints to derive a lower bound for the MCLS-LS problem, we get *N* ULS-LS problems which need to be optimally solved. Since each item is considered separately, it is convenient to remove the item index *i* to make reading easier [13]. The ULS-LS problem has the following aggregate formulation:

$$\min \sum_{t=1}^{T} (\alpha_t x_t + \beta_t y_t + \gamma_t S_t) + \sum_{t=1}^{T} \pi_t (v_t x_t + f_t y_t - C_t) \tag{3}$$

## 2.6 OPTIMAL BATCH SIZE

The number of manufactured units in a production run is referred to as batch size. Where there is a large setup cost, managers tend to increase the batch size to spread the setup cost over more units. This can be expensive if the extra units produced are not used or sold immediately, as they may become obsolete. Consequently, a production system which that batch sizes is generally considered more cost-effective [14].

Finding **optimal batch sizes** in a production environment, is a problem faced by many manufacturers. The smaller batch sizes would reduce the stock and help the company manufacture according to customer orders which is one of Lean's manufacturing objectives. However, the increased number of long setups may decrease the production time available and expose the production line to the risk of unmet customer demand. Bigger batch sizes will reduce setup numbers and increase the time available for production, but they will also increase the value of inventory levels. For a longer period of time more products will be in stock and exposed to deterioration. A big storage would also be needed to keep the goods in stock. Lack of optimization causes more obstacles as a larger product mix is present in a production environment. Here, we are going to see the models used to select optimal ordering and manufacturing batch sizes.

## 2.7 MODELS USED TO SELECT OPTIMAL ORDERING BATCH SIZE

The below given are some models used to select optimal ordering batch size which is described with assumptions, notations and formulas.

### 2.7.1 ECONOMIC ORDER QUANTITY

This is the quantity of both the product order and the actual order that a company can buy to reduce inventory costs including holding costs and ordering costs. It is the optimal inventory size to be ordered from the supplier to minimize the company's total annual inventory cost. The EOQ formula is best applied in situations in which there is a constant demand, ordering and holding costs over time.

### 2.7.2 INVENTORY MODELS

In inventory management there is one basic problem which is to find out the order quantity, this is economical form from overall operational point of view. The problem here lies in balancing the two conflicting costs, i.e., the cost of purchasing and cost of transporting inventories. Stock models help to assess the order volume that minimizes overall costs (sum of costs for ordering and costs for transporting inventories). Models of an inventory are classified as shown in (*Figure 12*).

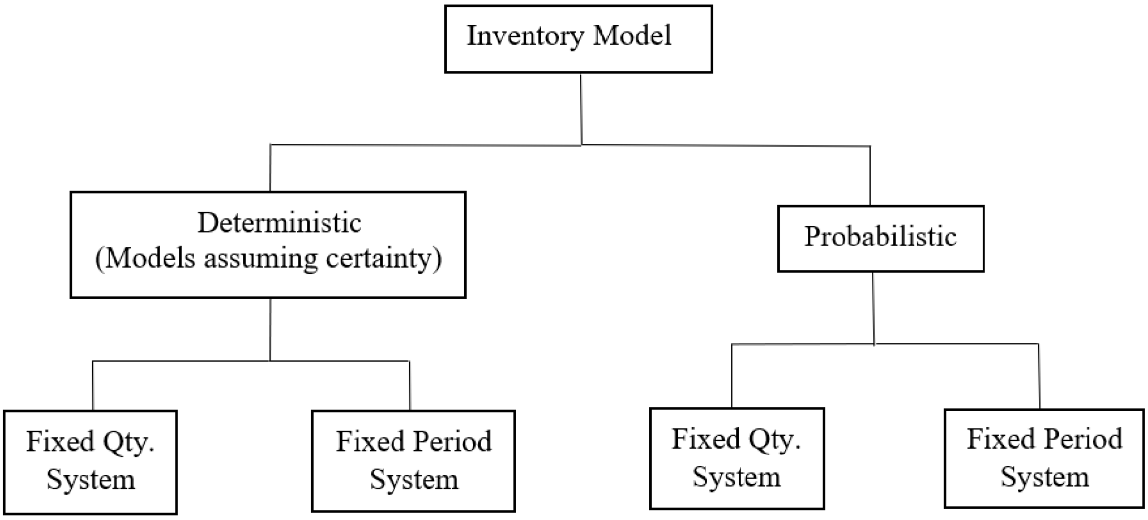


*Figure 12: Inventory Model* [15]

#### 2.7.2.1 MODEL 1: ECONOMIC ORDER QUANTITY WITH IMMEDIATE STOCK REPLENISHMENT

(Basic Inventory Model)

<u>*Assumptions:*</u>

I. Demand is deterministic, so it is proven to be continuous.
II. Instant stock replenishment (Lead Time is zero)
III. The price of the products is set (discounts for quantities are not allowed)
IV. Price of ordering does not differ with amount of order.

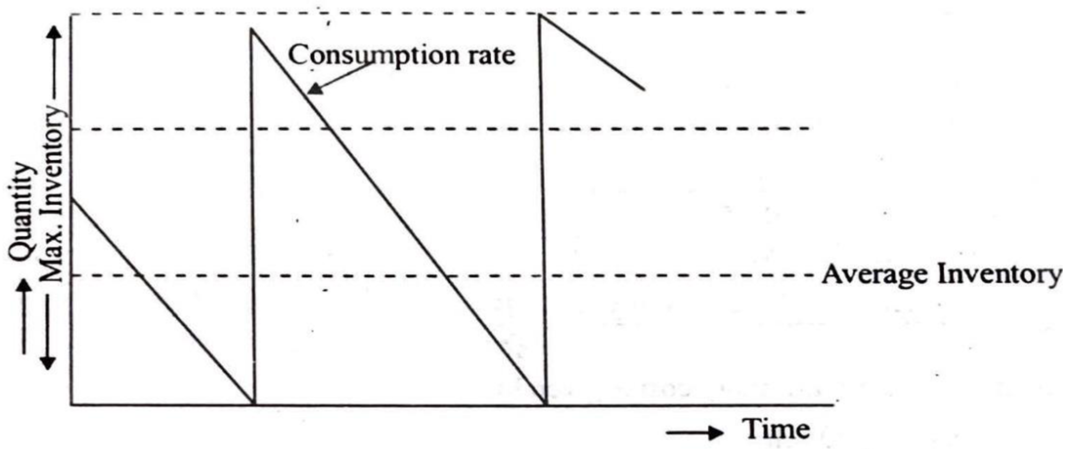


*Figure 13: Basic Inventory Model* [15]

Let D be the yearly demand (units per annum)

$C_o$ = Ordering costs (price /order)

$C_h$ =Inventory carrying costs (price/unit/unit time)

$C_p$ = Price per unit

$Q$ = Order quantity

$Q*$ = Economic order quantity

$N$ = Number of orders placed/ year

$T_c$ = Total cost per annum

$$Q^* = \sqrt{\frac{2DC_o}{C_h}} \tag{4}$$

$$T_{cm} = \sqrt{2DC_o}.C_h \tag{5}$$

#### 2.7.2.2 MODEL 2: ECONOMIC ORDER QUANTITY IN CASE STOCK REPLENISHMENT IS NOT IMMEDIATE

(Production Model)

This model is applicable if inventory continuously builds up at a steady pace over a period of time after making an order or when the items are purchased and used (or sold).

Since this model is uniquely tailored to the industrial context where output and use are parallel, it is called the "Production Model."

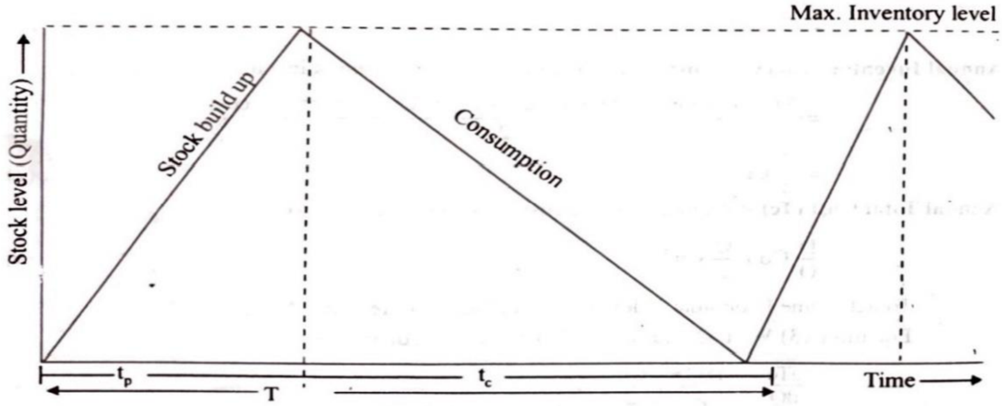


*Figure 14: Production Inventory Level* [15]

*Assumptions:*

I. The item is sold or consumed at known constant demand cost.
II. The setting up expense is constant, and the scale of the lot does not change.
III. Production changes are not sudden but are incremental.

- Let *p* be the production rate.
- *D* is demand or consumption rate.
- Inventory replenishment throughout the time *tp* during this system build-up, and consumption occurs during the entire cycle *T*.

$$Q^* = \sqrt{\frac{2DC_o}{(1 - d/p)C_h}} \tag{6}$$

$$N^* = \frac{Annual\ demand}{Economic\ batch\ Qty\ (EBQ)} = \frac{D}{Q^*} \tag{7}$$

### 2.7.2.3 MODEL 3: AN INVENTORY MODEL ALLOWING FOR SHORTAGES

In certain practical cases it is not permitted to have shortages or stock outs. So, it must be stopped the stocks out circumstances. Occasions that stock-out becomes economically justifiable. This condition is usually found when costs per unit are very high.

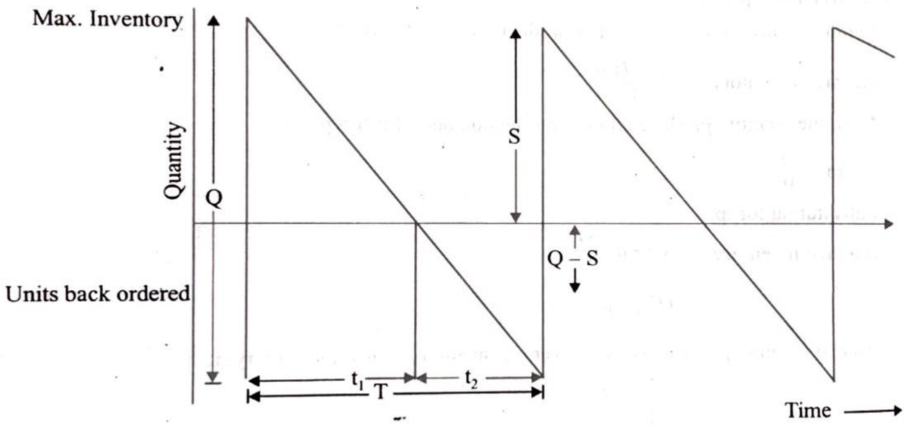


*Figure 15: Production Inventory Level* [15]

$C_s$ = Cost shortage (store-out costs) per unit per period

$S$ = Balance units are satisfied after back orders

$Q$-$S$ = Number of shortages per order

$t_1$ = Time period in which inventory is positive

$t_2$ = shortage exists with time duration

$T$ =Time between the receipt of orders

The fundamental premise is that sales are not lost due to stick-out or shortages.

$$Q^* = \sqrt{\frac{2DC_0\,(C_s + C_h)}{C_h \qquad C_s}} \tag{8}$$

$$T_{cm} = \sqrt{2DC_o.C_h\left(\frac{C_s}{C_h + C_s}\right)} \tag{9}$$

#### 2.7.2.4 Model 4: Inventory Model with Discounts in Price

The supplier also offers discounts when the products are purchased in big amounts. However, if the item is imported to take advantage of the sale, the overall amount of inventory will increase, and therefore the cost of holding inventory will increase. Benefits from big orders to the purchaser include reduced cost per item, lower cost of packaging and storage, lower cost of processing and lower cost of purchasing due to less order numbers.

Such benefits are to be compared with the cost of holding increased. As the order size grows, more space for stocking products will be given.

Therefore, a determination must be made as to whether the seller will stick to the amount of economic order or raise the same to take advantage of the fact that, at large volumes, the cost of output per item is smaller (scale economy) and therefore part of the profit may be passed on to the consumer.

Let annual consumption be '$D$' (Demand)
$C_1$ = Basic price that is in price per unit.
$C_2$= Discount price per unit.
$C_o$= Ordering cost
$I$ = Inventory carrying cost which is expressed in percentage (%) of inventory investment in average.
$Q_B$= Price break quantity.

$$Q_{2=}\sqrt{\frac{2DC_o}{C_2 I}} \tag{10}$$

Compare $Q_2$ with $Q_B$ for Price break quantity
If $Q_2 \geq Q_B$, Order quantity $Q_2$.
If $Q_2 < Q_B$ Compute $Q_1$ and calculate.
Annual total cost $Q_1$ and $Q_B$

Annual total cost $Q_1(T_{c\,Q1}) = D.C_1 + \frac{D.C_O}{Q_1} + \frac{Q_1.C_1 I}{2}$ (11)

Annual total cost $Q_B(T_{c\,QB}) = D.C_2 + \frac{D.C_O}{Q_B} + \frac{Q_B.C_2 I}{2}$ (12)

If $T_{c\,QB} < T_{c\,Q1}$ select $Q_B$, Otherwise purchase $Q_1$. If $(Q_B)$ the total annual cost at price break quantity is less than annual total cost $Q_1$, order quantity $Q_B$. A flow chart is shown in (*Figure 16*) [15].

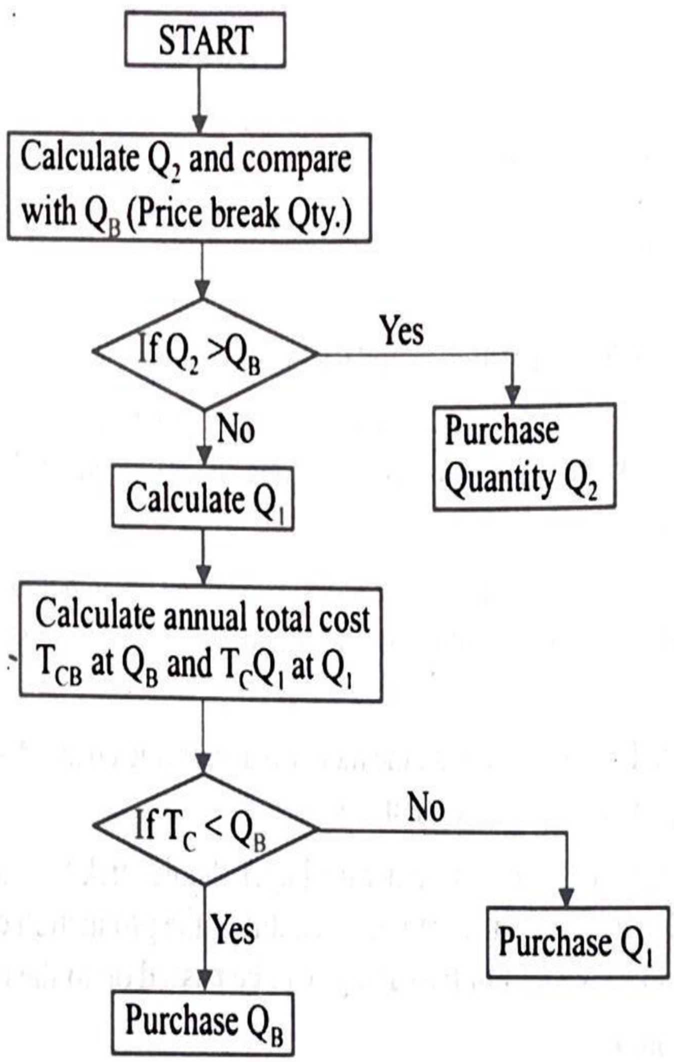


*Figure 16: Inventory Model with Shortage Permission* [15]

## 2.8 MODELS USED TO SELECT OPTIMAL MANUFACTURING BATCH SIZE

The below given are some models used to select optimal manufacturing batch size which is described with assumptions, notations and formulas.

### 2.8.1 AN OPTIMAL BATCH SIZE FOR A MANUFACTURING SYSTEM UNDER PERIODIC DELIVERY

In this area, a general cost model is created thinking about both provider (of raw material) and purchaser (of finished products) perspectives. This model is utilized to decide an ideal requesting strategy for obtainment of raw materials, and the assembling group size to limit the complete expense for meeting equivalent shipments of the finished items, at fixed stretches, to the purchasers.

So as to locate an economic order quantity (EOQ) for the raw materials and an economic production quantity (EPQ) for the production run, the accompanying expenses are generally considered:

- Raw material inventory carrying cost.
- Finished goods inventory carrying cost and
- Raw material ordering cost.
- Manufacturing set-up cost.

*Assumptions:*

- Production rate is finite and constant.
- No shortages are permitted.
- The capacity of production exceeds the demand.
- After a set period of time, a fixed quantity of the product is delivered.

