POLITEKNIK MALAYSIA

KEMENTERIAN PENGAJIAN TINGGI

KOLEJ KOMUNITI MALAYSIA

MANUFACTURING CONTROL

2nd Edition

JABATAN KEJURUTERAAN MEKANIKAL

ZAFARIDA BINTI KADIR
MUHD NASAE BIN MAHYUDDIN

MANUFACTURING CONTROL

ZAFARIDA BINTI KADIR
MUHD NASAE BIN MAHYUDDIN

"This book is dedicated to all students and lecturers of Polytechnic Malaysia"

MANUFACTURING CONTROL 2nd Edition

Writer
ZAFARIDA BINTI KADIR
MUHD NASAE BIN MAHYUDDIN

e ISBN 978-967-2740-27-8

All rights reserved

No part of this publication may be reproduced, stored in retrieval system, or transmitted, electronics, mechanical, photocopying, recording or otherwise, without the prior permission of the publisher, except by a reviewer who may quote brief passages in review.

© Politeknik Tuanku Sultanah Bahiyah

Second Edition

Issued in 2022

Published by:

Politeknik Tuanku Sultanah Bahiyah,
Kulim Hi-Tech Park,
09090 Kulim, Kedah.
Tel : 04-403 3333/014-7555318/014-7555319
Fax : 04-403 3033

Preface

Manufacturing Control book were written as a reference for Polytechnic Malaysia students especially those who taken DJF51062 - Manufacturing Control course. In this edition, this book covers all topics in Manufacturing Control course. This book provides knowledge about basic principles and concept on managing an organization and major levels in manufacturing planning and control system (MPC) which will help students in making forecast, production plan, control production and manage inventory. This course also gives knowledge about production scheduling. It also includes knowledge in managing MRP system (material management), production scheduling and inventory management.

Contents

1. Operation Management and Forecasting 1

Apply Management in Manufacturing 2
- Define the term of management
- Explain the basic function of management

Explain The Principle of Organization and Planning 4
- Basic principle of an organization and terms
- Oriented organization
- Planning horizon for an organization

Manufacturing Planning and Control (MPC) 7
- Importance of Manufacturing Planning and Control (MPC)
- Five major levels in MPC System

Forecasting 9
- Solve forecasting
- Forecasting method

Calculate Forecast Errors 13
- Mean Absolute Deviation (MAD)
- Mean Squared Error (MSE)
- Mean Absolute Percent Error (MAPE)

Exercises 14

2. Product Scheduling 16

Master Production Schedule (MPS) 17
- MPS Definition
- Concept
- Importance of MPS
- Benefits of MPS
- Formula for MPS
- Major functions of MPS
- Element in developing Master Production Schedule
- Meet Demand by Referring to Order and Forecast
- Short term ability

Scheduling Service and Manufacturing Process 23
- Performance measure terms

Job Shop Scheduling 25
- Priority sequencing rules
- Priority sequencing rule work-step
- Performance measures analysis
- Johnson's rule
- Johnson's Rule Optimum Sequence

Exercises 37

3. Inventory Control 40

Concept of Inventory in Manufacturing 41
- Definition of inventory
- Functions of inventory
- Disadvantages of inventory
- Objective of inventory control
- Inventory models based on demand

Types of Inventory 43
- Raw material inventory
- Work-in-process inventory (WIP)
- Maintenance/repair/operating (MRO) supply inventory
- Finished goods inventory

Characterize Inventory Using Inventory Management Method 44
- Inventory counting systems
- Two-Bin system
- Universal bar code
- A B C analysis
- Inventory accuracy

Inventory Model and Cost 47
- Inventory Management Cost
- Inventory Models for Independent Demand
  - Economic Order Quantity (EOQ) Models
  - Fixed-Time Period Models
  - Quantity Discount Models
- Key Inventory Terms
- Effective Inventory Management

Exercises 55

4. Productivity and Capacity Planning 57

Productivity in Production Performance 58
- Productivity Definition
- Factors Influencing The Productivity
- Productivity Terms

Calculate Workers Productivity 61
- Single Productivity
- Multifactor Productivity

Schedule Capacity Planning Using Decision Trees 63
- Design capacity
- Effective capacity
- Utilization
- Capacity planning
- Decision trees for capacity decisions

Exercises 65

5. Material Requirement Planning (MRP) **67**

Define Basic Concept of MRP 68
- The major objectives of MRP
- MRP Steps and Processes

The Element for Process of MRP 70

Organize inventory using MRP 71
- Product Tree Structure
- Time phase structure
- Bill of material
- MRP Table

Exercises 79

Bibliography **83**

1 Operation Management and Forecasting

Manufacturing is an operations which transform raw material through manufacturing engineering or manufacturing process by the use of labour, machinery and tools into finished goods. Finished products are made or process base on demand. Process of turning raw materials begins with product design and material selection. The materials are modified during various manufacturing processes to create finished product. This operation is the core in any manufacturing organizations and operation management is responsible for managing that core. While forecasting are a basic input in the decision processes of operation management to provide information on future demand.

In this chapter, student will learn about (i) management in manufacturing, (ii) principle of organization and planning, (iii) concept of Manufacturing Planning and Control, (iv) forecasting approach method and (v) forecast errors calculations.

APPLY MANAGEMENT IN MANUFACTURING

Define The Term of Management

The process used to accomplish organizational goals through **planning**, **organizing**, **directing** and **controlling** people and other organizational resources.

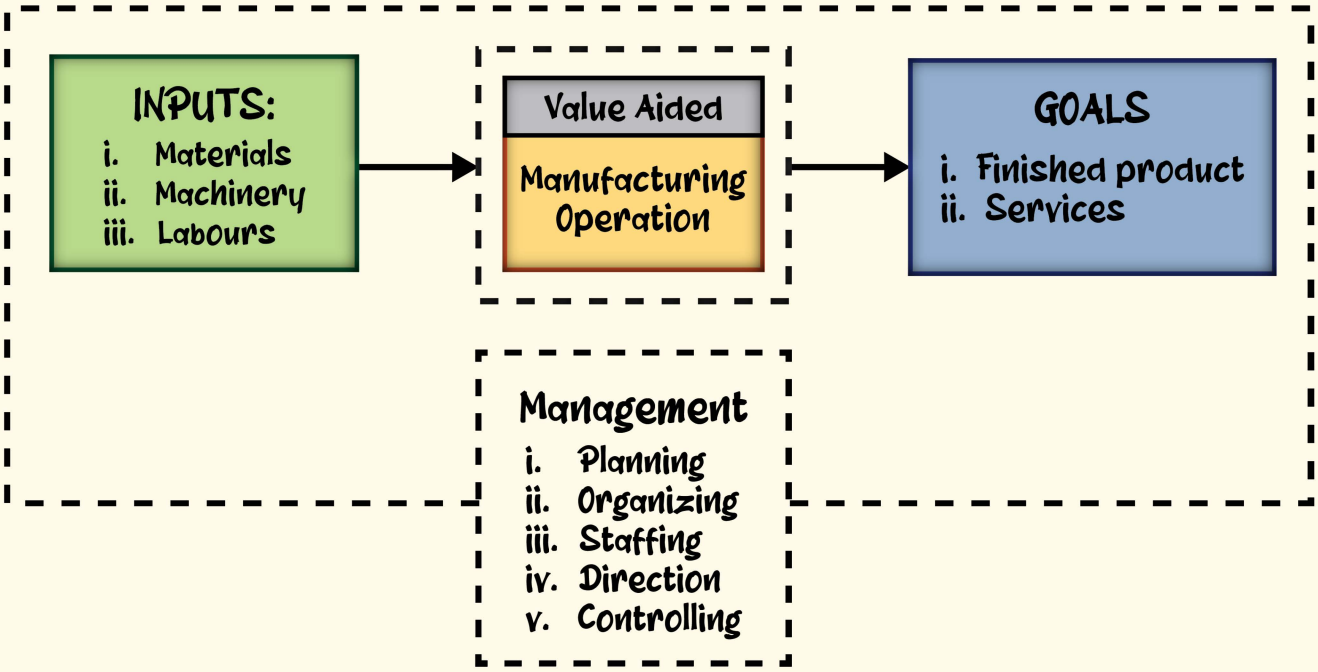


Figure 1.1: Management in manufacturing

Explain The Basic Function of Management

Planning

Planning is a key management function because other function often depends on having good plan.