*The following are the notations used to develop the cost functions:*

$D_p$ demand rate of a product $p$, units per year

$P_p$ production rate, units per year (here, $P_p > D_p$ )

$Q_p$ production lot size

$H_p$ annual inventory holding cost (cost/unit/year)

$A_p$ setup cost for a product $p$ (cost/setup)

$r_i$ amount/quantity of raw material $i$ required in producing one unit of a product

$D_i$ demand of raw material $i$ for the product $p$ in a year, $D_i = r_i D_p$

$W_p$ Weight of single unit of finished product.

$Q_i$ ordering quantity of raw material $i$

$A_i$ ordering cost of a raw material $i$

$H_i$ annual inventory holding cost for raw material $i$

$PR_i$ price of raw material $i$

$Q_i^*$ optimum ordering quantity of raw material $i$

$Q_p^*$ Optimal production Lot Size.

$x$ shipment quantity to customer (units/shipment)

$L$ time between successive shipments, $= x/D_p$

$T$ cycle time measured in year, $= Q_p/D_p$

$m$ number of full shipments $= T/L$

n number of shipments during production uptime

$T_1$ production uptime in a cycle

$T_2$ production down time in a cycle $= T - T_1$

$TC_s$ Total cost of the system

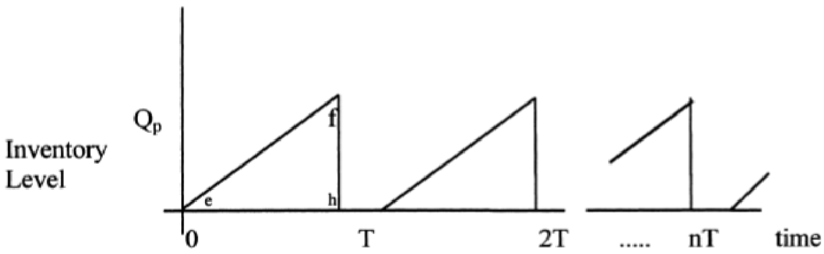


*Figure 17: Finished Product Inventory System* [16]

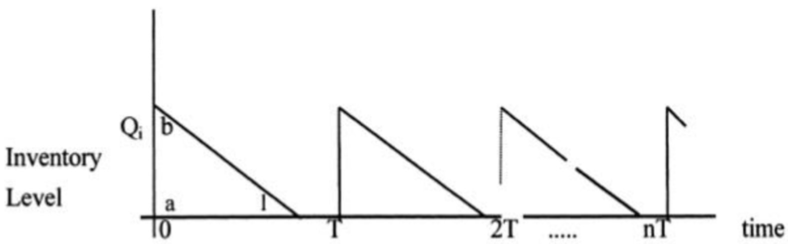


*Figure 18: Raw Material Inventory System* [16]

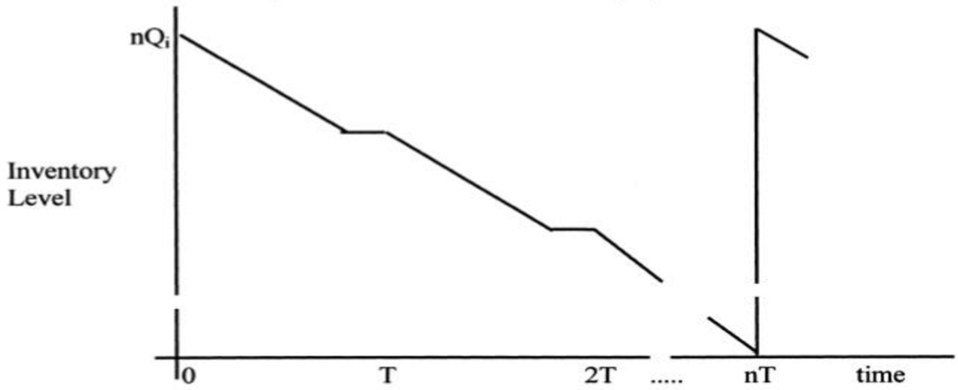


*Figure 19: Raw material Inventory System* [16]

#### 2.8.1.1 OPTION 1, CASE A

In this model, we consider the ordering quantity of raw material to be equivalent to the necessity of the raw material for a batch of the production system. The raw material replenished at the start of a manufacturing cycle would be consumed entirely by the end of the cycle. This is shown in above (*Figure 17*) & (*Figure 18*).

From figures (17) & (18),

$t_s$ = production time (cycle)
$T$ = length of production cycle (time)
Raw material inventory in a cycle time $T$ = area (*abl*) = ${}^{1}/_{2}\, Q_i t_s$
Finished product inventory in a cycle = area (*efh*) = ${}^{1}/_{2}\, Q_p t_s$
So average raw material inventory in a cycle $({}^{1}/_{2}\, Q_i t_s)/T = Q_i D_p/2P_p$
So average finished product inventory in a cycle $({}^{1}/_{2}\, Q_p t_s)/T = Q_p D_p/2P_p$

Initially, let 's consider $i$ = 1 which is for one raw material only. In this case, the overall expense of the system is equal to the sum of the finished product's set-up expense, the finished product 's inventory keeping cost, the raw material ordering cost and the raw material inventory keeping cost, i.e.

$$TC_s = A_p \frac{D_p}{Q_p} + H_p \frac{Q_p D_p}{2P_p} + A_1 \frac{D_1}{Q_1} + \frac{Q_1 D_p}{2P_p} H_1 \tag{13}$$

Differentiating TCs with respect to $Q_p$ and then equating to zero, we get the economic lot size,

$$Q_p^* = \sqrt{\frac{2P_p(A_p + A_i)}{H_p + r_i H_i}} \tag{14}$$

Case of multiple raw materials:

$$Q_p^* = \sqrt{\frac{2P_p(A_p + \sum_i A_i)}{H_p + \sum_i r_i H_i}} \tag{15}$$

### 2.8.1.2 OPTION 2, CASE A

Ordering quantity of raw material is assumed as $i\ to\ be\ n_i\ (intiger\ value)$ times the quantity required for one lot of a production. This is shown in (*Figure 17*) & (*Figure 19*)

Let us consider $i = 1$. Total cost of the system, $TC_s$ , is the amount of the setup cost, finished product inventory holding cost, raw material ordering cost, and raw material inventory holding cost, i.e.,

$$TC_s = \frac{D_p}{Q_p}\left(A_p + \frac{A_1}{n_1}\right) + \frac{Q_p}{2}\left(H_p \frac{D_p}{P_p} + r_1 \frac{D_p}{P_p} H_1 + n_1 r_1 H_1 - r_1 H_1\right) \tag{16}$$

Now differentiating $TC_s$ with respect to $Q_p$ and then equating to zero we get the joint economic lot size:

$$Q_p^* = \sqrt{\frac{2D_p\left(A_p + \frac{A_1}{n_1}\right)}{\frac{D_p}{P_p}(H_p + r_1 H_1) + H_1 r_1 (n_1 - 1)}} \tag{17}$$

Case of multiple raw materials:

$$Q_p^* = \sqrt{\frac{2D_p\left(A_p + \sum_i \frac{A_i}{n_i}\right)}{\frac{D_p}{P_p}(H_p + \sum_i r_i H_i) + \sum_i H_i r_i (n_i - 1)}} \tag{18}$$

#### 2.8.1.3 OPTION 2, CASE B

The raw material ordering quantity is assumed as *i to be* $n_i$ the quantity needed for one batch of output, where $n_i$ is an integer. The buyer demand is constant and the production batch is delivered in multiple instalments [16].

The buyer demand is constant but the production batch is delivered in multiple instalments.

This is shown in (*Figure 20*) & (*Figure 21*)

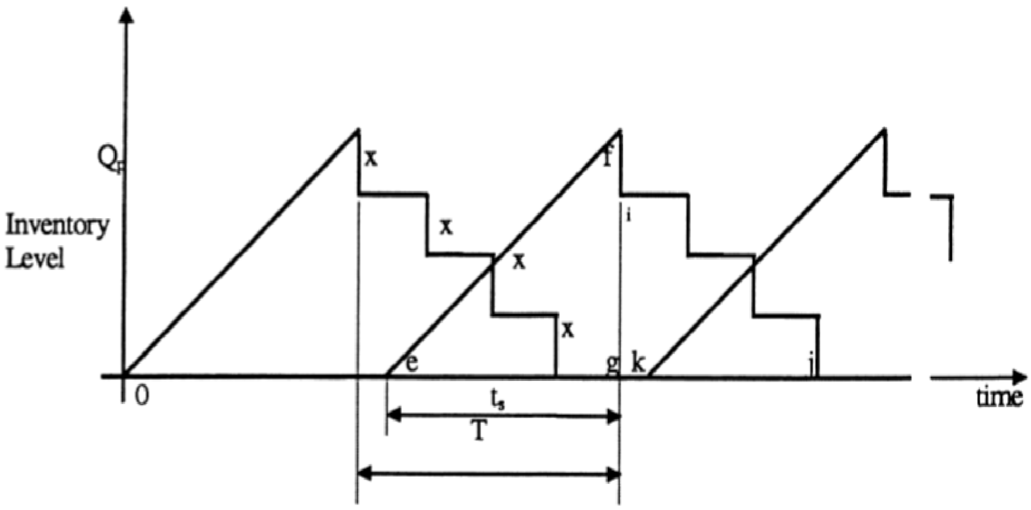


*Figure 20: Finished Product Inventory Level* [16]

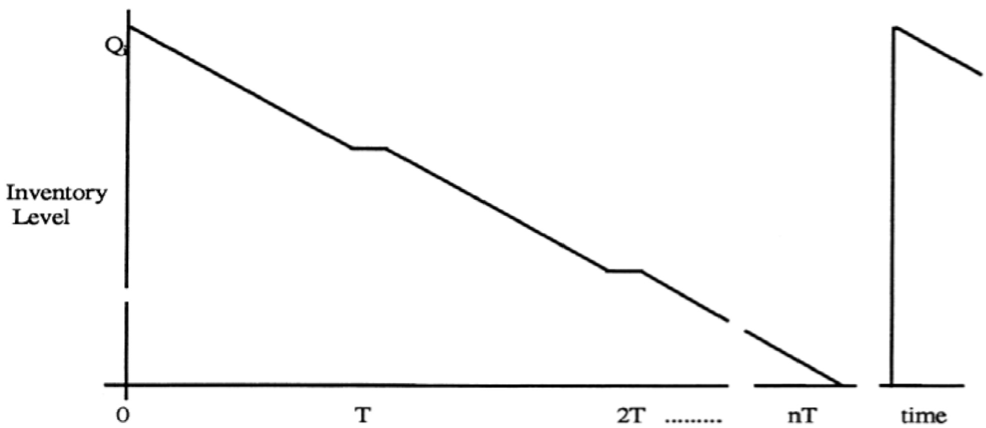


*Figure 21: Raw Material Inventory System* [16]

Let us now consider $i = 1$. Total cost of the system,

$$TC_s = \frac{D_p}{Q_p}\left(A_p + \frac{A_1}{n_1}\right) + \frac{Q_p}{2}(KK) - \frac{x}{2}H_p \tag{19}$$

Where,

$$KK = \left(\frac{D_p}{Q_p} + 1\right) H_p + r_1 H_1 \left(\frac{D_p}{Q_p} + n_1 - 1\right) = CC + n_1 r_1 H_1 \text{ and} \tag{20}$$

$$CC = \left(\frac{D_p}{Q_p} + 1\right) H_p + r_1 H_1 \left(\frac{D_p}{P_p} - 1\right) \tag{21}$$

### 2.8.2 AN OPTIMAL BATCH SIZE FOR A JIT MANUFACTURING SYSTEM

JIT's main focus is on identifying and overcoming challenges in the production process. It shows hidden inventory problems. Just in Time method prevents a company from using excessive inventory and smooth production operations if a specific task takes longer than expected or a defective part in the system is discovered. This is also one of the key reasons why the industries (which opt for JIT) are investing in preventive maintenance; when a part / equipment breaks down, the whole manufacturing cycle stops.

A batch production system, where a manufacturer is considered to be using several raw materials to manufacture a product. Traditionally, the economic lot sizes are determined separately for manufacturing a product and purchasing raw materials. However, their ordering quantities depend on the batch quantity of the product as the raw materials are used in production.

Hence, the problem of economic purchase of raw materials from economic batch quantity is not desirable to be isolated. As a result, the optimum production lot size of a product and the ordering quantities of the related raw materials need to be determined together. This could be done by treating production and purchase as components of a single system, thus minimizing the system's total cost.

***Mathematical Formulation***

In this part two cases are discussed, where in case 1 the ordering quantity of raw material is assumed to be equal to the raw material required for one batch of production system.

That is, raw materials replenished at the start of a production cycle will be completely consumed at the end of the production run if the JIT supply system is used and in case 2, it is assumed that the ordering quantity of a raw material to be *n* times the quantity required for one lot of a product, where $n$ is an integer and this case is not favourable for JIT environment. Effective algorithms may be applied to solve the above problems using an optimization technique [17].

*The following are the notations used to develop the cost functions:*

$D_p$ demand rate of a product $p$, units per year

$P$ production rate, units per year (here, $P > D_p$ )

$Q_p$ production lot size

$H_p$ annual inventory holding cost (cost/unit/year)

$A_p$ setup cost for a product $p$ (cost/setup)

$A_r$ ordering cost of a raw material $r$

$H_r$ annual inventory holding cost for raw material $r$

$Q_r$ ordering quantity of raw material $r$

$D_r$ demand of raw material , $D_r = f_r D_p$

$f_r$ Quantity of raw material $r$ required in producing one unit of a product.

$f_p$ weight of single unit of finished product.

$Q_p^*$ Optimal production Lot Size.

$Q_r^*$ optimum ordering quantity of raw material $i$

$x$ shipment quantity to customer at a regular interval (units/shipment)

$L$ time between successive shipments, $= x/D_p$

$T$ cycle time measured in year, $= Q_p/D_p$

$m$ number of shipments during the cycle time $= T/L$

$n$ number of shipments during production uptime

$T_1$ production uptime in a cycle

$T_2$ production downtime in a cycle $= T - T_1$

$TC$ Total cost of the system

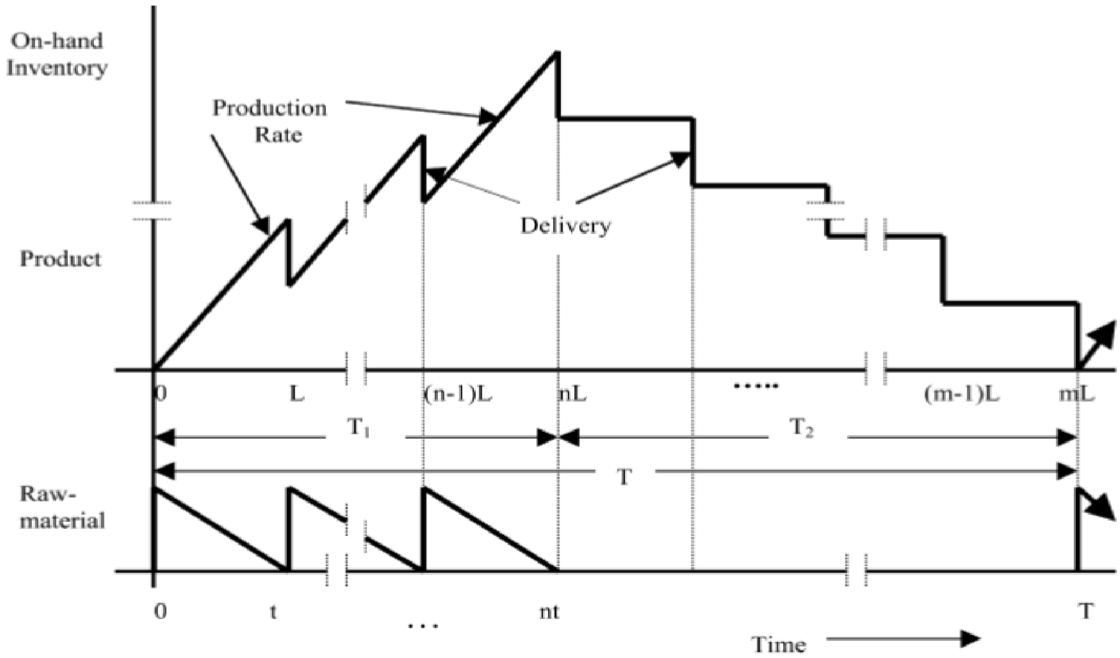


*Figure 22: Inventory level with time for product (top), and raw material (bottom)* [17]

### 2.8.2.1 CASE 1

In order to find an optimal manufacturing quantity, it is necessary to differentiate $TC1$ with respect to $Qp$In order to find an optimal manufacturing quantity, it is necessary to differentiate $TC_1$ with respect to $Q_p$. It contains an integer variable *m* but the function is non-differentiable in this case. For a given *m*, however, it can be seen that *TC* is a convex function of $Q_p$. The integer variable *m* can be replaced by $Q_p$/*x*, as we assumed in the previous section. So, the new cost equation is,

$$TC_1 = \frac{D_p}{Q_p}(A_r + A_p) + Q_p\left(\frac{D_p}{2P} f_r H_r - \frac{D_p}{2P} H_p + \frac{H_p}{2}\right) + \frac{xH_p}{2} \qquad (22)$$

$TC_1$ is a convex function. Then, differentiating $TC_1$ with respect to $Q_p$ and then equating to zero, we get

$$Q_p^* = \sqrt{\frac{D_p(A_p + A_r)}{KK}} \qquad (23)$$

Where,

$$KK = \frac{D_p}{2P} f_r H_r - \frac{D_p}{2P} H_p + \frac{H_p}{2} \tag{24}$$

#### 2.8.2.2 CASE 2

Substituting the integer variable m by $Q_p/x$,

$$TC_2 = \frac{D_p}{Q_p} A_p + Q_p \left(1 - \frac{D_p}{2P}\right) H_p - \frac{H_p}{2} Q_p + \frac{D_r}{P_L} A_r + \frac{D_p}{P} \left(\frac{f_r PL}{2}\right) H_r + \frac{x H_p}{2} \tag{25}$$

It can also be shown that $TC_2$ is a convex function. Now, differentiating $TC_2$ with respect to $Q_p$ and then,

$$Q_p^* = \sqrt{\frac{D_p A_p}{\frac{H_p}{2}\left(1 - \frac{D_p}{P}\right)}} \tag{26}$$

### 2.8.3 ECONOMIC PRODUCTION QUANTITY MODEL

The Economic production quantity is the optimal size of the lot to be manufactured in a production unit in order to prevent excessive financial blockages and excess storage costs. To ensure uninterrupted work, this production quantity is necessary [18].

Batch production (Economic production quantity) is a technique that is widely used for a series of small batches to distribute the total production instead of mass production in one go. Production of goods in batches is sometimes necessary because, for example, some equipment used in production (e.g., dyes) can wear out and need to be replaced before production can run again.

*Assumptions:*

- Constant demand and easy restocking.
- Constant price of the product.
- Constant quantity.
- Holding, set-up and ordering costs remain unchanged.

*The following are the notations used to develop the cost functions:*

$Q^*$ - Economic production quantity

$D$ - Total demand (units per year)

$C_s$ – Unit setup cost (€ per production run)

$C_h$ – Unit holding cost (€ per unit per year)

$P$ – Pro–duction rate (units per year)

$TC$ – Total cost of the system

$I_{max}$ – Maximum inventory level

Total cost at EPQ

$$TC = 2.\left(\frac{D}{Q^*}.C_s\right) \tag{27}$$

Maximum inventory level can be calculated in the system by

$$I_{max} = Q^*\left(1 - \frac{D}{P}\right) \tag{28}$$

Then, the following EPQ formula can be stated as follows:

$$Q^* = \sqrt{\frac{2.D.C_s}{C_h.\left(1 - \frac{D}{P}\right)}} \tag{29}$$

Daily demand is considered in EPQ. When the annual demand is given, it should be divided into the number of working days which correspond [19].

### 2.8.4 PRODUCTION MODEL

Production model describes the product as set of resources and the sequence of operations performed on the resources to convert it as an end product. This model works on the production rate, raw material consumption, inventory levels and shipment cycle and provide an optimized production quantity to meet the demand while minimising the overall cost associated with the product [20].

<u>*Assumptions:*</u>

- Demand is known and constant
- The size of supply is constant
- The production capacity is greater than demand
- Withdrawals from the store is uniform (distribution)

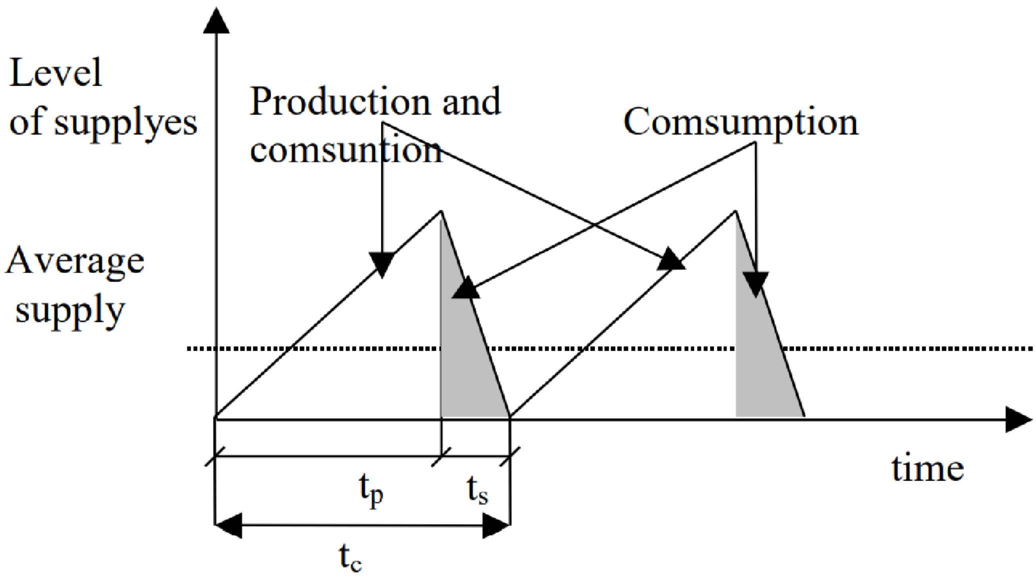


*Figure 23: Production model [20]*

<u>*The following are the notations used to develop the cost functions:*</u>

$p$ Production rate, units per Year.

$n_{pp}$ Number of shipment Cycles per year. (D/Q)

$D$ Demand rate of a product p, units per Year.

$n_s$ Stocking cost of single unit of finished product per year.

$h$ Consuming Rate.

$N(Q)$ Objective function (Expenses)

$Q$ Optimal production Lot Size.

So objective function (expenses) is,

$$N(Q) = n_s.(p-h).\left(\frac{Q}{p}\right).\left(\frac{1}{2}\right) + n_{pp}.\frac{D}{Q} \tag{30}$$

Optimal batch size is then,

$$Q = \sqrt{\frac{2.n_{pp}.\mathrm{D}}{n_s}}.\sqrt{\frac{p}{p-h}} \tag{31}$$

## 2.9 SIMULATION

Simulation is described as the process of creating a model using some special computer software of an actual or proposed system in order to identify and understand the system's limiting factors or to forecast the system's future behaviour. Simulation is possible in any system that can be quantified using equations or rules.

It is a powerful and important tool because it allows one to test various models, plans, or proposals without having to experiment with a real system, which can be prohibitively expensive, time consuming, or simply impractical. Since simulation is such a powerful tool for understanding complex issues and supporting decision-making, there are several different methods and tools available. Some of the tools are,

- Spreadsheets
- Discrete Event Simulators
- Agent-Based Simulators
- Continuous Simulators
- Hybrid Simulators

Simulation is a tool for decision-making and support. Alternative designs, plans, and policies are evaluated, compared, and optimized using simulation software [21].

# 3. PRODUCTION PORTFOLIO ANALYSIS AND SELECTION OF REPRESENTATIVE PRODUCTS

KAMAX s.r.o. is a Hardware & Fastener Manufacturing company located in Turnov, Czech Republic. It produces about 1400 different products. In this chapter the various production processes and the representative products for the optimization of manufacturing batch sizes are discussed.

## 3.1 DIFFERENT PROCESS USED IN MANUFACTURING SYSTEM

The following are the various processes which is currently used by the company, these processes may vary for each product.

### 3.1.1 COLD HEADING

Cold heading feeds wire into a machine, cuts it into pieces, and hammers it. The material is not heated or machined, but at room temperature it forms into its desired shape using a repeated series of high-speed dies, hammers, and punches. The ability to form material rather than removing it allows this method to be extremely efficient and cost-effective for manufacturing large quantities.

### 3.1.2 HEAT TREATMENT

Heat treatment is a process used to increase mechanical strength, ductility, toughness and, for some alloys, corrosion resistance. A critical part of the manufacturing process is the heat treatment of fasteners and fixations. Temperature, time, and atmosphere controls decide the fastener 's efficiency, capability and reliability. The finished fastener properties have to reach a specified strength range; if the material properties are not right after heat treatment, the fastener will fail in its operation.

### 3.1.3 SURFACE COATING

The primary aim of surface treatment is to provide protection against corrosion to the fasteners. Another vital function is friction control which purpose is to ensure users can assemble the fasteners correctly. To some extent, the colour can be controlled by surface treatment to suit the appearance of fasteners with the rest of the product, or to differentiate the fasteners in an assembly line.

### 3.1.4 ADHESIVE

Adhesive fasteners swiftly replace traditional joining methods such as screws, nuts, bolts, rivets, welds and other mechanical fasteners. Bonding metal parts with adhesives permits bonding of dissimilar materials such as thermoplastics or composites by assemblers. Additionally, it will fill the need for strong-yet-flexible bonds from consumers, such as connecting flexible plastics to a thin wire.

### 3.1.5 THREAD ROLLING

Thread rolling is a method of metal rolling which is commonly used in the manufacturing industry to produce screws, bolts and other fasteners. A common thread rolling process used in the manufacture of threaded parts in industry involves shaping threads onto a blank metal by pressing and rolling between two die. The surfaces of the die hold the form, and the force of the action forms the threads into the material.

### 3.1.6 CNC MACHINE

CNC machining refers to computer software that is pre-programmed to control the movement of factory machinery and tools during the manufacturing process. From mills and routers to grinders and lathes, the process can be used to power a wide variety of complex machinery. With CNC machining, three-dimensional cutting tasks can be completed in a single set of commands.

### 3.1.7 PARTS WASHING

Parts washers are well known and are mostly used to clean parts that are contaminated with industrial waste materials such as, for example and not limitation, hydrocarbons, oils and greases. This process is not working for all the production line but used in some cases.

### 3.1.8 PACKAGING

The last step in the product manufacturing operation is packaging, it is the process in which product is brought and packaged together. The bolts are packaged after quality check to ensure consistency and uniformity. This packaging is done to protect the product from damages and facilitate marketing and distribution to manufactures, consumers and distributors.

## 3.2 SELECTION OF REPRESENTATIVE PORDUCTS

By performing the ABC analysis, the company selected six different products as the representatives for six different part families which are major contributors of production and related activities, for the optimization of batch sizes. The reason behind the selection of those six products is because it represents pretty much the entire portfolio of the company which is delivered to its customers. And those products are selected based on quantities, technologies, throughput time etc.

### 3.2.1 PART 1 (OEM HIGH RUNNER)

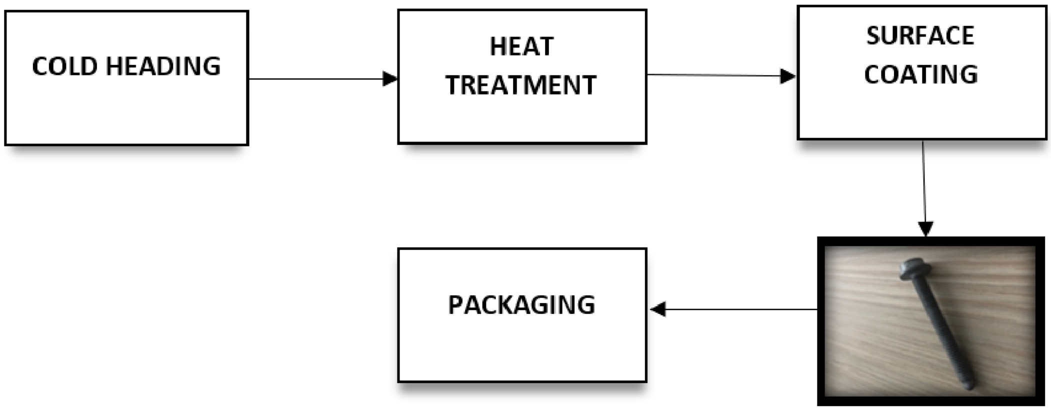


*Figure 24: Process flow chart of OEM High Runner [source: own]*

In this product it consists of three processes which is to be done to obtain a complete product. In this surface coating alone is outsourced.

### 3.2.2 PART 2 (TIER 1 HIGH RUNNER)

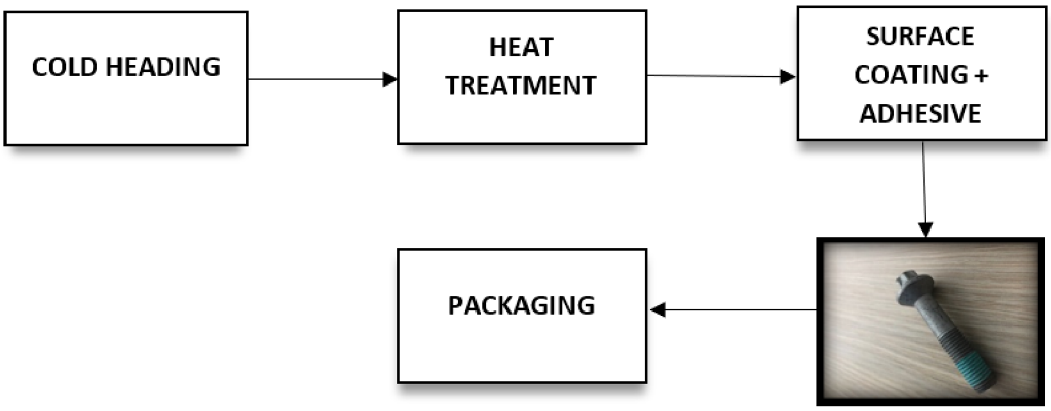


*Figure 25: Process flow chart of TIER 1 High Runner [source: own]*

In this product it consists of four processes which is to be done to obtain a complete product. In this surface coating and adhesive is outsourced.

### 3.2.3 PART 3 (TIER 1 – PART WITH SECONDARY OPERATION STEP)

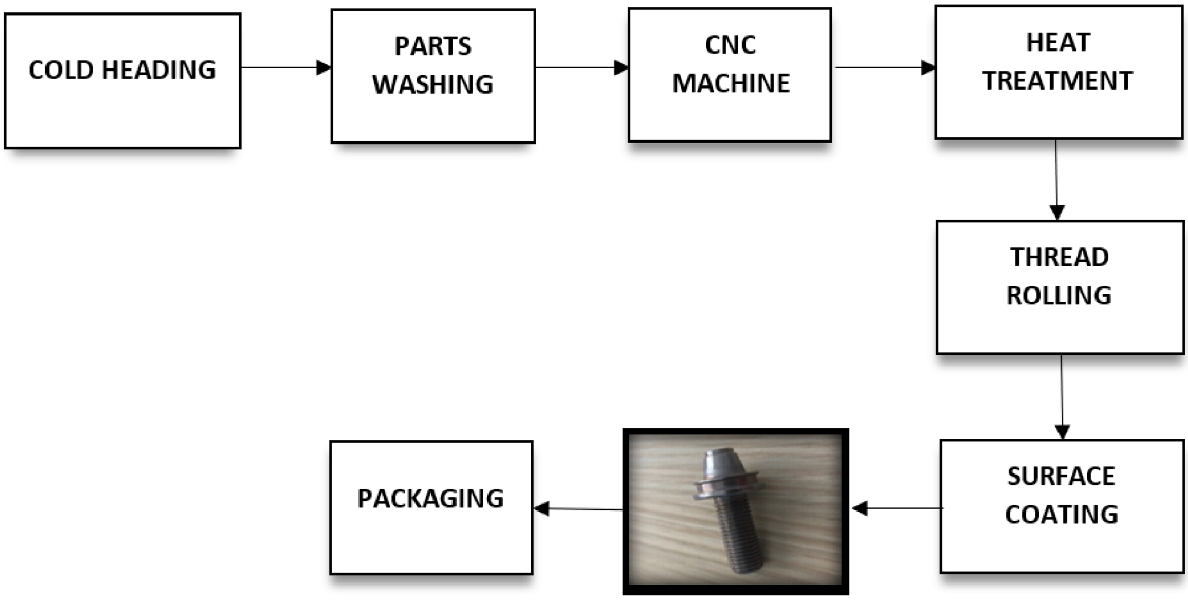


*Figure 26: Process flow chart of TIER 1 – Part with Secondary Operation Step [source: own]*

In this product it consists of six processes which is to be done to obtain a complete product. In this surface coating alone is outsourced.

### 3.2.4 PART 4 (PART WITHOUT EXTERNAL STEP)

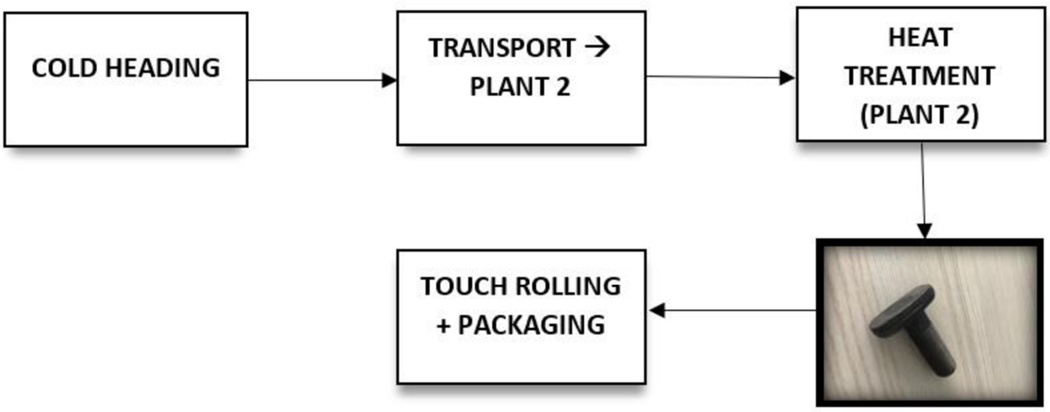


*Figure 27: Process flow chart of Part Without External Step [source: own]*

In this product it consists of three processes which is to be done to obtain a complete product.