Includes :

i. Setting organizational goals and objectives.
ii. Developing strategies to reach those goals.
iii. Determining resources needed.
iv. Setting standards.

Organizing

Involves :-

i. Allocating resources, assigning task, and establishing procedures for accomplishing goals.
ii. Preparing a structure (organization chart) showing lines of authority and responsibility.
iii. Recruiting, selecting, training, and developing employees.
iv. Placing employees where they'll be most effective. (creating conditions & systems in which everyone & everything work together)

Staffing

Staffing is the process of filling positions/posts in the qualified personnel

Process of :

i. Organization with adequate and acquiring
ii. Deploying
iii. Retaining a workforce

Objectives :-

i. To understand all function of in an organization
ii. To understand issues related to job analysis & to overcome the problem

Directing

Includes:-

i. Guiding, training, coaching and motivating employees to work effectively to accomplish organizational goals & objectives.
ii. Giving assignment.
iii. Explaining routine.
iv. Clarifying policies.
v. Providing feedback on performance.

Controlling

Includes :-

i. Measuring results against corporate objectives.
ii. Monitoring performance relative to standards.
iii. Taking corrective action, (when necessary)
iv. Recruiting, selecting, training, and developing employees.
v. lacing employees where they'll be most effective. (creating conditions & systems in which everyone & everything work together)

EXPLAIN THE PRINCIPLE OF ORGANIZATION AND PLANNING

Organization is a process of identifying and grouping the work to be done, defining and assigning responsibilities and authority and establishing relationships with the aim of enabling people to work together effectively in achieving objectives.

Basic Principle of an Organization and Terms

i. Authority

The power and right to give orders & make others obey/ to make final decision.

ii. Duties

The work that has to be done.

iii. Responsibility

The obligation to perform assignment.

iv. Accountability

The state of being answerable for the completion of an assignment.

Oriented Organization

Product Oriented - one that organises its activities, products and services around the wants and needs of its customers. A product-orientated firm has its primary focus on its product and on the skills, knowledge and systems that support that product.

Functional Oriented - A functional organizational structure is a structure that consists of activities such as coordination, supervision and task allocation. The organizational structure determines how the organization performs or operates. The term organizational structure refers to how the people in an organization are grouped and to whom they report. Common functions within an organization include production, marketing, human resources, and accounting.

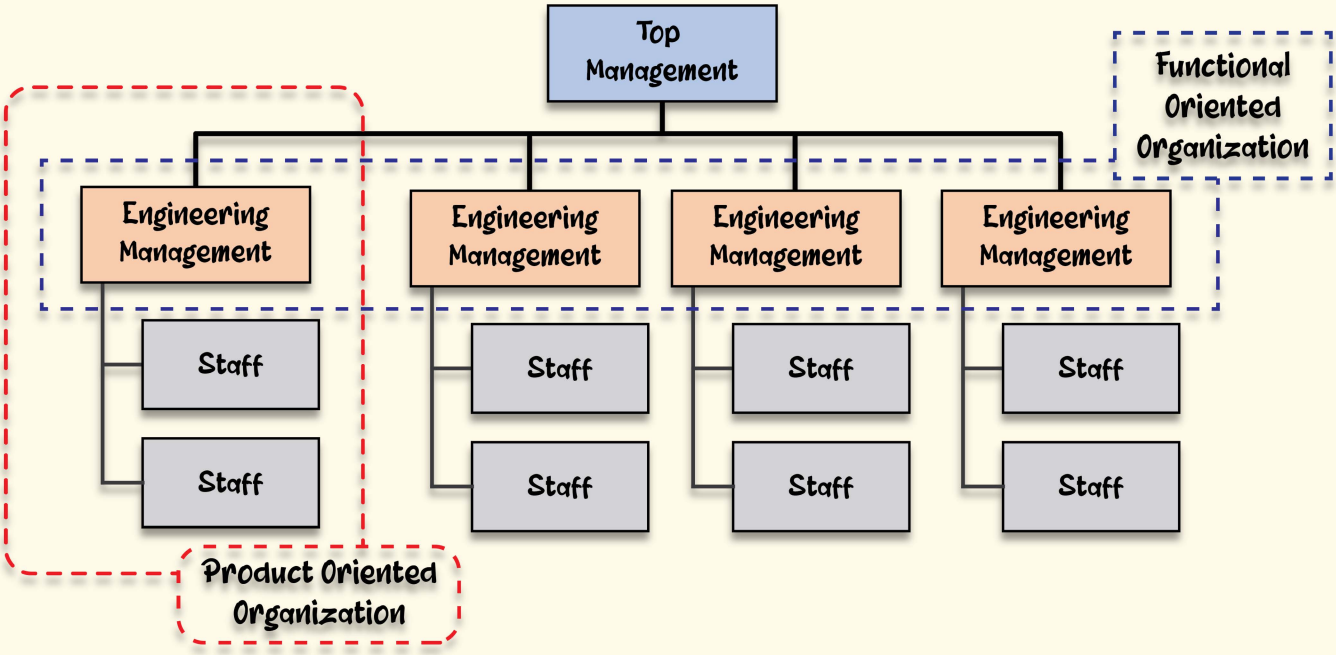


Figure 1.2: Product oriented organization and functional oriented organization

Planning Horizon for an Organization

Planning is a continuous process. It's unlikely that a plan that worked yesterday would be successful in today's market.

Types of planning:

Long range planning

i. Known as a **Strategic planning**
ii. Determines the major goals of the organization as well as the policies, procedures and strategies for obtaining and using resources to achieve those goals.
iii. 5 years or more in time span.

Example:

Planning for new product, capital expenditures, research & development

Medium range planning

i. Known as a **Tactical planning**
ii. Spans from 1 years to 5 years.
iii. Developing detailed about what is to be done, who is to do it and how it is to be done.

Example:

Sales planning, budgeting, production planning.

Short range planning

i. Known as an **Operational planning**
ii. Is the process of setting work standards and schedules necessary to implement the tactical objectives.
iii. Less than 1 years.

Example:

Sales planning, budgeting, production planning.

MANUFACTURING PLANNING AND CONTROL (MPC)

A Manufacturing Planning and Control system provides:

i. Information and support which enables managers to efficiently direct the flow of material
ii. Manage the utilization of people and equipment
iii. Respond to customer requirements by utilizing the capacity of suppliers
iv. Internal facilities include customers.
v. MPC is often a module in an Enterprise Resource Planning (**ERP**) system

Importance of Manufacturing Planning and Control (MPC)

i. Better Service to Customers

Better quality of goods at reasonable prices as per promised delivery dates. Delivery in time and proper quality

ii. Fewer Rush Orders

Production, operations move smoothly as per original planning and matching with the promised delivery dates.

iii. Better Control of Inventory

Maintaining inventory at proper levels and, thereby, minimizing investment in inventory.

iv. More Effective Use of Equipment

The workers can be communicated well in advance if any retrenchment, lay-offs, transfer, etc. is likely to come about.

v. Reduced Idle Time

Less man-hours are lost, which has a positive impact on the cost of production.

vi. Improved Plant Morale

It ensures even flow of work and avoids rush orders. It maintains healthy working conditions in the plant thus, there is improve plant morale as a by-product.

vii. Good public image

Customer's satisfaction leads to increased sales, increased profits, industrial harmony and ultimately good public image of the enterprise.

vii. Lower capital requirements

Helps in minimizing capital investment in equipment and inventories.

Five Major Levels in MPC System

i. Strategic business plan

A strategic business plan is a step-by-step guide a business puts in writing to achieve its business goals and objectives.