### 3.2.5 PART 5 (LOW RUNNER – AFTERSALES MARKET)

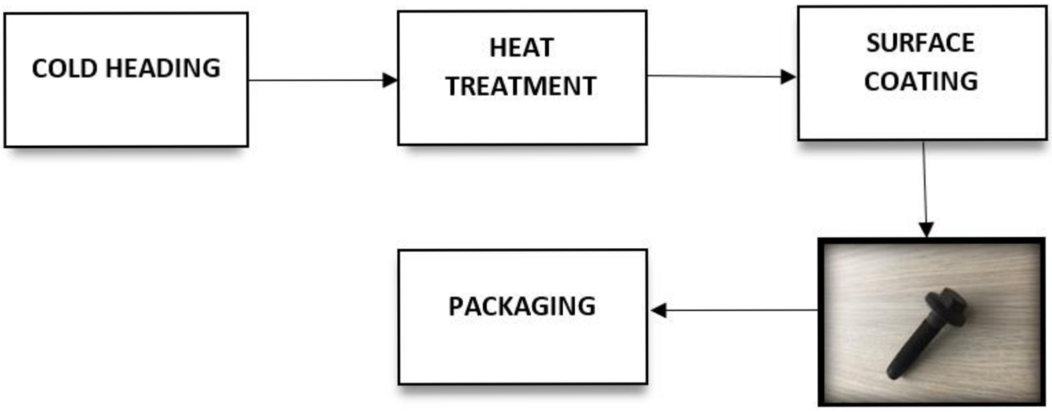


*Figure 28: Process flow chart of Low Runner – Aftersales Market [source: own]*

In this product it consists of three processes which is to be done to obtain a complete product. In this surface coating alone is outsourced.

### 3.2.6 PART 6 (OEM PART WITH WASHER)

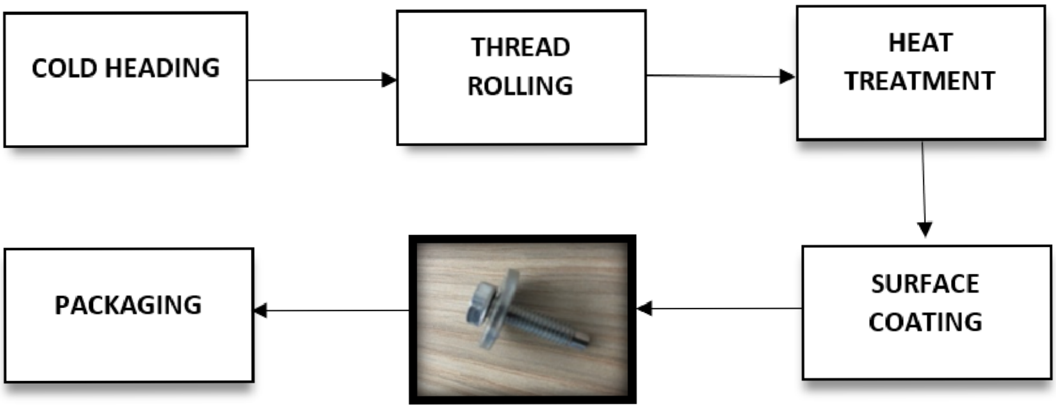


*Figure 29: Process flow chart of OEM Part with Washer [source: own]*

In this product it consists of four processes which is to be done to obtain a complete product. In this surface coating and washer is outsourced.

# 4. ANALYSIS OF CURRENT APPROACH

In this chapter the current approaches which is followed by the company is explained by gathering data, analysis and measurement of current processes which are necessary to model batch sizes.

## 4.1 PRODUCTION BATCH SIZE

In the company ABC analysis is used to define **Production batch size** in current process, where it is seen how many parts from which PN (part number) that are produced. The last 90days is considered and split it in the way that part numbers creating the most volume are in A category, mid-volume in B category and the most of part numbers falls in C category. From the older example (Figure 30) parts from most valuable to the limit of 70% of overall value (cumulated) create A group, parts of average important to the limit of 90% of overall value create B group and parts of least important create C group.

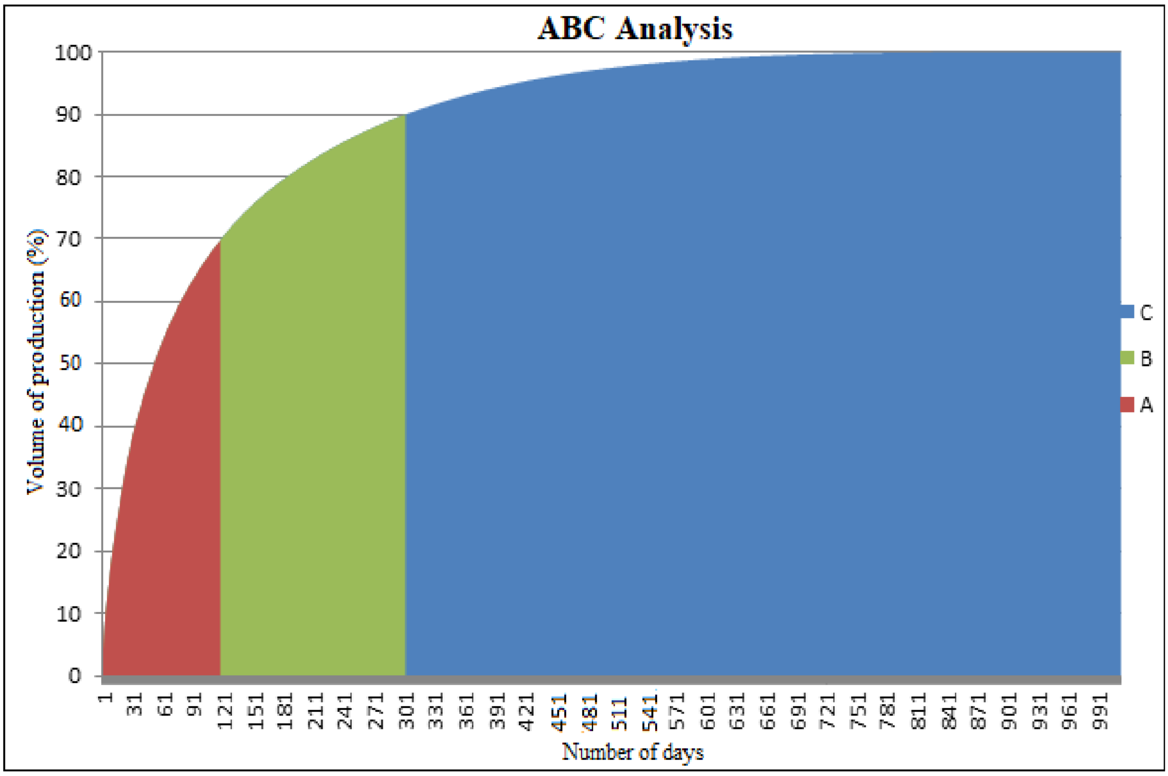


*Figure 30: ABC Analysis Example [source: own]*

This analysis is done four times per year for all the parts and changes can be done on more frequent basis in case of Ramp-up parts or if the parts get obsolete and only aftermarket is served.

| Group | Cold heading Batch size | Heat treatment, thread rolling, machining Batch size | Packaging Batch size |
|---|---|---|---|
| A | W02 | W01 | Daily basis |
| B | W04 | W02 | W01 |
| C | W08-W52 | W04-W52 | W01-W52 |

*Table 1: Production Batch Size*

Wxx – It means how many weeks (xx) of customer demand are covered from one batch. Example: W01 – means that the production lot covers one week of customer demand.

This is a basic framework so the planner sees how big lot size (for how many weeks) should be produced by the company and according to current call-offs which creates the order for that particular number of pieces.

## 4.2 ORDERING BATCH SIZE

The **ordering batches size** (meant for raw material) are done two months in advance and as it usually uses one raw material for more part numbers. It is done as cumulation of all materials being scheduled for that week.

The ordering batch size is dynamic which changes with respect to the customer demand. For this "fine planning" is used. Where the production plan for next week's demand is considered and the raw material is purchased based on this demand. The company's suppliers are quite flexible and the warehouses are reachable by truck within 24 hours, hence the quantity of the raw material procured is equal to the manufacture batch size of the respective week.

**Raw material Usage percentage**

For raw material usage percentage, for 100% production quantity 105% of raw material (wire) is purchased. This is also used for the material disposition.

**Shifts**

In the company the production is run in three 8 hours shifts per day with 30 minutes break in the middle per each shift, except for heat treatment which runs two 12 hours shifts per day with personal breaks without any influence on the machine's performance.

**Packaging**

For packaging in a box, the box size is 350 kg of bolts and 40 kg of box itself as reference in all cases.

**Transportation**

Maximum transportation size: Internal processes – 4 boxes per forklift ride.

Drive to external processes: 24 tons of brutto weight.

**Number of machines**

The company has standard routing for each part with one machine per step. It does not dedicate 1 machine just to single part. But it uses one machine for more parts (example: It has 6 heat treatment lines and 13.000 active part numbers), 30 cold heading machines equipped by thread rolling station, 5 cold heading machine, 10 thread rolling machines, 1 part washing machine, 15 various CNC machines, 4 packing machines and 18 packing machines equipped by automatic inspection. This is explained clearly in Part 1 – Additional information.

**Technological constrains**

Generally, it does not produce less than 5.000 pieces in one batch in cold heading, heat treatment and secondary operations (e.g., thread rolling). There is also technical constraint of 400 kg as a minimum batch for heat treatment. For surface coating it generally depends on the coating and production line at supplier but all batches lower than 100 kg causes trouble.

**Due dates**

Every delivery has a defined customer due date given by a specific day. Every delay matter and causes special transport (also airfreight) and this delay can cause stoppage of car manufacturer with unbelievably high cost which would need to be covered by the company if it would cause it.

### 4.2.1 PART 1 (OEM HIGH RUNNER) – M6X55

This product has a monthly demand of 2.000.000 pieces and ordering size which means customer demand of 100.000 pieces per day. In this case the demand is stable.

| Process | Setup time (min) | Throughput (parts/hour) | Delivery time (ext.) | Production lot size | Transport frequency |
|---|---|---|---|---|---|
| Cold heading | 194 | 8.200 | - | 2 weeks | - |
| Heat treatment | 23 | 35.000 | - | 1 week | - |
| Surface coating | - | - | 3 working days | 3 days | twice a day |
| Packaging | 22 | 8.900 | - | 1 day | - |

*Table 2: (OEM High Runner) – M6x55*

**Monthly demand:** 2.000.000 pcs
**Ordering size (customer demand):** 100.000 pcs/ day – (Demand is stable)
**Product weight:** Weight – input: 0,0123 kg
Weight – output: 0,0123 kg

**Process:** It describes the series of steps needed to achieve a complete product.

**Surface coating:** This process alone is outsourced for all Part numbers.

**Setup time:** Setup time in a machine refers to the time taken to prepare a machine for the next run after it had produced the last part of the previous run.

**Process speed:** It means how many parts run per hour. In case of this product, if this part is on the cold header the throughtput is 8.200 pieces per hour.

**Surface treatment lead time:** Company's suppliers guarantee the standard lead time which depends on technology and complexity of surface treatment. From logistics point of view, it is black box that how and what the suppliers does in the plant. So, it is considered the lead time for surface coating is 3 days. It means if the parts are given on Tuesday for surface coating, it is expected that the parts are coated and ready to be loaded back on Friday (as it is three days).

**Production lot size:** It means how big lot sizes is run at once. In case of cold heading the lot is as big as to cover 2 weeks of customer demands → In this case the customer demand for two weeks is approximately 1 million pieces. So, the lot size is one million pieces.

**Transportation frequency to surface coating:** It means how often the truck goes to surface treatment → In this case the truck goes twice per day. It tells if it is necessary to consider some special, not frequent service which at the end increases lead time. In this case it is not because every working day all the ready parts of different part number are taken to surface coating and back. So, it need not be considered.

**Ordering size:** It tells how often and how big batches is customer picking up from the company (which is customer demand). In this case the monthly demand of 2 million pieces has a stable demand of 100.000 pieces per day (which means 2 million pieces split by 20 working days per month)

**Additional information:**

*Machine usage* – One machine is not just dedicated to a single part. So, in case of part: 1, 1.000.000 pieces (2 weeks demand coverage) in one lot are produced→ Theoretically: Setup + (1.000.000: 8.200 = 122 hours of production = 5,4 working days) and then different parts are produced in this machine for next approximately 4,5 working days after which again it is switched to this high running part.

*Details of after how many pieces done in cold heading, the heat treatment starts* - Generally, if the batch for HT (Heat treatment) is ready then HT can start. In case of part 1: there is a batch covering two weeks demand (approx. 1.000.000 pieces) to be cold headed and if batch for HT (in this case 1 week demand = 500.000 pcs.) is ready HT can be scheduled and started.

*Details of after heat treatment how many pieces are sent to surface coating* - In this case all parts which are ready are loaded. It delivers every day 40 tons of its different parts to the surface coater. There are also days where 400.000 pieces on one truck being delivered and then there can be Zero on following days as there is no stock ready to be loaded by the company.

*For 24 hours run time* – The actual time available is 22,5 hours and for heat treatment alone is 24 hours. And 75% of the actual available time is accounted for the value-added activities. Having this available time data and process speed data for each production process, number of pieces produced in a given period of time can be calculated.

#### 4.2.2 PART 2 (TIER 1 HIGH RUNNER) – M12X57, 5 - MKL

| Process | Setup time (min) | Throughput (parts/hour) | Delivery time (ext.) | Production lot size | Transport frequency |
|---|---|---|---|---|---|
| Cold heading | 211 | 5.500 | - | 4 weeks | - |
| Heat treatment | 18 | 14.000 | - | 2 weeks | - |
| Surface coating + adhesive | - | - | 15 working days Inc. Transport | 1 week | Every working day |
| Packaging | 17 | 5.800 | - | 2.5 days | - |

*Table 3: (TIER 1 High Runner) – M12x57, 5 – MKL*

**Monthly demand:** 770.000 pcs

**Ordering size (customer demand):** 20.000-60.000 pcs. Daily/weekly same variations

**Product weight:** Weight – input: 0,0643 kg

Weight – output: 0,0643 kg

#### 4.2.3 PART 3 (TIER 1 – PART WITH SECONDARY OPERATION STEP) – M10X25

| Process | Setup time (min) | Throughput (parts/hour) | Delivery time (ext.) | Production lot size | Transport frequency |
|---|---|---|---|---|---|
| Cold heading | 220 | 7.500 | - | 4 weeks | - |
| Parts washing | 10 | 16.885 | - | 2 weeks | - |
| CNC machine | 120 | 1.250 | - | 2 weeks | - |
| Heat treatment | 18 | 29.268 | - | 2 weeks | - |
| Thread rolling | 120 | 7.500 | - | 2 weeks | - |
| Surface coating | - | - | 4 working days | 1 week | Twice a day |
| Packaging | 13 | 9.240 | - | 2.5 days | - |

*Table 4: (TIER 1 – Part with Secondary Operation Step) – M10x25*

**Monthly demand:** 520.000 pcs

**Ordering size (customer demand):** 65.000 Twice a week

**Product weight:** Weight – input: 0,0415 kg

Weight – output: 0,041 kg

**Additional Information:** In this product Surface coating alone is out sourced and it takes a period of four days to reach back to the company from surface coaters. For this the transport frequency is two times a day truck drops the product to them.

### 4.2.4 PART 4 (PART WITHOUT EXTERNAL STEP) – M16X45

| Process | Setup time (min) | Throughput (parts/hour) | Delivery time (ext.) | Production lot size | Transport frequency |
|---|---|---|---|---|---|
| Cold heading | 311 | 4.300 | - | 6 weeks | - |
| Transport to plant 2 | Every day 4 times / takes 3 hours including handling | | | | |
| Heat treatment (plant 2) | 18 | 7.704 | - | 3 weeks | - |
| Touch rolling + packaging | 25 | 4.950 | - | 1.5 weeks | - |

*Table 5: (Part Without External Step) – M16x45*

**Monthly demand:** 240.000 pcs

**Ordering size (customer demand):** 75.000 Every Monday

**Product weight:** Weight – input: 0,1335 kg

Weight – output: 0,1168 kg

**Additional Information:** For touch rolling + Packaging the production lot size which covers 1,5 weeks demand in a batch runs only twice in three weeks. In this case Monthly demand is 240.000 pcs and partial quantities are picked up by the customer every Monday. 6 weeks batch size represents 1,5 months coverage meaning, its cold heading batch has approximately 320.000 pcs and it is produced every 6 months in order to cover exactly what customer wants.

### 4.2.5 PART 5 (LOW RUNNER – AFTERSALES MARKET) – M16X70

| Process | Setup time (min) | Throughput (parts/hour) | Delivery time (ext.) | Production lot size | Transport frequency |
|---|---|---|---|---|---|
| Cold heading | 302 | 4.950 | - | 1 year | - |
| Heat treatment | 18 | 6.800 | - | 1 year | - |
| Surface coating | - | - | 2 working days | 1 year | twice a day |
| Packaging | 25 | 4.950 | - | single orders | - |

*Table 6: (Low Runner – Aftersales Market) – M16x70*

**Yearly demand:** 25.000 pcs, which is delivered once or twice per year.

**Ordering size (customer demand):** 1-3 single orders per year (200-20.000 pcs)

**Product weight:** Weight – input: 0,1456 kg
Weight – output: 0,1324 kg

**Additional Information:** Due to its demand is yearly, in this case aftermarket is done were the yearly demand 25.000 pcs is produced once per year and delivers it to the customers by distribution centre or wholesaler who distributes the partial quantaties to the customers (e.g., car repair stores).This is organized to save setup times and transportation costs from company to the customer.

### 4.2.6 PART 6 (OEM PART WITH WASHER) – M8X100

| Process | Setup time (min) | Throughput (parts/hour) | Delivery time (ext.) | Production lot size | Transport frequency |
|---|---|---|---|---|---|
| cold heading | 288 | 6.210 | - | 8 weeks | - |
| thread rolling | 150 | 5.250 | - | 2 weeks | - |
| heat treatment | 18 | 11.150 | - | 2 weeks | - |
| surface coating | - | - | 2 working days | 2 weeks | twice a day |
| packaging | 32 | 1.260 | - | 1 week | - |

*Table 7: (OEM Part with Washer) – M8x100*

**Monthly demand:** 105.000 pcs.

**Ordering size (customer demand):** 3.000-10.000 pcs. Per day – strong variation and this demand known for 3 months.

**Product weight:** Weight – input: 0,372 kg

Weight – output: 0,397 kg, this equals part weight + Washer weight

**Additional Information:** In this product washer is outsourced and the output weight 0,397 kg mentions both bolt and washer weight.

## 4.3 CAPACITY EQUATION

The capacity equation is the set of calculations done in a production line to determine the various data such as production batch size, batch duration, number of batches, total time demand and time fund and utilization of the machines, which are required for the production operations to be carried out efficiently and to meet the customer's demand on time.

### 4.3.1 TECHNOLOGICAL PROCESS

| | Technological Process | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cold heading | | Parts washing | | CNC M/c | | Heat treatment | | Thread rolling | | Packing | |
| α | Tac | Tbc | Tac | Tbc | Tac | Tbc | Tac | Tbc | Tac | Tbc | Tac | Tbc |
| 0,15 | (min) | (min) | (min) | (min) | (min) | (min) | (min) | (min) | (min) | (min) | (min) | (min) |
| 1 | 0,007 | 194 | 0 | 0 | 0 | 0 | 0,002 | 23 | 0 | 0 | 0,007 | 22 |
| 2 | 0,011 | 211 | 0 | 0 | 0 | 0 | 0,004 | 18 | 0 | 0 | 0,010 | 17 |
| 3 | 0,008 | 220 | 0,004 | 10 | 0,048 | 120 | 0,002 | 18 | 0,008 | 120 | 0,006 | 13 |
| 4 | 0,014 | 311 | 0 | 0 | 0 | 0 | 0,008 | 18 | 0 | 0 | 0,012 | 25 |
| 5 | 0,012 | 302 | 0 | 0 | 0 | 0 | 0,009 | 18 | 0 | 0 | 0,012 | 25 |
| 6 | 0,010 | 288 | 0 | 0 | 0 | 0 | 0,005 | 18 | 0,011 | 150 | 0,048 | 32 |

*Table 8: Technological Process*

In this chapter the selected six different products are being studied and for its corresponding production operations the data shown in (Table 8) are calculated by using three major available data $T_{ac}, T_{bc}$ and $\alpha$ .

$T_{ac}$ – Process time per piece

$T_{bc}$ – Setup time per batch

$\alpha$ – Ratio of Setup time to the Process time

### 4.3.2 MINIMUM BATCH SIZE

| | Minimum batch size. | | | | | |
|---|---|---|---|---|---|---|
| | Cold Heading (Pieces) | Parts Washing (Pieces) | CNC Machining (Pieces) | Heat Treatment (Pieces) | Thread rolling (Pieces) | Packing (Pieces) |
| 1 | 176.756 | 0 | 0 | 89.444 | 0 | 21.756 |
| 2 | 128.944 | 0 | 0 | 28.000 | 0 | 10.956 |
| 3 | 183.333 | 18.761 | 16.667 | 58.536 | 100.000 | 13.347 |
| 4 | 148.589 | 0 | 0 | 15.408 | 0 | 13.750 |
| 5 | 166.100 | 0 | 0 | 13.600 | 0 | 13.750 |
| 6 | 198.720 | 0 | 0 | 22.300 | 87.500 | 4.480 |

*Table 9: Minimum Batch Size*

Minimum batch size is the least number of pieces in a production batch required to run the production operation economically, without which the cost of the non-value-added activity increases. Minimum batch size is one among the criteria for setting optimal batch size, it provides the lower range for the optimal batch size. Minimum batch size is calculated using the following formula

$$B_{min} = T_{bc}/(T_{ac} * \alpha) \quad (27)$$

$B_{min}$ – Minimum batch size

$T_{bc}$ – Process time per piece

$T_{ac}$ – Setup time per batch

α = 0,15 (Constant)

$T_{bc}$ values in (Table 8) is divided by the product of $T_{ac}$ values and α in (Table 8).

### 4.3.3 CURRENT BATCH SIZE

| | Current batch size or lot size. | | | | | |
|---|---|---|---|---|---|---|
| | Cold Heading (Pieces) | Parts Washing (Pieces) | CNC Machining (Pieces) | Heat Treatment (Pieces) | Thread rolling (Pieces) | Packing (Pieces) |
| 1 | 1.000.000 | 0 | 0 | 500.000 | 0 | 100.000 |
| 2 | 770.000 | 0 | 0 | 385.000 | 0 | 96.250 |
| 3 | 520.000 | 260.000 | 260.000 | 260.000 | 260.000 | 65.000 |
| 4 | 360.000 | 0 | 0 | 180.000 | 0 | 90.000 |
| 5 | 25.000 | 0 | 0 | 25.000 | 0 | 8.334 |
| 6 | 210.000 | 0 | 0 | 52.500 | 52.500 | 26.250 |

*Table 10: Current Batch Size/ Lot Size*

It is the set of pieces of the six products for its corresponding production operations for a single batch, which are currently being followed in the company for the production.

### 4.3.4 MANUFACTURING BATCH DURATION

| | Manufacturing Batch duration | | | | | |
|---|---|---|---|---|---|---|
| | Cold heading (min) | Parts washing (min) | CNC M/c (min) | Heat treatment (min) | Thread rolling (min) | Packing (min) |
| 1 | 7.511 | 0 | 0 | 880 | 0 | 696 |
| 2 | 8.611 | 0 | 0 | 1.668 | 0 | 1.013 |
| 3 | 4.380 | 934 | 12.600 | 551 | 2.200 | 435 |
| 4 | 5.334 | 0 | 0 | 1.420 | 0 | 1.116 |
| 5 | 605 | 0 | 0 | 239 | 0 | 126 |
| 6 | 2.317 | 0 | 0 | 301 | 750 | 1.282 |

*Table 11: Manufacturing Batch Duration*

It is the lead time of a single batch to be worked, which includes both the process time of the parts and the batch setup time. It is calculated using the formula,

$$T_{MB} = T_{bc} + (T_{ac} * MB_C) \tag{28}$$

$T_{MB}$ – Manufacturing Batch Duration

$MB_C$ – Current Manufacturing Batch Size

$T_{bc}$ values in (Table 8) is added with the product of $T_{ac}$ in (Table 8) and the corresponding values in (Table 10).

### 4.3.5 NUMBER OF MANUFACTURING BATCHES PER YEAR

| | No. of manufacturing batches/Year | | | | | |
|---|---|---|---|---|---|---|
| | Cold heading | Parts washing | CNC M/c | Heat treatment | Thread rolling | Packing |
| 1 | 24 | 0 | 0 | 48 | 0 | 240 |
| 2 | 12 | 0 | 0 | 24 | 0 | 96 |
| 3 | 12 | 24 | 24 | 24 | 24 | 96 |
| 4 | 8 | 0 | 0 | 16 | 0 | 32 |
| 5 | 1 | 0 | 0 | 1 | 0 | 3 |
| 6 | 6 | 0 | 0 | 24 | 24 | 48 |

*Table 12: Number of Manufacturing batches/Year*

This table comprises the number of manufacturing batches per year for the six products and its corresponding production operations. Number of manufacturing batches is considered as the number of new setups done. The yearly demand is divided by manufacturing batch size to obtain the number of manufacturing batches per year.

### 4.3.6 TOTAL TIME DEMAND

| | Total time demand/ Year | | | | | |
|---|---|---|---|---|---|---|
| | Cold heading | Parts washing | CNC M/c | Heat treatment | Thread rolling | Packing |
| | (min) | (min) | (min) | (min) | (min) | (min) |
| 1 | 180.266 | 0 | 0 | 42.247 | 0 | 167.078 |
| 2 | 103.332 | 0 | 0 | 40.032 | 0 | 97.218 |
| 3 | 52.560 | 22.414 | 302.400 | 13.224 | 52.800 | 41.767 |
| 4 | 42.674 | 0 | 0 | 22.718 | 0 | 35.709 |
| 5 | 605 | 0 | 0 | 239 | 0 | 378 |
| 6 | 13.902 | 0 | 0 | 7.212 | 18.000 | 61.536 |
| **Total Time Demand (min)** | **393.339** | **22.414** | **302.400** | **125.672** | **70.800** | **403.687** |

*Table 13: Total Time Demand*

Here the total time demand is the total amount of time period required separately to complete the production processes for all the six products to meet the monthly demand. It can be formulated as

$$T_d = T_{MB} * N_{MC} \tag{29}$$

$T_d$ – Total Time Demand

$T_{MB}$ – Manufacturing Batch Duration

$N_{MC}$ – Number of Manufacturing Batches/Year

Manufacturing batch duration in the (Table 11) are multiplied by the corresponding values of Number of manufacturing batches/year in the (Table 12) and the values are summed as shown in equation (32) to obtain the total time demand.

### 4.3.7 TOTAL TIME FUND

| | Total Time fund/ Year | | | | | |
|---|---|---|---|---|---|---|
| | Cold heading | Parts washing | CNC M/c | Heat treatment | Thread rolling | Packing |
| Days | 240 | 240 | 240 | 336 | 240 | 240 |
| No of shifts/day | 3 | 3 | 3 | 2 | 3 | 3 |
| Minutes in a shift | 450 | 450 | 450 | 720 | 450 | 450 |
| Total time for single machine (min) | 324.000 | 324.000 | 324.000 | 483.840 | 324.000 | 324.000 |
| Total no. of machines | 30 | 1 | 15 | 6 | 10 | 22 |
| Total production capacity (min) | **9.720.000** | **324.000** | **4.860.000** | **2.903.040** | **3.240.000** | **7.128.000** |

*Table 14: Total Time Fund*

Total time fund is the total duration of machine's availability in a particular period of time for performing the production operations, here it is the total time availability for a year. It is the product of number of working days in a year, number of shifts in a day and the number of working hours per shift for 1 machine, which is then calculated for the total number of machines available for the various production processes.

For all the production processes except heat treatment:

- Number of working days in a week is 5
- Number of working days in a month is 20 and
- Number of working days in year is 240

For heat treatment process:

- Number of working days in a week is 7
- Number of working days in a month is 28 and
- Number of working days in a year is 336 days.

For all the production process except heat treatment the working hours per shift is calculated excluding the break, which is 30 minutes per shift, so for 8 hours shift the working hours is (8*60) – 30 = 450 minutes. And the heat treatment process is carried out in two 12 hours shifts per day without break for 7 days in the week. Hence for heat treatment process working hours per shift is 12*60 = 720 minutes.

$$T_f = D * S * H \tag{30}$$

$T_f$ – Total time fund

$D$ – Days/Year

$S$ – Shifts/day

$H$ – Hours/shift

### 4.3.8 UTILIZATION OF MACHINES

| | Utilization of the Machines | | | | | |
|---|---|---|---|---|---|---|
| **TOTAL** | **Cold heading** | **Parts washing** | **CNC M/c** | **Heat treatment** | **Thread rolling** | **Packing** |
| **Time Demand (min)** | 393.339 | 22.414 | 302.400 | 125.672 | 70.800 | 403.687 |
| **Total Time Fund/ Year (min)** | 9.720.000 | 324.000 | 4.860.000 | 2.903.040 | 3.240.000 | 7.128.000 |
| **Utilization** | 4% | 7% | 6% | 4% | 2% | 6% |

*Table 15: Utilization of Machines*

Here utilization is the percentage usage of the total number of production machines available for all the six products combined. It is the ratio of total time demand to the total time fund.

Any production machine has two factors, available time and usage time, obtaining the ratio of this total usage time and the total available time gives the utilization of machines. Here the total usage time is the total time demand calculated in the (Table 13) and total available time is the total time fund calculated in (Table 14). Hence from the above-mentioned calculation utilization of machines can be formulated as

$$U_m = (T_d/T_f) * 100 \tag{31}$$

$U_m$ – Utilization of machines

$T_d$ – Total Time Demand

$T_f$ – Total time fund

The ultimate goal of the capacity equation is to determine the utilization of the machines in a production line which is done using the data such as process time, setup time, demand etc. The utilization is arrived from the various above discussed step by step calculations. It gives an insight of how efficient the production line is, the machines should neither be under-utilized nor over utilized and henceforth the necessary changes in the process and parameters can be done to optimize the overall production.

Here in (Table 15) the current utilization of the machines in the company for the six products is determined. Based on the current utilization values as a reference further optimization is done in the required direction.

### 4.3.9 TOTAL TIME FUND PER WEEK

| | Cold Heading, Part Washing, CNC M/c, Thread Rolling, Packing. | Heat Treatment |
|---|---|---|
| Days/Week | 5 | 7 |
| No of shifts/day | 3 | 2 |
| Minutes | 450 | 720 |
| Total Time/Week (min) | 6750 | 10080 |

*Table 16: Total time fund per week*

In this (Table 16) the total time available in a week is calculated. It is the product of number of working days per week, number of shifts per day and number of working hours per shift.

## 4.4 WITNESS 14 SIMULATION

Simulation is a process that uses special computer software to model the real production system. Basically, simulation helps create an organization's virtual setting through which some analysis and experiments are performed to reduce the time and cost of production.

Simulation is used to assist all the activities of an organization's inventory, assembly, transportation and production for preserving all the information for future improvement at optimized level.

In this part the company's current production system is designed and simulated for the current manufacturing batch in the Witness 14 Simulation software. This is done to analyse the current production system for its functioning, similar to the analytical approach but with more real time data and operation.

In this simulation method the production quantity and the machine utilization is determined for the specified duration and the results are compared with the actual data to verify whether the demand is met and the utilization matches the original values, which is mandatory so as to prove that the simulation model is designed well and runs correctly for the corresponding input data.

After confirming the correctness of the model, the same model is simulated for the optimized manufacturing batches which will be determined using various methods and the results are verified for the correctness of the newly determined optimized manufacturing batches. Calculation of optimized manufacturing batch and its verification are discussed in the up-coming chapters.

### 4.4.1 SIMULATION MODEL

The below (Figure 31) is the basic structure of the simulation model. It has six different products, thirty cold heading machines and six cold heading buffers one for each product, six heat treatment machines and a heat treatment buffer, twenty-two packing machines and a packing buffer, fifteen CNC machines and a CNC buffer, one part-washing machine and a part washing buffer, ten thread rolling machines and a thread rolling buffer and five buffers for surface coating which is being outsourced.