5 primary elements:

- The company vision
- Mission statement
- Critical success factors
- Strategies and actions for objectives
- Prioritized implementation timeline

ii. Production plan

The planning of production and manufacturing modules in a company or industry. It utilizes the resource allocation of activities of employees, materials & production capacity, in order to serve different customers.

iii. Master Production Schedule (MPS)

A plan for individual commodities to be produced in each time period such as production, staffing, inventory, etc. It is usually linked to manufacturing where the plan indicates when and how much of each product will be demanded.

iv. Material Requirements Plan (MRP)

A production planning, scheduling, and inventory control system used to manage manufacturing processes. Most MRP systems are software-based, while it is possible to conduct MRP by hand as well.

iv. Purchasing and Production Activity Control

Purchasing involves acquiring materials of right quality, at the right quantity, at right time from a right source and at a reasonable price. Production control is the activity of monitoring and controlling any particular production or operation. Production control is often run from a specific control room or operations room.

FORECASTING

Forecast is a requirement for a service company to plan (more / less) the production, staffing, to order a material and etc. so that they have enough funding to support the whole system.

Solve forecasting

i. Process of predicting a future event.

ii. Forecasts useful in projecting:

- Staffing levels,
- Inventory levels,
- Factory capacity

Forecasting method

Naive Method

i. Assumes demand in next period is the same as demand in most recent period

ii. Sometimes cost effective & efficient

Example: If May sales were 48, then June sales will be 48

Moving Average (MA) Forecasting

i. MA is a series of arithmetic means
ii. Used if little or no trend
iii. Used often for smoothing
iv. Provides overall impression of data over time

Equation :

$$\boldsymbol{MA} = \frac{\sum Demand\ in\ previous\ \boldsymbol{n}\ periods}{\boldsymbol{n}}$$

$*\ n\ is\ the\ number\ period\ in\ the\ moving\ average$

Example 1.1 Forecast using Moving Average Method

You are manager of a museum store that sells historical replicas. You want to forecast sales (000) for 2021 using a 3-period moving average.

Year	2016	2017	2018	2019	2020
Sales	4	6	5	3	7

Solution

Time	Response	Moving Total	Moving Avg.
	Y_i	(n=3)	(n=3)
2016	4	NA	NA
2017	6	NA	NA
2018	5	NA	NA
2019	3	**4 + 6 + 5 = 15**	**15 / 3 = 5.0**
2020	7	**6 + 5 + 3 = 14**	**14 / 3 = 4.7**
2021	NA	**5 + 3 + 7 = 15**	**15 / 3 = 5.0**

Weighted Moving Average Forecasting

i. Used when trend is present
ii. Older data usually less important
iii. Weights based on intuition
iv. Often lay between 0 & 1, & sum to 1.0

Equation :

$$\boldsymbol{WMA} = \frac{\sum(Weight\ for\ period\ \boldsymbol{n})(Demand\ in\ period\ \boldsymbol{n})}{\sum Weight}$$

$*\ n$ *is the number period in the moving average*

Example 1.2 Forecast using Weight Moving Average Method

Use the data from example 1.1, estimate the demand with the weighted moving average in which weighting the past 3 years as follows:

Solution

Weighted Applied	Period
3	Last year
2	2 Year ago
1	3 Year ago
6	∑ of weights

Year	Sales	∑ (weight for period n) (demand in period n)	Forecast 3 year weighted moving average
2016	4		
2017	6		
2018	5		
2019	3	(5x3) + (6x2) + (4x1) = 31	31 / 6 = 5.17
2020	7	(3x3) + (5x2) + (6x1) = 25	25 / 6 = 4.17
2021	NA	(7x3) + (3x2) + (5x1) = 32	32 / 6 = 5.33

Exponential Smoothing Forecasting

i. Form of weighted moving average
   - Weights decline exponentially
   - Most recent data weighted most

i. Requires smoothing constant (a)
   - Ranges from 0 to 1
   - Subjectively chosen

i. Involves little record keeping of past data

Equation :

New forecast = last period's forecast + α(last period's actual demand – last period's forecast)

$$F_t = F_t - 1 + \alpha[(A_t - 1) - (F_t - 1)]$$

F_t = *Forecast value*
A_t = *Actual value*
α = *Smoothing constant*

Example 1.3 Forecast using Exponential Smoothing Method

You're organizing a Kwanza meeting. You want to forecast attendance for 2016 using exponential smoothing.
(a = .10) The 2021 forecast was 175

Year	2016	2017	2018	2019	2020
Attendant	180	168	159	175	190

Solution

Year	Attendant	Forecast, Ft (a=0.10)
2016	180	175.00 (Given)
2017	168	175.00 + 0.10(180-175.00) = 175.50
2018	159	175.50 + 0.10(168-175.50) = 174.75
2019	175	174.75 + 0.10(159-174.75) = 173.18
2020	190	173.18 + 0.10(175-173.18) = 173.36
2021	NA	173.36 + 0.10(190-173.36) = 175.02

CALCULATE FORECAST ERRORS

Forecasting almost always receive errors results due to unpredictable factors that cause the forecast to deviate from actual demand. To minimize forecast errors by selecting appropriate forecast technique, it is important to measure the accuracy for any forecasting technique used.

Forecast error for a given period t is simply the difference found by subtracting the forecast from actual demand:

$$e_t = A_t - F_t$$

F_t = *Forecast value*
A_t = *Actual value*

In this subtopic, we will go through forecast error measuring technique: Mean Absolute Deviation (MAD), Mean Squared Error (MSE) and Mean Absolute Percent Error (MAPE)

Mean Absolute Deviation (MAD)

Mean absolute deviation of a data set is the average of the absolute deviations from a central point.

$$MAD = \frac{1}{n}\sum_{t=1}^{n}|e_t|$$

Mean Squared Error (MSE)

The mean squared error (MSE) of an estimator measures the average of the squares of the errors or deviations, that is, the difference between the estimator and what is estimated.

$$MSE = \frac{1}{n}\sum_{t=1}^{n}(A_t - F_t)^2$$

Mean Absolute Percent Error (MAPE)

Mean absolute percentage error (MAPE), is a measure of prediction accuracy of a forecasting method in statistics, for example in trend estimation.

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{A_t - F_t}{A_t} \times 100\right|$$

**Expressed as a percentage*

Exercises

1. Define TWO basic functions of management.
2. Define the basic functions of management given below:
   i. Planning
   ii. Directing
   iii. Controlling

3. State THREE methods to measure forecasting error
4. Define the following organization terms
   i. Authority
   ii. Duty
   iii. Responsibility
   iv. Accountability

5. Define management and its functions
6. Auto Sales at X Automobile Bhd. is as shown in table below Authority

Week	1	2	3	4	5	6	7	8
Auto sale	8	10	9	11	10	13	12	-

   i. Calculate the forecast sales using a 3-month moving average from week 4 until week 8.
   ii. Calculate the forecast sales on week 4 until week 8 using a 3-month weighted moving average using 1, 2 and 3 with the heaviest weight applied to the most recent week.
   iii. Accountability

7. Exponential smoothing is used to forecast smartphone sales. Two values of α are examined, α=0.6 and α=0.2. Evaluate which a if preferable by using Mean Absolute Deviation (MAD). Assume the forecast for January was 22 smartphones. Actual sales are given in table below

Month	January	February	March	April	May	June
Demand (unit)	20	21	15	14	13	16

Exercises

8. Number of sales of women's robe in all sizes at cloth store in Penang, over the past 10 weeks are shown in the table below

Week	1	2	3	4
Demand (unit)	200	303	287	298

9. Sales of music record in all genre at Johny's music store in Penang, over the past 10 weeks are shown in the table below

Week	1	2	3	4	5	6	7	8	9	10
Demand	20	21	28	37	25	29	36	22	25	28

10. Car sales in Das Car Auto Company during the half year of 2021 are shown in the table below

Month	January	February	March	April	May	June
Sales (unit)	37	42	53	50	43	38

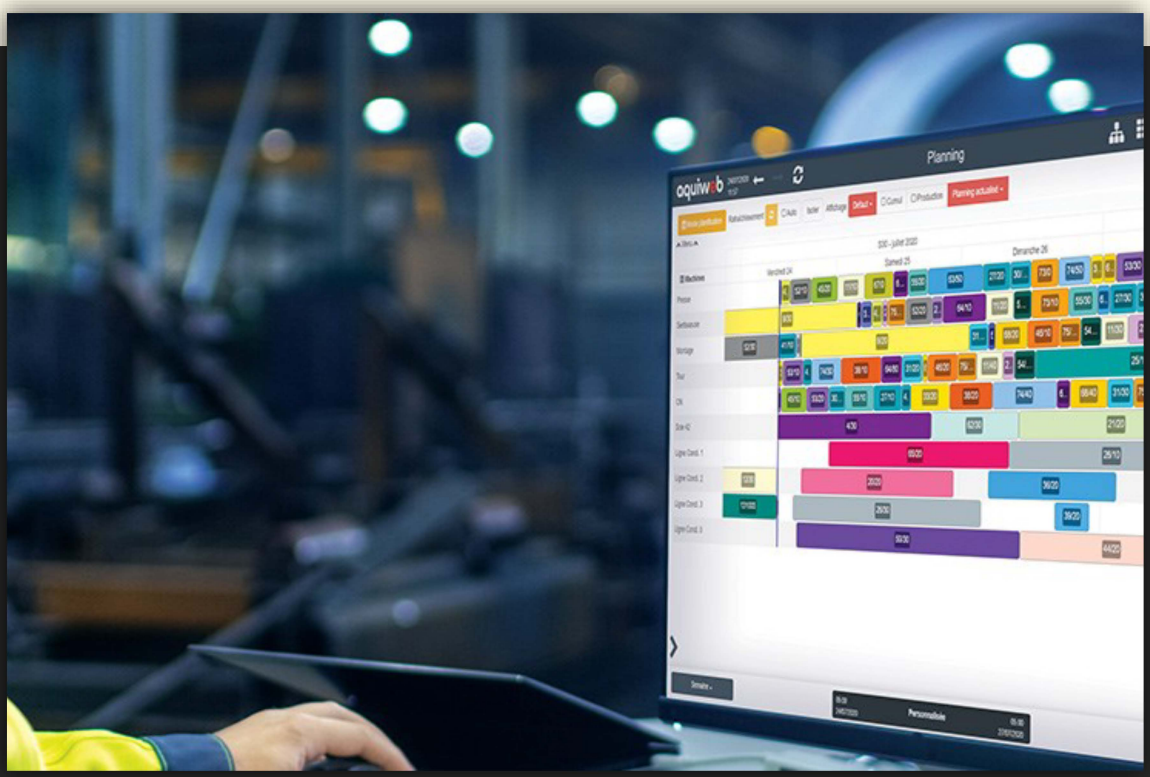
Based on the data, calculate;

i. The forecasting sales for April 2021 until July 2021 by using THREE (3) months moving average.

ii. Calculate the Mean Absolute Deviation (MAD) for Question 10 (i) result.

11. Delta Sdn. Bhd. is the largest water pump company in Sabah and they have set up a team to forecast the demand of pump in Kota Kinabalu. Table below shows the information that they had collected.

Month	Actual Demand	Forecasting
1	895	888
2	880	890
3	890	885
4	892	890
5	885	892
6	898	895



2 Product Scheduling

Scheduling is a short term execution plan of production planning model. Production scheduling consists activities performed in a manufacturing company in order to manage and control the execution of a production process an how the factory resources should be utilized to complete the plan. While operation scheduling a type of scheduling in assigning jobs to workstations or employees are assigned to jobs for a specified time periods. An effective scheduling can yield cost savings, increases in productivity, minimize utilization and minimize work-in-progress inventory.

In this chapter, student will learn about (i) Master Production Schedule (MPS), (ii) scheduling service and manufacturing process and (iii) sequencing jobs.

MASTER PRODUCTION SCHEDULE (MPS)

MPS Definition

Master Production Schedule is a timetable that specifies the quantity of a product or items and when it should be produce. A Master Production Schedule must states the requirements for individual end items by date and quantity.

Concept

A Master Production Schedule must be in accordance with company aggregate plan. This plan are taken from product demand (forecasts, regular, late) and distributed sending by date.

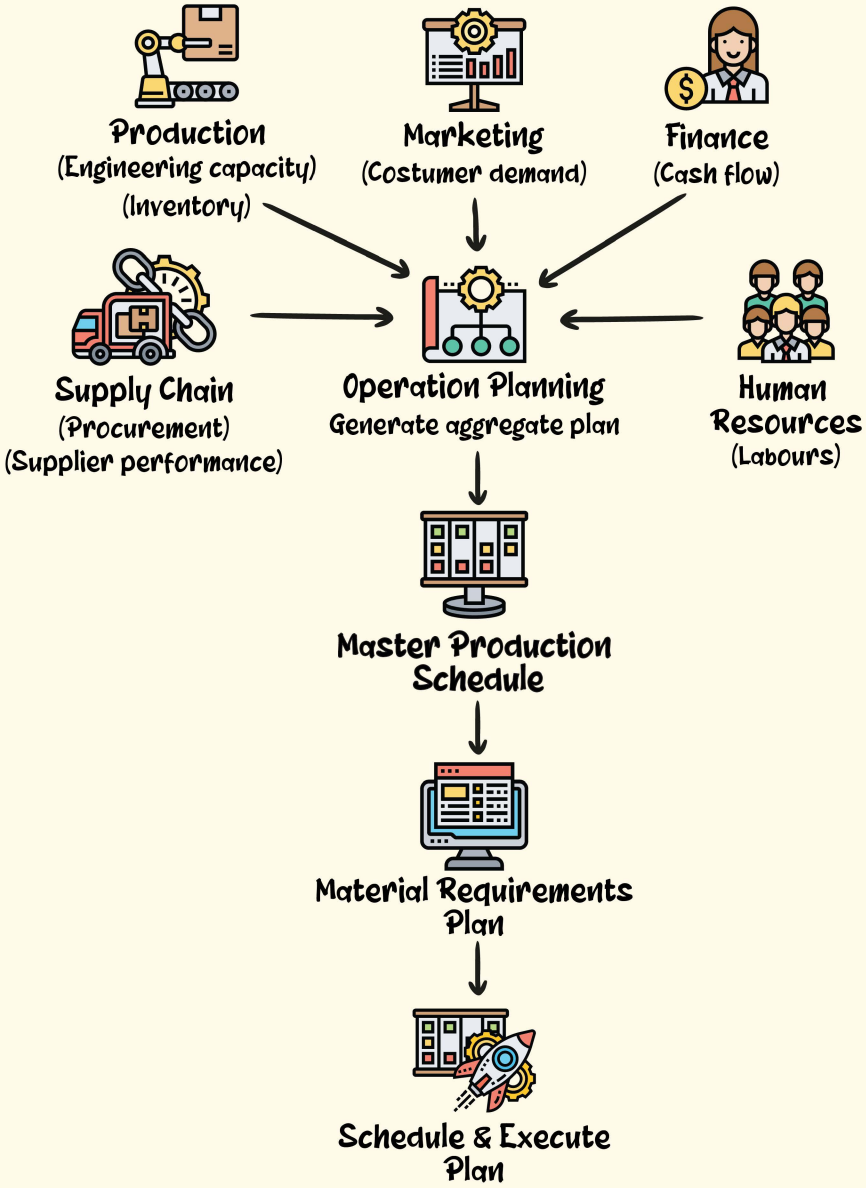


Figure 2.1: Production planning process

Usually the plan were developed by the operation planning team which include **financial data**, **costumer demand**, **engineering capabilities**, **labours**, **inventory**, **supplier performance** and other considerations. From all collective data, production schedule were developed based on the needs of maximum demand and capacity.

Importance of MPS

An effective MPS provides:

i. Basis for making customer delivery promises.
ii. Utilizing plant capacity effectively.
iii. Attaining the firm's strategic objectives as reflected in the production plan .
iv. Resolving trade-off between manufacturing and marketing.