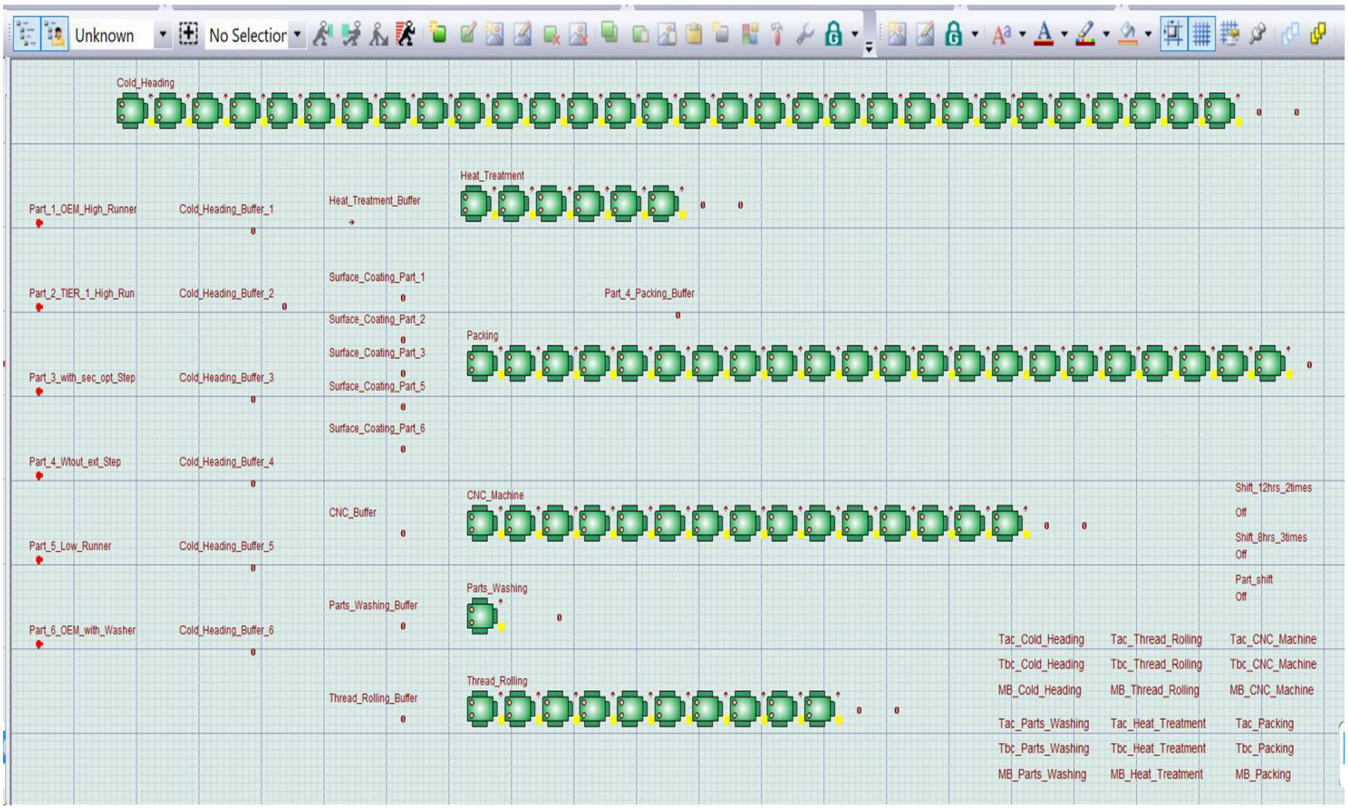


*Figure 31:Simulation Model [source: own]*

### 4.4.2 INPUT ATTRIBUTES

The simulation is run based on the various input attributes. The following are the different inputs for the simulation model.

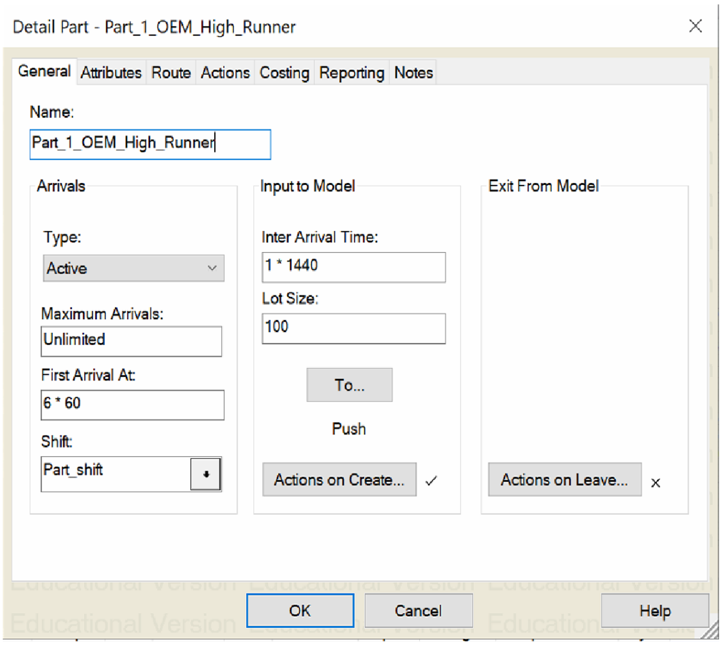


*Figure 32:Part Table [source: own]*

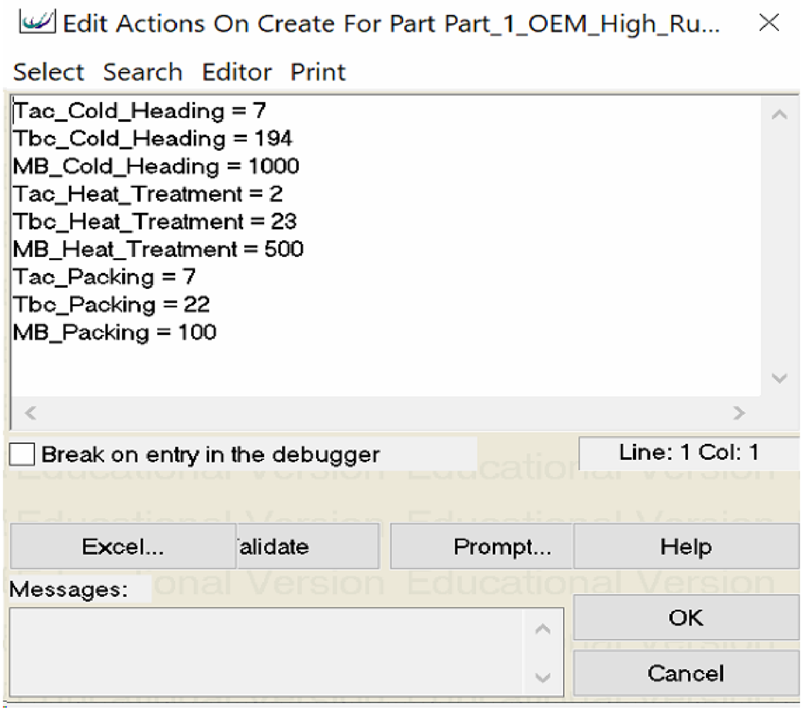


*Figure 33: Actions on Create [source: own]*

The major inputs for a product are process time, setup time, manufacturing batch size and inter arrival time.

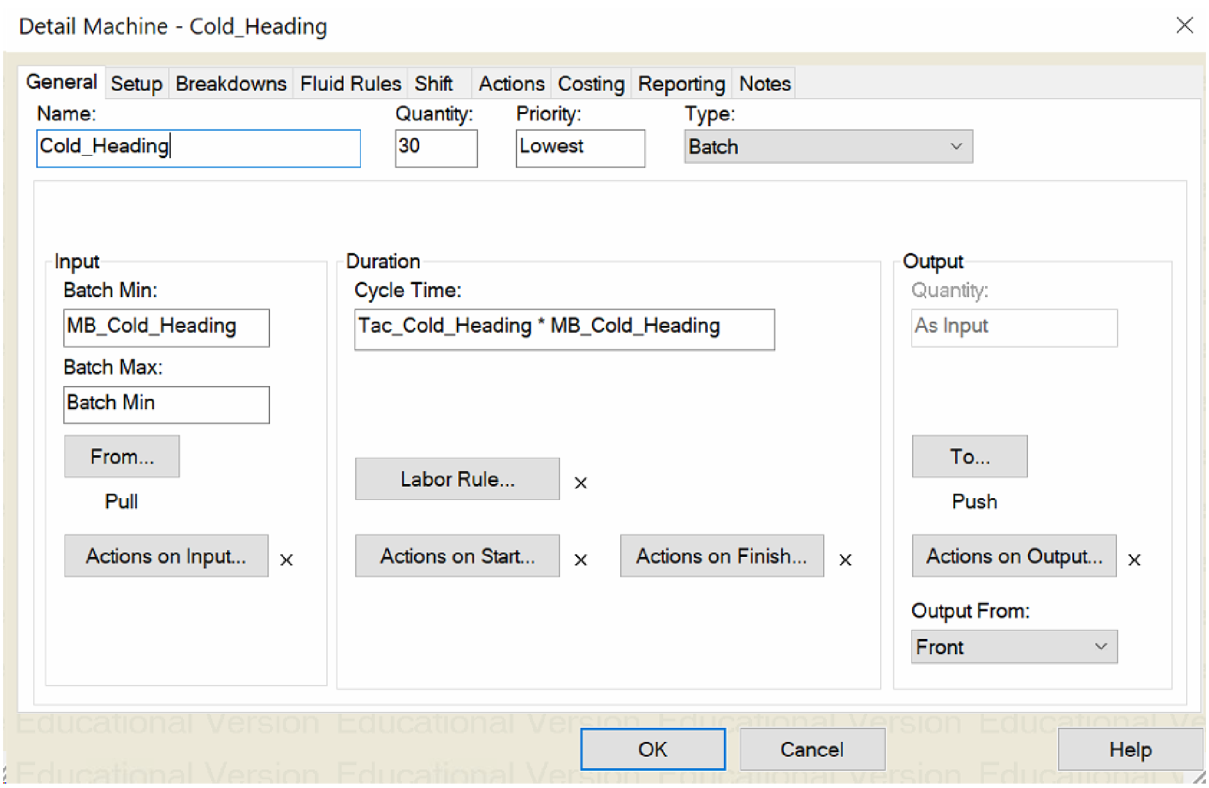


*Figure 34: Machine Details [source: own]*

The inputs for a machine include machine quantity, machine type, cycle time, setup mode and shift system. With the following inputs the model is simulated for one year with two months of warmup period, the warmup time is added to the simulation runtime, so the total run time in this case will be fourteen months.

### 4.4.3 CURRENT BATCH SIZE SIMULATION RESULT

The two important results are number of assembled parts i.e. the production quantity which is obtained from the part statistics and the machine's utilization percentage which is the sum of 'busy' percentage and 'setup' percentage obtained from the machine statistics. The production quantity is compared with the product's yearly demand and verified whether the demand is met or not.

The manufacturing batch size are in the divisible of thousand due to the technical constraints of the software hence the resulted production quantity is in the divisible of thousand, thus by multiplying the obtained production quantity by thousand and comparing it with the actual values, the demand is met for all the six products and hence this simulation model is proved to be correct.

Part Statistics   Report by On Shift Time

| Name | No. Entered | No. Shippe | No. Scrapp | No. Assemb | No. Rejecte | W.I.P. | Avg W.I.P. | Avg Time | Sigma Ratin |
|---|---|---|---|---|---|---|---|---|---|
| Part_1_OEM_High_Runner | 27638 | 253 | 0 | 25617 | 0 | 1768 | 1553.87 | 21130.53 | 6.00 |
| Part_2_TIER_1_High_Run | 10843 | 110 | 0 | 9621 | 0 | 1112 | 1155.73 | 40059.90 | 6.00 |
| Part_3_with_sec_opt_Step | 7882 | 91 | 0 | 6500 | 0 | 1291 | 929.29 | 44311.83 | 6.00 |
| Part_4_Wtout_ext_Step | 3162 | 46 | 0 | 2955 | 0 | 161 | 198.86 | 23636.75 | 6.00 |
| Part_5_Low_Runner | 26 | 0 | 0 | 26 | 0 | 0 | 1.14 | 16504.50 | 6.00 |
| Part_6_OEM_with_Washer | 1758 | 27 | 0 | 1371 | 0 | 360 | 306.34 | 65491.04 | 6.00 |

*Figure 35: Part Statistics for Current Batch size [source: own]*

Machine Statistics   Report by On Shift Time

| Name | % Idle | % Busy | % Filling | % Emptying | % Blocked | % Cycle Wait | % Setup | % Setup Wait | % Broken Down | % Repair Wait | No. Of Operations |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cold_Headin | 97.47 | 2.45 | 0.00 | 0.00 | 0.00 | 0.00 | 0.08 | 0.00 | 0.00 | 0.00 | 56 |
| Parts_Washi | 94.46 | 5.49 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 26 |
| CNC_Machin | 95.57 | 4.39 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 0.00 | 0.00 | 26 |
| Thread_Rolli | 98.33 | 1.49 | 0.00 | 0.00 | 0.00 | 0.00 | 0.18 | 0.00 | 0.00 | 0.00 | 65 |
| Heat_Treatm | 96.48 | 3.44 | 0.00 | 0.00 | 0.00 | 0.00 | 0.08 | 0.00 | 0.00 | 0.00 | 117 |
| Packing | 96.17 | 3.73 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 0.00 | 0.00 | 527 |

*Figure 36: Machine Statistics for Current Batch Size [source: own]*

## 4.5 COMPARISION OF ANALYTICAL AND SIMULATION APPROACH

From the simulation result the machine statistics table is obtained, from which the busy percentage and setup percentage are summed to get the total utilization percentage for the machies. When comparing with the utilization from the analytical method the values match with very minor deviation, the deviation is due to the fact that the analytical approach is more like theoretical and direct mathematical calculation whereas the simulation model corresponds to more of the real time situation.

The analytical calculation is based on the yearly demand whereas simulation is based on the delivery frequency to the customer (mostly daily demand) where for some products there is range for the shipment quantity.

The simulation software does not accept real numbers and hence the input values in real numbers are rounded-off to the nearest integer.

These differences in the input characteristics accounts to minor deviation in the final results between both the approaches.

| | Machine Utilization Comparison (Current State) | | | | | |
|---|---|---|---|---|---|---|
| | Cold heading | Parts washing | CNC M/c | Thread rolling | Heat Treatment | Packing |
| Busy % | 2,45 | 5,49 | 4,39 | 1,49 | 3,44 | 3,73 |
| Setup % | 0,08 | 0,05 | 0,04 | 0,18 | 0,08 | 0,1 |
| Total | 2,53 | 5,54 | 4,43 | 1,67 | 3,52 | 3,83 |
| Simulation | 3% | 6% | 4% | 2% | 4% | 4% |
| Analytical | 4% | 7% | 6% | 2% | 4% | 6% |

*Table 17: Machine Utilization Comparison (Current State)*

# 5. OPTIMIZED APPROACH TO SELECT BATCH SIZES

In this chapter the different models for determining the optimal manufacturing batch size are selected and the respective equations are computed using various data such as demand, production rate, holding cost, setup cost, etc., and the optimal manufacturing batch size and the total cost for the respective models are determined.

## 5.1 VARIOUS MODELS FOR DETERMINING OPTIMAL BATCH SIZE

For the various production operations the optimal manufacturing batch is computed using the models Capacity Equation, Periodic Delivery, Just in Time, Economic Production Quantity and Production Model and are tabulated as in the below (Table 18).

The company's current manufacturing batch the alpha value is 0,15.

The company runs mass production and the alpha value for the mass production is in the range 0,02 – 0,05. Hence the alpha values 0,02, 0,025 and 0,05 are accounted for the computation of the new optimal batch size.

To increase the productivity and to increase the Profit to Area ratio the current inventory facility can be converted to production shop floor, by doing so the maximum area of the plant can be utilised for production activities which increases the profit per sq.m. of the company.

The inventory for the goods can be rented from an outside facility which might slightly increase the inventory holding cost but the increased profit levels will be higher than the warehouse expenses.

Average cost for renting warehouse space in Czech Republic is 4,5€ per sq.m. per month, this does not include transportation cost assuming the warehouse facility to be located next to the company's production facility. The average holding capacity of an area of 1 sq.m. is 5 tons and has a storing facility of 5 racks arranged one above the other which approximates the storing capacity to 1 ton per rack.

Hence the rent for 1 sq.m. of area, 4,5€ per month is divided among the 5 racks i.e., 0,9€ per rack per month which translates to 0,9€ per ton per month and 0,03€ per ton per day. Inventory holding cost also includes the warehouse operational cost and employee wages, which may cost up to three times the renting cost, including which the total inventory holding cost sums to 0,09€ per ton per day.

Similarly, for a sophisticated storing facility maximum of 6,5€ can be charged per month for renting an area of 1 sq.m, which equals to a total inventory holding cost of 0,13€ per ton per day.

0,07 is the inventory holding cost for company's current storage facility and 0,09 and 0,13 are the inventory holding costs of the newly rented storage facility. For these holding costs optimal manufacturing batch is calculated using the models Periodic Delivery, Just in Time, Economic Production Quantity and Production Model.