Benefits of MPS

i. Ability to make an adjustments to fluctuations in demand and still minimize waste.
ii. Helps prevent shortages and scheduling mishaps.
iii. Improves efficiency in the location of production resources.
iv. Provides more effective cost controls and more accurate estimates of material requirements and delivery dates.
v. Reduces lead times throughout the year.
vi. Provides an effective communication conduit with the sales team for planning purposes.

Formula for MPS

Monthly production:

$$\boldsymbol{Monthly\ Production\ (MP) = \frac{Balance\ hour\ in\ a\ month}{Standard\ time}}$$

The remaining hours available in a month:

$$\boldsymbol{Production\ period\ (PP) = \frac{Total\ production\ each\ station}{Monthly\ production\ (MP)}}$$

Major Functions of MPS

The MPS are planning to fulfil three major functions:

i. To achieve desired customer service levels.
ii. To make the most efficient use of resources.
iii. To maintain a desirable level of inventory.

Element in Developing Master Production Schedule

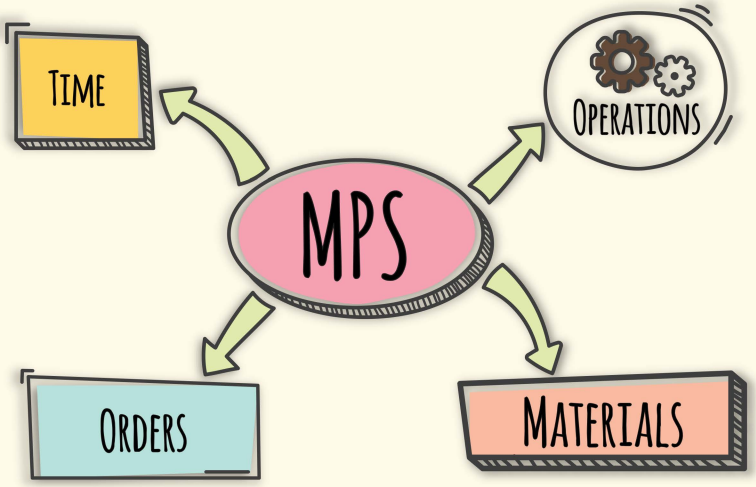


Figure 2.2: Master Production Schedule elements

i. Materials - List all the materials for the manufacture of each product.
ii. Operations - The complete list of operations for the production process operations.
iii. Time - The standard time of each operation.
iv. Orders - Total orders (quantity orders & stocks).

Meet Demand by Referring to Order and Forecast

i. The method should be easy to understand and should be simple to use.
ii. The method selected should give minimum forecast errors at the optimal cost.
iii. The cost to make the forecast should be reasonable i.e., not very expensive.

Short Term Ability

Short-term production planning is the planning phase during which the actual orders are continuously scheduled and produced. In short-term planning, there is significant uncertainty arising from material orders and the workforce and machines While short term (days, hours, minutes) schedules translate capacity decisions, aggregate planning and master schedules into job sequences and specific assignments of personnel, materials and machinery.

Example 2.1 Construct Master Production Schedule

MGA Sdn. Bhd. is a local company that to produce 4000 units of new products next year. The product consists of 2 stages of operation which is shown in table below.

Operation	Standard time (hour/unit)	Monthly Capacity (hour/month)
1	1.5	1200
2	3.0	2000

i. Solve the monthly production (unit/month) and production period time (month).

ii. Construct the Master Production Schedule for this company and state when the products can be distributed.

Solution (i)

Operation 1	Operation 2
MP = 1200 / 1.5 = **800 unit** PP = 4000/ 800 = **5 months**	MP = 2000 / 3 = **667 unit** PP = 4000 / 667 = **6 months**

Solution (ii)

Month	Operation 1	Operation 2
1	800	
2	800	667
3	800	667
4	800	667
5	800	667
6		667
7		665

Example 2.2 Construct Master Production Schedule

Gopal Limited Sdn. Bhd. is going to produce a new toy product. The predicted order in year 2021 is 10,000 units. There are five (5) stations to produce the product. Station 1 with manufacturing rate is 6 hours/ unit. Station 2 with 10 hours per unit of standard time, station 3 needs 15 hours working hours to process one unit work piece. Station 4 took 8 hours/unit and station 5 needs 12 hours per unit ABC. Data for monthly production time are as below:

Operation	1	2	3	4	5
Monthly Capacity (hour/month)	15000	10000	21000	10000	18000

Calculate:

i. Monthly production and duration production.

ii. Build the MPS table.

iii. Analyze the data from MPS.

Solution (i)

Operation 1	Operation 2
MP = 15000 / 6 = **2500 unit** PP = 10000 / 2500 = **4 months**	MP = 10000 / 10 = **1000 unit** PP = 10000 / 1000 = **10 months**
Operation 3	**Operation 4**
MP = 21000 / 15 = **1400 unit** PP = 10000 / 1400 = 7.1 ≈ **8 months**	MP = 10000 / 8 = **1250 unit** PP = 10000 / 1250 = **8 months**

Operation 5
MP = 18000 / 12 = **1500 unit** PP = 10000 / 1500 = 6.7 ≈ **7 months**

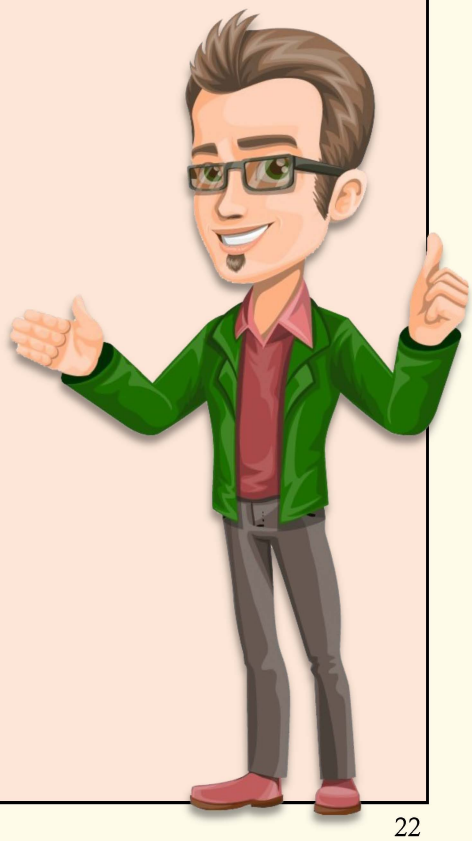
Example 2.2 Construct Master Production Schedule

Solution (ii)

Month	Station 1	Station 2	Station 3	Station 4	Station 5
1	2500				
2	2500	1000			
3	2500	1000			
4	2500	1000			
5		1000	1400		
6		1000	1400		
7		1000	1400	1250	
8		1000	1400	1250	1500
9		1000	1400	1250	1500
10		1000	1400	1250	1500
11		1000	1400	1250	1500
12			200	1250	1500
13				1250	1500
14					1500

Solution (iii)

i. There are 5 stations involved
ii. Station 1 will start production in month 1
iii. Station 2 will start production in month 2
iv. Station 3 will start production in month 5
v. Station 4 will start production in month 7
vi. Station 5 will start production in month 8
vii. New product will market on month 15



SCHEDULING SERVICE AND MANUFACTURING PROCESS

Each manufacturing operations have its own production demand, production process, machines capability and capacity, inventory capacity and workforce quantity. This differentiate plays importance role in how a company organize its operations and what scheduling techniques should be use. A correct scheduling technique depend on demand volume, nature of production operation and overall complexity of jobs. There are four important criteria when determining which scheduling technique should be used. Figure below shows scheduling technique criteria. These four criteria are used to evaluate scheduling performance.

Minimize completion time

- Evaluate by determining the average completion time per job

Minimize utilization

- Evaluate by determining the percentageof the facility is utilized

Minimize work-in-progress inventory

- Evaluate by determining the average number of jobs in the system
- The relationship between the number of jobs in the system and WIP inventory wil be high. The fewer the number of job in the system, the lower the inventory

Minimize costumer waiting time

- Evaluate by determining the average number of late days

Figure 2.3: Scheduling technique criteria

Performance Measure Terms

The quality of each scheduling technique can be measure on how well its performs on the four scheduling criteria. In scheduling, the performance measure is used to choose which technique should be used. There are six performance measure terms should be understand in scheduling.

Job Flow Time

i. Amount of time from start to finish the job.
ii. Amount of time to complete the job.
iii. The time a job spends in the service or manufacturing system.

Makespan

i. Total amount of time required to complete a group of jobs .
ii. The length of time between the start of the first job in the group and the completion of the last job in the group.

Past Due

i. Job's lateness or tardiness.
ii. The amount of time by which a job missed its due date.

Work-in-progress

i. Product or components that are no longer raw materials but have yet to become finished products.
ii. Show whether the job are overdue or under due.

Total Inventory

i. The sum of scheduled receipts and on-hand inventories = scheduled receipts for all item + on-hand inventories of all item.

Utilization

i. The degree to which equipment, space, or the workforce is currently being used, measured as the ratio of the average output rate to maximum capacity.
ii. The process of tracking actual time or scheduled time against the capacity of a resource.

JOB SHOP SCHEDULING

Job shop scheduling is a short-term scheduling used in process-focused facilities. Job shop facilities are a manufacturing and service organizations that specializes in low to medium volume production and utilizes job or batch processes which based on customer demand. Usually customer demand frequently changes in volume and variety. Job shop scheduling required work sequence, time required of jobs to be completed, and the capacity and availability of a work center to establish a time-based plan which set out a series of events with the time or date when they should occur. It relates to the use of equipment, facilities and human activities in an organization. An effective job shop scheduling can yield cost savings and increase in productivity.

Figure 2.5: Workstation is an area where one person works, usually with special equipment, on a specialized job

Priority sequencing rules

One of scheduling aspect is sequencing work at workstations. Sequencing decisions determine both the order in which jobs are processed at various work centers, and the order in which jobs are processed at individual workstations within the work centers. By knowing the expected processing time, sequencing allow us to estimate the start and finish times of each jobs.

Priority sequencing rule is a way to determine what job to process next. It provide guidelines for the sequence in which job should be worked. In using this sequencing rules, processing time and due date are important pieces of information. Priority sequencing rules try to meet scheduling criteria in minimizing completion time, minimizing number of jobs in the system and minimizing job lateness while maximizing facility utilization. This book will cover three type of priority sequencing rule:

First come first served (FCFS)

FCFS give highest priority to a job or customer which arriving first at the workstation. This rule treated each job equally, with no job stepping ahead of others that are already in line. It is commonly used at service facilities. FCFS processed jobs in order which arrive first.

Figure 2.6: FCFS: customer waiting in line to use vending machine

Earliest due date (EDD)

EDD is a priority sequencing rule that minimizes maximum lateness. EDD takes jobs that has earliest due date to be process next. EDD is suitable to a product that has lateness as an issue.

For example, a product cannot be assembled until all of its components are available. If these components were not already in inventory, they must be ordered prior to when the product assembly can begin. In this case, due date of the component is the start date for the assembly process.

$$Critical\ Ratio\ (CR) = \frac{Time\ remaining}{Workdays\ remaining} = \frac{Due\ date - Today's\ date}{Work\ (lead)\ time\ remaining}$$

Critical ratio (CR)

Jobs are processed according to the smallest ratio of time remaining until due date to processing time remaining. CR is an index number obtained from dividing the time remaining until due date by the work time remaining. As opposed to others priority rules, critical ratio is more dynamic and easily updated. It tends to perform better than FCFS and EDD on the average job-lateness criterion. The formula for critical ratio is:

- Job with critical ratio less than 1 means the jobs is behind schedule.
- Job with CR equals to 1 means the job is on schedule.
- Job with CR greater than 1 means the job is ahead of schedule.

Priority sequencing rule work-step

i. Rearrange the job sequence based on the priority sequencing rule used.
   - FCFS = which comes first will be arranged first.
   - EDD = earliest due date will be arranged first.
   - CR = lowest critical ratio will be arranged first.

ii. Count flow time for each job = *flow time*$_{(n-1)}$ + *processing time*$_{(n)}$.

iii. Find job lateness = *flow time*$_{(n)}$ – *due date*.

iv. Find makespan (total processing time), total flow time, total job lateness.

v. Perform performance measure analysis to determine the effectiveness of the priority sequencing rule used.

Performance measures analysis

Each jobs require different priority sequencing rule and each priority sequencing rule is not the best solution. In order to choose which priority sequencing rule suitable for the jobs, it will depend on how each rule performs on four criteria: the priority rules try to minimize completion time, maximize facility utilization, minimize number of jobs in the system, and minimize job lateness. The performance are measured using:

i. Average completion time

$$\boldsymbol{Average\ completion\ time = \frac{Total\ flow\ time}{Number\ of\ jobs}}$$

ii. Average number of jobs

$$\boldsymbol{Average\ number\ of\ jobs = \frac{Total\ flow\ time}{Total\ job\ work\ (processing)\ time}}$$

iii. Average job lateness

$$\boldsymbol{Average\ job\ lateness = \frac{Total\ late\ days}{Number\ of\ jobs}}$$

iv. Utilization

$$\boldsymbol{Utilization = \frac{Total\ job\ work\ (processing)\ time}{Total\ flow\ time} \times 100}$$

Example 2.3 First come first served

Table below contain information about a five jobs that just arrived at a workshop. They are the only ones now waiting to be processed. Assume jobs arrived in the order shown.

Job	Processing time (days)	Due date (days)	Workdays remaining (days)
A	10	12	12
B	7	11	10
C	15	35	15
D	4	32	12
E	8	20	17

i. Sequence the jobs using first come first serve priority rule.

ii. Measure the effectiveness of sequence from example 2.3 (i).

Solution (i)

Sequence these jobs **based on job orders**.

Job	Processing time (days)	Flow time (days)	Due date (days)	Job lateness (days)
A	10	**10**	12	10-12 = -2 ≈ **0**
B	7	10+7 = **17**	11	17-11 = **6**
C	15	17+15 = **32**	35	32-35 = -3 ≈ **0**
D	4	32+4 = **36**	32	36-32 = **4**
E	8	36+8 = **44**	20	44-20 = **24**
Total	Makespan = **44**	**139**		**34**

Solution (ii)

i. Average completion time

$$Average\ completion\ time = \frac{Total\ flow\ time}{Number\ of\ jobs}$$

$$Average\ completion\ time = \frac{139}{5} = 27.8\ days$$

Example 2.3 First come first served

ii. Average number of jobs.

$$Average\ number\ of\ jobs = \frac{Total\ flow\ time}{Total\ job\ work\ (processing)\ time}$$

$$Average\ number\ of\ jobs = \frac{139}{44} = 3.16\ jobs$$

iii. Average job lateness.

$$Average\ job\ lateness = \frac{Total\ late\ days}{Number\ of\ jobs}$$

$$Average\ job\ lateness = \frac{34}{5} = 6.8\ days$$

iv. Utilization.

$$Utilization = \frac{Total\ job\ work\ (processing)\ time}{Total\ flow\ time} \times 100$$

$$Utilization = \frac{44}{139} \times 100 = 31.65\%$$

Example 2.4 Earliest due date

By using table from Example 2.3:

i. Sequence the jobs using earliest due date priority rule.

ii. Measure the effectiveness of sequence from example 2.4 (i).

Solution (i)

Sequence these jobs based on **earliest due date arrange first**.