The below table represents the results of optimal manufacturing batch size calculation for five different models and its respective iterations for Part – 1 OEM High Runner, in similar way the calculation is done for the remaining five parts. The proposed final models and its respective optimal batch size are discussed in the further chapters.

| | | Models and Optimal batch sizes | | | |
|---|---|---|---|---|---|
| | | **Iterations** | **Cold Heading** | **Heat Treatment** | **Packing** |
| Part: 1 - OEM High Runner | **Current Batch Size** | 0,15 | 1.000.000 | 500.000 | 100.000 |
| | Capacity Equation | 0,02 | 2.000.000 | 1.000.000 | 200.000 |
| | | 0,025 | 1.000.000 | 500.000 | 100.000 |
| | | 0,05 | 1.000.000 | 500.000 | 100.000 |
| | Periodic Delivery | 0,07 | 9.000.000 | 9.000.000 | 3.000.000 |
| | | 0,09 | 8.000.000 | 8.000.000 | 2.000.000 |
| | | 0,13 | 6.000.000 | 6.000.000 | 2.000.000 |
| | Just In Time | 0,07 | 9.000.000 | 3.000.000 | 3.000.000 |
| | | 0,09 | 8.000.000 | 2.000.000 | 2.000.000 |
| | | 0,13 | 6.000.000 | 2.000.000 | 2.000.000 |
| | Economic Production Quantity | 0,07 | 9.000.000 | 3.000.000 | 3.000.000 |
| | | 0,09 | 8.000.000 | 2.000.000 | 2.000.000 |
| | | 0,13 | 6.000.000 | 2.000.000 | 2.000.000 |
| | Production Model | 0,07 | 6.000.000 | 6.000.000 | 6.000.000 |
| | | 0,09 | 4.000.000 | 4.000.000 | 100.000 |
| | | 0,13 | 4.000.000 | 4.000.000 | 2.000.000 |

*Table 18: Models and Optimal batch sizes*

- **CAPACITY EQUATION**

The optimal manufacturing batch size can be set by considering factors such as minimum batch size, voice of process, customer demand, technological constrains, out of which minimum batch size is an important factor and the capacity equation helps in calculating the minimum batch size and the utilization of machines. For the different stages of production operation minimum batch size is calculated using process time, setup time and alpha value, for the three different alpha values three different minimum batch size is calculated and corresponding optimal manufacturing batch size is set.

- **PERIODIC DELIVERY**

The amount of raw material required for producing single product is known hence the raw material required for a batch is also known. Consumption rate of the raw materials is known from the technological parameters of the production machines, hence in this model the required raw material is delivered in equal quantities at fixed intervals. The raw material ordering quantity is equal to the manufacturing batch size in this case. This process incurs ordering cost of raw material, storing cost of raw material, storing cost of finished goods and setup cost of the production batch. In this model the manufacturing batch size is optimally set such that it balances the setup cost, ordering cost and the storing cost thus minimising the total cost.

- **JUST IN TIME**

The customer demands the finished goods to be supplied in small quantities to reduce his inventory holding cost, in such cases the manufacturer follows Just in Time method where the raw material is frequently delivered in small quantities to reduce the manufacturer's inventory holding cost. Larger batch size means higher storing cost, smaller batch size means higher setup cost. Raw material and the finished goods are supplied in small lots to reduce the inventory holding cost; hence the manufacturing batch size is optimally set such that the inventory holding cost and the setup cost are balanced to have reduced total cost while meeting the demand.

- **ECONOMIC PRODUCTION QUANTITY**

Economic production quantity is the inventory management model where the production quantity is optimized to keep the storage cost under control by eliminating excess production of goods, while ensuring enough production to have uninterrupted production and sales activity in the company. This model minimises the total cost by avoiding unnecessary blockage of funds in the company's inventory related activities.

- **PRODUCTION MODEL**

Production model describes the product as set of resources and the sequence of operations performed on the resources to convert it as an end product. This model works on the production rate, raw material consumption, inventory levels and shipment cycle and provide an optimized production quantity to meet the demand while minimising the overall cost associated with the product.

## 5.2 OPTIMAL BATCH SIZE FOR CURRENT PRODUCTION SYSTEM

Company's current holding cost in their own storage facility is 0,07€ per ton per day. For this holding cost optimal manufacturing batch is calculated using production Model.

| | Optimal Batch Size (Production Model) – 0,07 | | | | | |
|---|---|---|---|---|---|---|
| | Cold Heading (Pieces) | Parts Washing (Pieces) | CNC Machining (Pieces) | Heat Treatment (Pieces) | Thread rolling (Pieces) | Packing (Pieces) |
| OEM High Runner | 6.000.000 | - | - | 6.000.000 | - | 6.000.000 |
| TIER 1 High Runner | 1.540.000 | - | - | 1.540.000 | - | 1.540.000 |
| Tier 1 - Part with Sec. opt STEP | 1.040.000 | 1.040.000 | 1.040.000 | 1.040.000 | 1.040.000 | 1.040.000 |
| Part without External Step | 240.000 | - | - | 240.000 | - | 240.000 |
| Low Runner - Aft Sales Market | 6.250 | - | - | 6.250 | - | 6.250 |
| OEM Part with Washer | 210.000 | - | - | 210.000 | 210.000 | 210.000 |

*Table 19: Optimal Batch Size (Production Model) – 0,07*

The values in the (Table 19) are the optimized production batch size for the company's current production system.

## 5.3 OPTIMAL BATCH SIZE FOR INCREASED PRODUCTIVITY

To increase the productivity of the company the new suggestion in the production system is made which is to convert the current storing facility into a production facility so that the company's profit to area ratio increases.

In this newly suggested production system, it is recommended to rent a storage facility next to the company's production facility.

In this case two different holding costs are accounted for calculation:

- Average holding cost for renting a warehouse in Czech Republic which is 0,09€ per ton per day
- Possible maximum holding cost for renting a sophisticated storing facility in Czech Republic which is 0,13€ per ton per day.

### 5.3.1 PRODUCTION MODEL

The model recommended here is Production Model in which the optimal manufacturing batch size is calculated for two different holding costs, 0,09€ and 0,13€ and the results are tabulated below.

| | Optimal Batch Size (Production Model) – 0,09 | | | | | |
|---|---|---|---|---|---|---|
| | Cold Heading (Pieces) | Parts Washing (Pieces) | CNC Machining (Pieces) | Heat Treatment (Pieces) | Thread rolling (Pieces) | Packing (Pieces) |
| OEM High Runner | 5.000.000 | - | - | 5.000.000 | - | 5.000.000 |
| TIER 1 High Runner | 1.540.000 | - | - | 1.540.000 | - | 1.540.000 |
| Tier 1 - Part with Sec. opt STEP | 1.040.000 | 1.040.000 | 1.040.000 | 1.040.000 | 1.040.000 | 1.040.000 |
| Part without External Step | 240.000 | - | - | 240.000 | - | 240.000 |
| Low Runner - Aft Sales Market | 5.000 | - | - | 5.000 | - | 5.000 |
| OEM Part with Washer | 210.000 | - | - | 210.000 | 210.000 | 210.000 |

*Table 20: Optimal Batch Size (Production Model) – 0,09*

The values in the (Table 20) are the optimized manufacturing batch size for the newly optimized production system while renting an average inventory.

| | Optimal Batch Size (Production Model) – 0,13 | | | | | |
|---|---|---|---|---|---|---|
| | Cold Heading (Pieces) | Parts Washing (Pieces) | CNC Machining (Pieces) | Heat Treatment (Pieces) | Thread rolling (Pieces) | Packing (Pieces) |
| OEM High Runner | 4.000.000 | - | - | 4.000.000 | - | 4.000.000 |
| TIER 1 High Runner | 1.155.000 | - | - | 1.155.000 | - | 1.155.000 |
| Tier 1 - Part with Sec. opt STEP | 520.000 | 520.000 | 520.000 | 520.000 | 520.000 | 520.000 |
| Part without External Step | 240.000 | - | - | 240.000 | - | 240.000 |
| Low Runner - Aft Sales Market | 5.000 | - | - | 5.000 | - | 5.000 |
| OEM Part with Washer | 105.000 | - | - | 105.000 | 105.000 | 105.000 |

*Table 21: Optimal Batch Size (Production Model) – 0,13*

The values in the (Table 21) are the optimized manufacturing batch size for the newly optimized production system while renting a sophisticated inventory.

### 5.3.2 JUST IN TIME

As the storage facility is externally rented Just in Time model is suggested to reduce the inventory holding cost. For the newly suggested production system the optimal manufacturing batch size is calculated for the holding cost 0,13€ and the results are tabulated below.

| | Optimal Batch Size (Just in Time) – 0,13 | | | | | |
|---|---|---|---|---|---|---|
| | Cold Heading (Pieces) | Parts Washing (Pieces) | CNC Machining (Pieces) | Heat Treatment (Pieces) | Thread rolling (Pieces) | Packing (Pieces) |
| OEM High Runner | 6.000.000 | - | - | 2.000.000 | - | 2.000.000 |
| TIER 1 High Runner | 1.540.000 | - | - | 770.000 | - | 385.000 |
| Tier 1 - Part with Sec. opt STEP | 1.560.000 | 1.040.000 | 2.080.000 | 520.000 | 1.040.000 | 520.000 |
| Part without External Step | 600.000 | - | - | 240.000 | - | 120.000 |
| Low Runner - Aft Sales Market | 50.000 | - | - | 25.000 | - | 25.000 |
| OEM Part with Washer | 210.000 | - | - | 105.000 | 105.000 | 52.500 |

*Table 22: Optimal Batch Size (Just in Time) – 0,13*

The values in the (Table 22) are the optimized manufacturing batch size for the newly optimized production system while renting a sophisticated inventory.

# 6. VERIFICATION AND VALIDATION OF OPTIMIZED APPROACH

In this chapter the newly determined optimal production batches are verified by comparing the utilization of the machines obtained for the newly set production batches and current production batch.

Then the correctness of the new optimal production batches is validated to ensure that the range does not exceed the production capacity. Verification and validation are done by using analytical method and simulation method.

## 6.1 VERIFICATION BY ANALYTICAL METHOD

In analytical method the Capacity Equation is used for the verification and validation. Using the capacity equation, the utilization of the machines for the various stages of production are determined for the comparison.

### 6.1.1 VERIFICATION OF THE MACHINE'S UTILIZATION

For the current production batch and other optimized production batches the ratio of total time demand and total time fund gives the percentage utilization of the machines for all the six products combined, for the different production processes like Cold Heading, Parts Washing, etc.

In the below table for the different production processes the utilization of the machines for the optimized production batches is similar in some cases or bit lower to the utilization of the machines used for current production batch size.

Given the fact that if the utilization is similar or bit lower for the same number of machines it can be concluded that the machines are not under-utilized or over utilized and all the optimized production batch sizes are well under the production capacity. Same number of machines indicates that there are no new investments bound with the optimized production batches and while in bit reduced utilization percentage ensures that the increased availability of machine for other products.

1. Current Production System.
2. Optimized Production Batch, Without any changes to the Production system.
   (Production Model 0,07)

3. Optimized Production System, Converting inventory into production facility.
   (Production Model 0,09 - Avg Inventory)
4. Optimized Production System, Converting inventory into production facility.
   (Production Model 0,13 - sophisticated Inventory)
5. Optimized Production System, Converting inventory into production facility.
   (Just In Time 0,13 - sophisticated Inventory)

| | | Utilization of the Machines | | | | | |
|---|---|---|---|---|---|---|---|
| | TOTAL | Cold heading | Parts washing | CNC M/c | Heat treatment | Thread rolling | Packing |
| 1 | Time Demand (min) | 393.339 | 22.414 | 302.400 | 125.672 | 70.800 | 403.687 |
| | Total Time Fund/ Year (min) | 9.720.000 | 324.000 | 4.860.000 | 2.903.040 | 3.240.000 | 7.128.000 |
| | Utilization | 4% | 7% | 6% | 4% | 2% | 6% |
| 2 | Time Demand (min) | 389.023 | 22.234 | 300.240 | 123.670 | 65.940 | 393.976 |
| | Total Time Fund/ Year (min) | 9.720.000 | 324.000 | 4.860.000 | 2.903.040 | 3.240.000 | 7.128.000 |
| | Utilization | 4% | 7% | 6% | 4% | 2% | 6% |
| 3 | Time Demand (min) | 336.503 | 11.147 | 150.480 | 111.340 | 40.980 | 220.919 |
| | Total Time Fund/ Year (min) | 9.720.000 | 324.000 | 4.860.000 | 2.903.040 | 3.240.000 | 7.128.000 |
| | Utilization | 3% | 3% | 3% | 4% | 1% | 3% |
| 4 | Time Demand (min) | 394.395 | 22.294 | 300.960 | 124.868 | 67.560 | 220.548 |
| | Total Time Fund/ Year (min) | 9.720.000 | 324.000 | 4.860.000 | 2.903.040 | 3.240.000 | 7.128.000 |
| | Utilization | 4% | 7% | 6% | 4% | 2% | 3% |
| 5 | Time Demand (min) | 387.174 | 22.234 | 299.880 | 124.124 | 66.840 | 395.337 |
| | Total Time Fund/ Year (min) | 9.720.000 | 324.000 | 4.860.000 | 2.903.040 | 3.240.000 | 7.128.000 |
| | Utilization | 4% | 7% | 6% | 4% | 2% | 6% |

*Table 23: Utilization of the Machines*

## 6.2 VERIFICATION BY SIMULATION METHOD

In this part the newly optimized production batches are verified by simulating the different models in Witness 14 Simulation software. The four optimized manufacturing batches selected from the analytical approach are simulated in the previously designed simulation model by changing only the manufacturing batch size. The models are simulated based on the delivery frequency to the customer and hence the inter arrival time and the lot size are set based on the corresponding product's delivery interval and delivery quantity.

The newly defined optimized manufacturing batch is simulated for a specified time period to verify whether the model satisfies the customer demand without any major deviation. The two factors which are verified from the simulation results are number of assembled parts which is the production quantity and the machine's utilization percentage.

### 6.2.1 MODEL 1: PRODUCTION MODEL 0,07

The first model is the optimized production batch for the current production system without any changes in the system. Here 0,07 is the inventory holding cost for the current production system, which is the company's own inventory facility. The model is simulated for a period of one year i.e. 365 days with a warmup period of 120 days, the warmup period is added to the simulation run time hence the total simulation run time is 485 days. High warmup period is due to the big manufacturing batch size.

Part Statistics Report by On Shift Time

| Name | No. Entered | No. Shippe | No. Scrapp | No. Assemb | No. Rejecte | W.I.P. | Avg W.I.P. | Avg Time | Sigma Ratin |
|---|---|---|---|---|---|---|---|---|---|
| Part_1_OEM_High_Runner | 34552 | 3 | 0 | 13310 | 0 | 21239 | 13695.00 | 148967.61 | 6.00 |
| Part_2_TIER_1_High_Run | 13831 | 2 | 0 | 5524 | 0 | 8305 | 5552.11 | 150871.69 | 6.00 |
| Part_3_with_sec_opt_Step | 9100 | 3 | 0 | 3923 | 0 | 5174 | 3884.49 | 160433.80 | 6.00 |
| Part_4_Wtout_ext_Step | 4157 | 3 | 0 | 1905 | 0 | 2249 | 1333.68 | 120579.55 | 6.00 |
| Part_5_Low_Runner | 26 | 0 | 0 | 13 | 0 | 13 | 8.56 | 123781.00 | 6.00 |
| Part_6_OEM_with_Washer | 2082 | 3 | 0 | 861 | 0 | 1218 | 846.32 | 152777.15 | 6.00 |

*Figure 37: Part Statistics for Production Model 0,07 [source: own]*

Machine Statistics Report by On Shift Time

| Name | % Idle | % Busy | % Filling | % Emptying | % Blocked | % Cycle Wait | % Setup | % Setup Wait | % Broken Down | % Repair Wait | No. Of Operations |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cold_Headin | 97.48 | 2.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 10 |
| Parts_Washi | 94.08 | 5.91 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 7 |
| CNC_Machin | 96.50 | 3.49 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 4 |
| Thread_Rolli | 98.84 | 1.13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 | 11 |
| Heat_Treatm | 96.56 | 3.43 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 16 |
| Packing | 97.74 | 2.26 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 14 |

*Figure 38: Machine Statistics for Production Model 0,07 [source: own]*

### 6.2.2 MODEL 2: PRODUCTION MODEL 0,09

The second model is the optimized production batch for the new optimized production system which is changing the company's inventory facility into production facility and renting an average outside inventory facility nearby. Here 0,09 is the inventory holding cost for the outside inventory facility. The model is simulated for a period of one year i.e. 365 days with a warmup period of 120 days, the warmup period is added to the simulation run time hence the total simulation run time is 485 days. High warmup period is due to the big manufacturing batch size.

Part Statistics Report by On Shift Time

| Name | No. Entered | No. Shippe | No. Scrapp | No. Assemb | No. Rejecte | W.I.P. | Avg W.I.P. | Avg Time | Sigma Ratin |
|---|---|---|---|---|---|---|---|---|---|
| Part_1_OEM_High_Runner | 32390 | 238 | 0 | 24088 | 0 | 8064 | 7675.03 | 89057.87 | 6.00 |
| Part_2_TIER_1_High_Run | 12492 | 29 | 0 | 9480 | 0 | 2983 | 3346.78 | 100692.65 | 6.00 |
| Part_3_with_sec_opt_Step | 8580 | 46 | 0 | 6406 | 0 | 2128 | 2552.29 | 111801.16 | 6.00 |
| Part_4_Wtout_ext_Step | 3770 | 36 | 0 | 2922 | 0 | 812 | 836.46 | 83388.94 | 6.00 |
| Part_5_Low_Runner | 25 | 0 | 0 | 25 | 0 | 0 | 6.13 | 92117.00 | 6.00 |
| Part_6_OEM_with_Washer | 1735 | 7 | 0 | 1298 | 0 | 430 | 433.06 | 93809.84 | 6.00 |

*Figure 39: Part Statistics for Production Model 0,09 [source: own]*

Machine Statistics Report by On Shift Time

| Name | % Idle | % Busy | % Filling | % Emptying | % Blocked | % Cycle Wait | % Setup | % Setup Wait | % Broken Down | % Repair Wait | No. Of Operations |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cold_Headin | 97.90 | 2.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 11 |
| Parts_Washi | 94.91 | 5.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 12 |
| CNC_Machin | 95.87 | 4.11 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 13 |
| Thread_Rolli | 98.56 | 1.39 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 0.00 | 0.00 | 20 |
| Heat_Treatm | 96.85 | 3.14 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 25 |
| Packing | 96.17 | 3.80 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 | 356 |

*Figure 40: Machine Statistics for Production Model 0,09 [source: own]*

### 6.2.3 MODEL 3: PRODUCTION MODEL 0,13

The third model is the optimized production batch for the new optimized production system which is changing the company's inventory facility into production facility and renting a sophisticated outside inventory facility nearby. Here 0,13 is the inventory holding cost for the outside inventory facility. The model is simulated for a period of one year i.e. 365 days with a warmup period of 100 days, the warmup period is added to the simulation run time hence the total simulation run time is 465 days. High warmup period is due to the big manufacturing batch size.