Job	Processing time (days)	Flow time (days)	Due date (days)	Job lateness (days)
B	7	**7**	11	7-7 = **0**
A	10	7+10 = **17**	12	17-12 = **5**
E	8	17+8 = **25**	20	25-20 = **5**
D	4	25+4 = **29**	32	29-32 = -3 ≈ **0**
C	15	29+15 = **44**	35	44-35 = **9**
Total	Makespan = **44**	**122**		**19**

Solution (ii)

i. Average completion time

$$Average\ completion\ time = \frac{Total\ flow\ time}{Number\ of\ jobs}$$

$$Average\ completion\ time = \frac{122}{5} = 24.4\ days$$

ii. Average number of jobs

$$Average\ completion\ time = \frac{Total\ flow\ time}{Number\ of\ jobs}$$

$$Average\ completion\ time = \frac{139}{5} = 27.8\ days$$

iii. Average job lateness

$$Average\ job\ lateness = \frac{Total\ late\ days}{Number\ of\ jobs}$$

$$Average\ job\ lateness = \frac{19}{5} = 3.8\ days$$

Example 2.4 Earliest due date

iv. Utilization

$$Utilization = \frac{Total\ job\ work\ (processing)\ time}{Total\ flow\ time} \times 100$$

$$Utilization = \frac{44}{122} \times 100 = 36.07\%$$

Example 2.5 Critical ratio

Use table from example 2.3. Assume jobs arrived in the order shown. Today is day 1, and work begin today.

i. Sequence the jobs using critical ratio priority rule.

ii. Measure the effectiveness of sequence from example 2.5 (i).

Solution (i)

Find each job critical ratio

$$Critical\ Ratio\ (CR) = \frac{Time\ remaining}{Wordays\ remaining} = \frac{Due\ date - Today's\ date}{Work\ (lead)\ time\ remaining}$$

$$Job\ A = \frac{12-1}{12} = 0.9 \qquad Job\ B = \frac{11-1}{10} = 1$$

$$Job\ C = \frac{35-1}{15} = 2.27 \qquad Job\ D = \frac{32-1}{12} = 2.58$$

$$Job\ E = \frac{20-1}{17} = 1.12$$

Sequence these jobs based on **critical ratio matrixes**.

CR	Job	Processing time (days)	Flow time (days)	Due date (days)	Job lateness (days)
0.9	A	10	**10**	12	0
1	B	7	**17**	11	6
1.12	E	8	**25**	35	0
2.27	C	15	**40**	32	8
2.58	D	4	**44**	20	24
	Total	Makespan = **44**	**136**		**38**

Example 2.5 Critical ratio

Solution (ii)

i. Average completion time

$$Average\ completion\ time = \frac{Total\ flow\ time}{Number\ of\ jobs}$$

$$Average\ completion\ time = \frac{136}{5} = 27.2\ days$$

ii. Average number of jobs

$$Average\ number\ of\ jobs = \frac{Total\ flow\ time}{Total\ job\ work\ (processing)\ time}$$

$$Average\ completion\ time = \frac{136}{5} = 27.2\ days$$

iii. Average job lateness

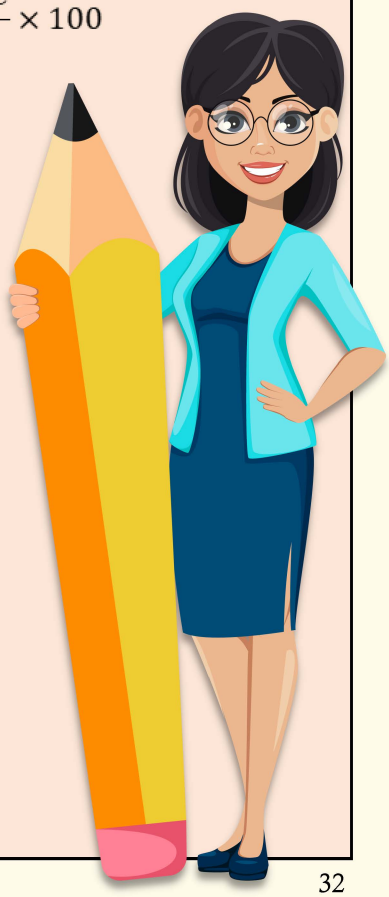
$$Average\ job\ lateness = \frac{Total\ late\ days}{Number\ of\ jobs}$$

$$Average\ job\ lateness = \frac{38}{5} = 7.6\ days$$

iv. Utilization

$$Utilization = \frac{Total\ job\ work\ (processing)\ time}{Total\ flow\ time} \times 100$$

$$Utilization = \frac{44}{136} \times 100 = 32.35\%$$



Example 2.6 Critical ratio

The following jobs were receive at proton service centre. Assume jobs arrived in the order shown.

Job	Processing time (days)	Due date (days)
A	6	22
B	12	14
C	14	30
D	2	18
E	10	25
F	4	34

i. Sequence the jobs using critical ratio priority rule.

ii. Measure the effectiveness of sequence from example 2.6 (i).

Solution (i)

Find each job critical ratio

$$Critical\ Ratio\ (CR) = \frac{Time\ remaining}{Wordays\ remaining} = \frac{Due\ date - Today's\ date}{Work\ (lead)\ time\ remaining}$$

$$Job\ A = \frac{22-0}{6} = 3.67 \qquad Job\ B = \frac{14-0}{12} = 1.67$$

$$Job\ C = \frac{30-0}{14} = 2.14 \qquad Job\ D = \frac{18-0}{2} = 9$$

$$Job\ E = \frac{25-0}{10} = 2.5 \qquad Job\ F = \frac{34-0}{4} = 8.5$$

Sequence these jobs based on **critical ratio matrixes.**

CR	Job	Processing time (days)	Flow time (days)	Due date (days)	Job lateness (days)
1.67	B	12	**12**	14	**0**
2.14	C	14	**26**	30	**0**
2.5	E	10	**36**	25	**11**
3.67	A	6	**42**	22	**20**
8.5	F	4	**46**	34	**12**
9	D	2	**48**	18	**30**
	Total	Makespan = **48**	**210**		**38**

Example 2.6 Critical ratio

Solution (ii)

i. Average completion time

$$Average\ completion\ time = \frac{Total\ flow\ time}{Number\ of\ jobs}$$

$$Average\ completion\ time = \frac{210}{6} = 35\ days$$

ii. Average number of jobs

$$Average\ number\ of\ jobs = \frac{Total\ flow\ time}{Total\ job\ work\ (processing)\ time}$$

$$Average\ number\ of\ jobs = \frac{210}{48} = 4.38\ jobs$$

iii. Average job lateness

$$Average\ job\ lateness = \frac{Total\ late\ days}{Number\ of\ jobs}$$

$$Average\ job\ lateness = \frac{38}{6} = 6.3\ days$$

iv. Utilization

$$Utilization = \frac{Total\ job\ work\ (processing)\ time}{Total\ flow\ time} \times 100$$

$$Utilization = \frac{48}{210} \times 100 = 22.86\%$$

Johnson's rule

There are situation for a group of jobs that has to be processed on two machines. These jobs must go through two different machines or work centres in the same order whereas these work centres can only work one job at a time. To sequence these jobs, Johnson's rule technique will be use. Johnson's rule is an approach that minimizes the total time for sequencing a group of jobs through two work centers while minimizing total idle time in the work centers. For the technique to work, there are conditions to be meet:

i. Job time must be known and constant.

ii. Job times must be independent of sequence.

iii. Jobs must follow same two-step sequence.

iv. Job priorities cannot be used.

v. All units must be completed at the first work center before moving to second.

Johnson's Rule Optimum Sequence

i. List time required to process each job at each machine. Set up a one-dimensional matrix to represent desired sequence with number of slots equal to number of jobs.

ii. Select smallest processing time at either machine. If that time is on work center 1, put the job as near to beginning of sequence as possible.

iii. If smallest time occurs on work center 2, put the job as near to the end of the sequence as possible.

iv. Remove job that has already selected from list.

v. Repeat steps (ii - iv) until all slots in matrix are filled and all jobs are sequenced.

Example 2.7 Johnson's rule

Use Johnson's rule to find the optimum sequence for processing the jobs shown below.