Part Statistics Report by On Shift Time

| Name | No. Entered | No. Shippe | No. Scrapp | No. Assemb | No. Rejecte | W.I.P. | Avg W.I.P. | Avg Time | Sigma Ratin |
|---|---|---|---|---|---|---|---|---|---|
| Part_1_OEM_High_Runner | 33300 | 16 | 0 | 27125 | 0 | 6159 | 7956.29 | 89798.54 | 6.00 |
| Part_2_TIER_1_High_Run | 12987 | 23 | 0 | 9663 | 0 | 3301 | 3517.68 | 101800.66 | 6.00 |
| Part_3_with_sec_opt_Step | 8710 | 22 | 0 | 6538 | 0 | 2150 | 2639.73 | 113905.44 | 6.00 |
| Part_4_Wtout_ext_Step | 3819 | 15 | 0 | 3177 | 0 | 627 | 775.89 | 76357.64 | 6.00 |
| Part_5_Low_Runner | 26 | 0 | 0 | 26 | 0 | 0 | 3.56 | 51501.00 | 6.00 |
| Part_6_OEM_with_Washer | 1665 | 7 | 0 | 1438 | 0 | 220 | 399.79 | 90245.31 | 6.00 |

*Figure 41: Part Statistics for Production Model 0,13 [source: own]*

Machine Statistics Report by On Shift Time

| Name | % Idle | % Busy | % Filling | % Emptying | % Blocked | % Cycle Wait | % Setup | % Setup Wait | % Broken Down | % Repair Wait | No. Of Operations |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cold_Headin | 97.79 | 2.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 13 |
| Parts_Washi | 94.49 | 5.49 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 | 13 |
| CNC_Machin | 95.59 | 4.39 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 13 |
| Thread_Rolli | 98.45 | 1.47 | 0.00 | 0.00 | 0.00 | 0.00 | 0.08 | 0.00 | 0.00 | 0.00 | 29 |
| Heat_Treatm | 96.72 | 3.26 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 28 |
| Packing | 96.10 | 3.89 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 83 |

*Figure 42: Machine Statistics for Production Model 0,13 [source: own]*

### 6.2.4 MODEL 4: JUST IN TIME 0,13

The fourth model is the optimized production batch for the new optimized production system which is changing the company's inventory facility into production facility and renting a sophisticated outside inventory facility nearby. Here 0,13 is the inventory holding cost for the outside inventory facility. The model is simulated for a period of one year i.e. 365 days with a warmup period of 120 days, the warmup period is added to the simulation run time hence the total simulation run time is 485 days. High warmup period is due to the big manufacturing batch size.

Part Statistics Report by On Shift Time

| Name | No. Entered | No. Shippe | No. Scrapp | No. Assemb | No. Rejecte | W.I.P. | Avg W.I.P. | Avg Time | Sigma Ratin |
|---|---|---|---|---|---|---|---|---|---|
| Part_1_OEM_High_Runner | 31110 | 13 | 0 | 22646 | 0 | 8451 | 8647.09 | 104465.52 | 6.00 |
| Part_2_TIER_1_High_Run | 12725 | 16 | 0 | 7589 | 0 | 5120 | 3814.89 | 112674.90 | 6.00 |
| Part_3_with_sec_opt_Step | 9100 | 4 | 0 | 2137 | 0 | 6959 | 4717.75 | 194848.30 | 6.00 |
| Part_4_Wtout_ext_Step | 3600 | 15 | 0 | 3105 | 0 | 480 | 810.18 | 84582.48 | 6.00 |
| Part_5_Low_Runner | 13 | 1 | 0 | 12 | 0 | 0 | 2.10 | 60768.00 | 6.00 |
| Part_6_OEM_with_Washer | 1872 | 6 | 0 | 827 | 0 | 1039 | 823.14 | 165260.63 | 6.00 |

*Figure 43: Part Statistics for Production Model 0,13 [source: own]*

Machine Statistics Report by On Shift Time

| Name | % Idle | % Busy | % Filling | % Emptying | % Blocked | % Cycle Wait | % Setup | % Setup Wait | % Broken Down | % Repair Wait | No. Of Operations |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cold_Headin | 97.60 | 2.39 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 9 |
| Parts_Washi | 94.08 | 5.91 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 7 |
| CNC_Machin | 96.77 | 3.22 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 2 |
| Thread_Rolli | 99.19 | 0.76 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 0.00 | 0.00 | 14 |
| Heat_Treatm | 96.89 | 3.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 31 |
| Packing | 97.24 | 2.75 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 55 |

*Figure 44: Machine Statistics for Production Model 0,13 [source: own]*

## 6.3 VALIDATION OF THE OPTIMIZED MANUFACTURING BATCHES

In this part the four models selected from the analytical verification method which are verified in the simulation model are validated to substantiate the newly defined production batches for the final suggestion and also to eliminate the non-conforming models.

### 6.3.1 PRODUCTION QUANTITY COMPARISION

The production quantity is compared with the product's yearly demand. For this the number of assembled parts in the part statistics from the simulation result is multiplied by 1000 to obtain the actual production quantity as the input data are in the divisible of 1000, the resulted value is the respective product's total yearly production quantity. This value for the four selected models is compared with the yearly demand to verify whether the customer demand is satisfied.

| Production Quantity Comparison | | | | | | |
|---|---|---|---|---|---|---|
| Product → | 1 | 2 | 3 | 4 | 5 | 6 |
| Yearly Demand | 24.000.000 | 9.240.000 | 6.240.000 | 2.880.000 | 25.000 | 1.260.000 |
| Current Production System | 25.617.000 | 9.621.000 | 6.500.000 | 2.955.000 | 26.000 | 1.371.000 |
| PM 0,07 | 13.310.000 | 5.524.000 | 3.923.000 | 1.905.000 | 13.000 | 861.000 |
| PM 0,09 | 24.088.000 | 9.480.000 | 6.406.000 | 2.922.000 | 25.000 | 1.298.000 |
| PM 0,13 | 27.125.000 | 9.663.000 | 6.538.000 | 3.177.000 | 26.000 | 1.438.000 |
| JIT 0,13 | 22.646.000 | 7.589.000 | 2.137.000 | 3.105.000 | 12.000 | 827.000 |

*Table 24: Production Quantity Comparison*

On comparing the values in the above table it is evident that the Production Model (PM) 0,09 meets the customer demand with very minimal deviation, the Production Model (PM) 0,13 also meets the customer demand but with slightly higher quantity. But the Production Model (PM) 0,07 and Just In Time (JIT) 0,13 failed to meet the customer demand for all the six products and thus these two models are eliminated.

On further examination of the models PM 0,09 and PM 0,13, for the model PM 0,13 the deviation between yearly demand and the production quantity is quite high and it can be termed as over production for the required yearly demand. Due to the high costs associated with the overproduction the manufacturing batch determined in the model PM 0,13 is not suggested as the optimal manufacturing batch.

Whereas for the model PM 0,09 the deviation between yearly demand and the production quantity being 0-3%, the Production Model 0,09 is selected and proposed as the best optimal manufacturing batch for the six products in the company.

### 6.3.2 MACHINE UTILIZATION COMPARISON

The second criteria to be validated is the utilization of the machines. For the model which is selected as the optimized manufacturing batch from the validation process the utilization of the machines obtained from the simulation verification method and the utilization calculated in the analytical verification method are compared to authenticate the correctness of the entire model. Hence here the machine utilization for the model PM 0,09 is validated.

| | | Machine Utilization Comparison | | | | | |
|---|---|---|---|---|---|---|---|
| | | Cold heading | Parts washing | CNC M/c | Heat treatment | Thread rolling | Packing |
| Optimized Production System Converting inventory into production facility (Production Model 0,09 - Average Inventory) | Analytical | 3% | 3% | 3% | 4% | 1% | 3% |
| | Simulation | 2% | 5% | 4% | 3% | 1% | 4% |

*Table 25: Machine Utilization Comparison*

From the above table it is clear that the utilization of both the analytical and simulation methods match with very minor difference and the difference is due to the fact that the analytical approach is more like theoretical and direct mathematical calculation whereas the simulation model corresponds to more of the real time situation.

The analytical calculation is based on the yearly demand whereas simulation is based on the delivery frequency to the customer (mostly daily demand) where for some products there is range for the shipment quantity. The simulation software does not accept real numbers and hence the input values in real numbers are rounded-off to the nearest integer.

These differences in the input characteristics accounts to minor deviation in the final results between both the approaches. Hence it can be concluded that the selected model, i.e. the model PM 0,09 is faultless.

# 7. COMPARING CURRENT STATE WITH NEWLY DEFINED ONE

In this chapter the newly defined production system is compared with the company's current production system and the differences are recorded to highlight the improvements.

## 7.1 NEWLY DEFINED OPTIMAL MANUFACTURING BATCH

The following is the optimal manufacturing batch for the six products determined from the production model 0,09. This is the model which suggests a new production system which is converting the company's current inventory facility into production facility and rent an outside inventory facility nearby. This increases the productivity and the profit to area ratio of the company.

| | | Optimal batch size or lot size Pcs. | | | | | |
|---|---|---|---|---|---|---|---|
| | | Cold heading | Parts washing | CNC M/c | Heat treatment | Thread rolling | Packing |
| OEM High Runner | 1 | 4.000.000 | - | - | 4.000.000 | - | 100.000 |
| TIER 1 High Runner | 2 | 1.540.000 | - | - | 1.540.000 | - | 385.000 |
| Tier 1 - Part with Sec. opt STEP | 3 | 520.000 | 520.000 | 520.000 | 520.000 | 520.000 | 130.000 |
| Part without External Step | 4 | 240.000 | - | - | 240.000 | - | 60.000 |
| Low Runner - Aft Sales Market | 5 | 25.000 | - | - | 25.000 | - | 25.000 |
| OEM Part with Washer | 6 | 210.000 | - | - | 210.000 | 210.000 | 210.000 |

*Table 26: Optimal batch size or lot size pcs.*

This optimized manufacturing batch can also be set for the company's current production system if the company decides not to make any changes to the production system, i.e., not to convert its inventory facility into a production facility.

## 7.2 COMPARISON OF CURRENT AND NEW MANUFACTURING BATCH

In this part criteria such as the manufacturing batch, machine utilization, yearly production quantity and alpha value compared and the differences are recorded.

### 7.2.1 MANUFACTURING BATCH COMPARISON

The below table depicts the current manufacturing batch and the newly defined optimal manufacturing batch size. The alpha value for the production in current manufacturing batch is reduced from 0,15 to 0,025 in the newly defined optimal manufacturing batch.

Alpha value in production is the ratio of the setup time to the cycle time i.e., ratio of investment in the non-value added activity to the value added activity. Thus, lesser the alpha value lesser the production cost and higher the profit.

The pertinent alpha value for the mass production is in the range 0,02 – 0,05, thus by iterating various values in the analytical approach 0,025 is found to be the best value for the company's production.

| | | Manufacturing Batch Comparison | | | | | |
|---|---|---|---|---|---|---|---|
| | | Cold heading | Parts washing | CNC M/c | Heat treatment | Thread rolling | Packing |
| OEM High Runner | Current | 1.000.000 | - | - | 500.000 | - | 100.000 |
| | Optimized | 4.000.000 | - | - | 4.000.000 | - | 100.000 |
| TIER 1 High Runner | Current | 770.000 | - | - | 385.000 | - | 96.250 |
| | Optimized | 1.540.000 | - | - | 1.540.000 | - | 385.000 |
| Tier 1 - Part with Sec. opt STEP | Current | 520.000 | 260.000 | 260.000 | 260.000 | 260.000 | 65.000 |
| | Optimized | 520.000 | 520.000 | 520.000 | 520.000 | 520.000 | 130.000 |
| Part without External Step | Current | 360.000 | - | - | 180.000 | - | 90.000 |
| | Optimized | 240.000 | - | - | 240.000 | - | 60.000 |
| Low Runner - Aft Sales Market | Current | 25.000 | - | - | 25.000 | - | 12.500 |
| | Optimized | 25.000 | - | - | 25.000 | - | 25.000 |
| OEM Part with Washer | Current | 210.000 | - | - | 52.500 | 52.500 | 26.250 |
| | Optimized | 210.000 | - | - | 210.000 | 210.000 | 210.000 |

*Table 27: Manufacturing Batch Comparison*

### 7.2.2 MACHINE UTILIZATION COMPARISON

On collating the utilization values in the below table, it is clear that utilization values of the optimized production batch are very similar to the current batch's utilization, also the machine utilization of the optimized manufacturing batch is not higher than the current batch's utilization which means that the machine is not over utilised for the new production batch and the available capacity is not jeopardized for the other products manufactured in the company.

| Machine Utilization Comparison | | | | | | |
|---|---|---|---|---|---|---|
| **Process →** | **Cold heading** | **Parts washing** | **CNC M/c** | **Heat treatment** | **Thread rolling** | **Packing** |
| **Current Batch** | 3% | 6% | 4% | 4% | 2% | 4% |
| **PM 0,09** | 2% | 5% | 4% | 3% | 1% | 4% |

*Table 28: Machine Utilization Comparison*

### 7.2.3 YEARLY PRODUCTION QUANTITY COMPARISON

In the below table when comparing the production quantity for the current batch and the optimized batch with the yearly demand, the optimized batch PM 0,09 is closer to the yearly demand values and it can be concluded that the model PM 0,09 is optimal than the current manufacturing batch.

| Yearly Production Quantity Comparison | | | | | | |
|---|---|---|---|---|---|---|
| **Product →** | **1** | **2** | **3** | **4** | **5** | **6** |
| **Yearly Demand** | 24.000.000 | 9.240.000 | 6.240.000 | 2.880.000 | 25.000 | 1.260.000 |
| **Current Batch** | 25.617.000 | 9.621.000 | 6.500.000 | 2.955.000 | 26.000 | 1.371.000 |
| **PM 0,09** | 24.088.000 | 9.480.000 | 6.406.000 | 2.922.000 | 25.000 | 1.298.000 |

*Table 29: Yearly Production Quantity Comparison*

# 8. CONCLUSION

The aim of this thesis was to optimize the process in the production system by determining optimal manufacturing batches for six different products manufactured in the company KAMAX, s.r.o. This thesis work has been divided into three parts, theoretical part, analytical part and practical part.

In the theoretical part the subjects such as analysis tools for manufacturing process, production planning, models for determining optimal manufacturing batch and company's production portfolio have been studied and documented to aid the thesis work.

In analytical part the company's current approach was analysed and optimal manufacturing batches were determined by performing calculations in five different models used for determining the optimal manufacturing batch namely Capacity Equation, Periodic Delivery, Just in Time, Economic Production Quantity and Production Model for three different holding costs 0,07€/ton/day, 0,09€/ton/day and 0,13€/ton/day each. This resulted in obtaining four optimal manufacturing batches from two different models which were Production Model 0,07, Production Model 0,09, Production Model 0,13 and Just In Time 0,13.

In practical part the four newly defined manufacturing batches were verified and validated by simulating in the Witness 14 Simulation software which resulted in elimination of two optimal batches, Production Model 0.07 and Just in Time 0,13 due to under production and one optimal batch, Production Model 0,13 due to over production and thus concluded by selecting and proposing the Production Model 0,09 as the best optimal manufacturing batch.

The newly proposed production system PM 0,09 will have increased productivity and profit to area ratio as the inventory facility is suggested to be converted into production facility. Also the alpha value i.e., the investment on non-value added activities of the newly proposed system is lesser than the current system. With lesser machine utilization for the six products the newly proposed system has increased machine availability for other products produced in the company. With the above mentioned improvements, the newly proposed production batch PM 0,09 if implemented, the company's production system will be optimized.

Optimal ordering batch was not determined as the company uses only one raw material for maximum number of products and the planning and ordering is done well in advance and there was no need for optimising the ordering batches. Also, the optimal transportation batch was not determined as the transportation is out sourced on the grounds of mutual agreement between the company and the customers. The company's requirement in this thesis work was to determine only the optimal manufacturing batch which was satisfied.

# 9. REFERENCE


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