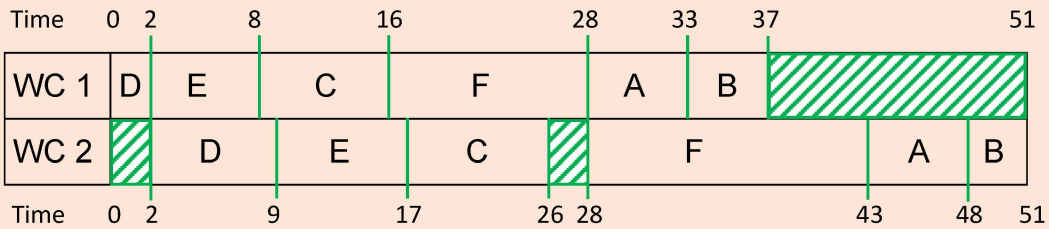
Job	Processing time (hours)	
	Work center 1	Work center 2
A	5	5
B	4	3
C	8	9
D	2	7
E	6	8
F	12	15

Solution

Sequence job order using Johnson's rule

Job	Processing time (hours)	
	Work center 1	Work center 2
D	2	7
E	6	8
C	8	9
F	12	15
A	5	5
B	4	3

Construct time-phased chart



Idle

Analysis

- Total working hours = 51 hour
- Idle time WC 1 = 14 hour
- Idle time WC 2 = 4 hour

Exercises

1. Give 4 benefits of MPS.
2. State 4 elements in MPS.
3. Describe the Priority Sequencing Rules below:
   i. First come, first served
   ii. Earliest due date
   iii. Critical ratio

4. XX Bakery is making a new flavour cupcake. The total amount required is 2000 cup cakes.

Station	Standard Time (hour / unit)	Total hour left in month
1	0.25	110
2	0.10	100
3	0.20	130
4	0.25	100
5	0.40	150

   i. Calculate the monthly production (unit/month) and production period (month) for each station.
   ii. Construct the Master Production Schedule.

5. Aman Sdn Bhd is a local company that to produce 10000 units of new design shoes next year. The shoes consist of two stages of operation which is shown in Table below Auto Sales at X Automobile Bhd. is as shown in table below

Operation	Standard Time (hour / unit)	Monthly Capacity (hour / month)
1	1.5	2000
2	3.0	2500

   i. Solve the monthly production (unit/month) and production period time (month).
   ii. Construct the Master Production Schedule for this company.

Exercises

6. Tangga Raj Sdn Bhd is a local company that to produce 6,000 units of new design vase next year. The vase consists of two stages of operation which is shown in Table below .

Operation	Standard Time (hour / unit)	Monthly Capacity (hour / month)
1	1.5	1500
2	3.0	1800

   i. Solve the monthly production (unit/month) and production period time (month).
   ii. Construct the Master Production Schedule for this company.

7. The Jogy Company wants to produce 2000 units of sugar cane juice machines for the local market. The product will be produced in 5 levels of operations. Table below shows the operating level for each product.

Operation	Monthly Production Time (hour/month)	Standard Time (hour)
1	310	1/3
2	320	2/5
3	450	2/3
4	370	3/4
5	310	1/2

   Based on the data:
   i. Calculate the capacity and period of production for each process.
   ii. Develop the MPS.

8. Association CAB's company receives order for several products that need to be prepared on table below:

Job	Processing Time (Days)	Due Date (Days)
A	7	7
B	4	3
C	5	7
D	10	8
E	3	6

   Measure the effectiveness of sequence for:
   i. First come, first served.
   ii. Earliest due date.
   iii. Critical ratio.

Exercises

9. Abu and sons company receives order for several products that need to be prepared on table below:

Job	Processing Time (Days)	Due Date (Days)	Workdays remaining (days)
A	14	30	16
B	10	26	15
C	7	15	8
D	6	17	6
E	3	6	5

Measure the effectiveness of sequence for:

i. First come, first served.

ii. Earliest due date.

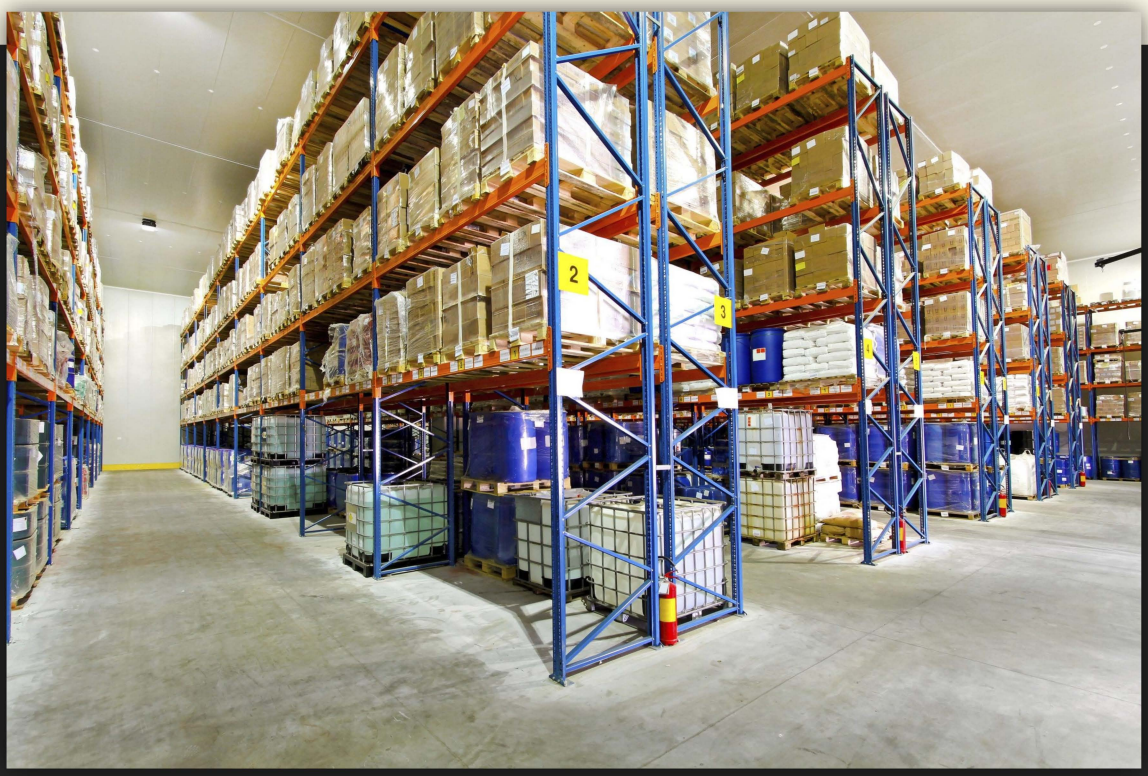
iii. Critical ratio.

10. Six jobs are to be processed through a two-step operation. The first operation involves sanding, and the second involves painting. Processing times are as follows. Sequence job order using Johnson's rule.

Job	Operation 1 (hour)	Operation 2 (hour)
A	16	5
B	3	13
C	9	6
D	8	7
E	2	14
F	18	11

11. Use Johnson's Rule to find the total time for the following set of jobs through two work centers at a printing company.

Order	Printing (hour)	Binding (hour)
A	15	3
B	4	10
C	11	8
D	7	8
E	5	7



3 Inventory Control

An inventory is a stock or store of goods located in firms. Each manufacturing firms typically stock hundreds or even thousands of items in inventory, ranging from small things such as pencils, paper clips, screws, nuts, and bolts to large items such as machines, trucks, construction equipment, and airplanes. Inventory control means to have the right goods, in sufficient quantities, in the right place, at the right time and the right timing and costs of ordering and carrying inventories.

In this chapter student will learn about (i) concept of inventory in manufacturing, (ii) characterize inventory using inventory management method and (iii) analyze the inventory model and cost.

CONCEPT OF INVENTORY IN MANUFACTURING

Definition of Inventory

Stocks of materials - the goods or merchandise (raw materials, purchased parts, partially finished items, and finished goods, as well as spare parts for machines, tools, and other supplies) kept on the premises of a shop or warehouse and available for sale or distribution.

Stored capacity - represents the actual capacity of a warehouse. It directly relates to the size of the storage area, the height of the warehouse (usable space), the structure and turnover rate of the inventories and ultimately the economic efficiency of a warehouse.

Functions of Inventory

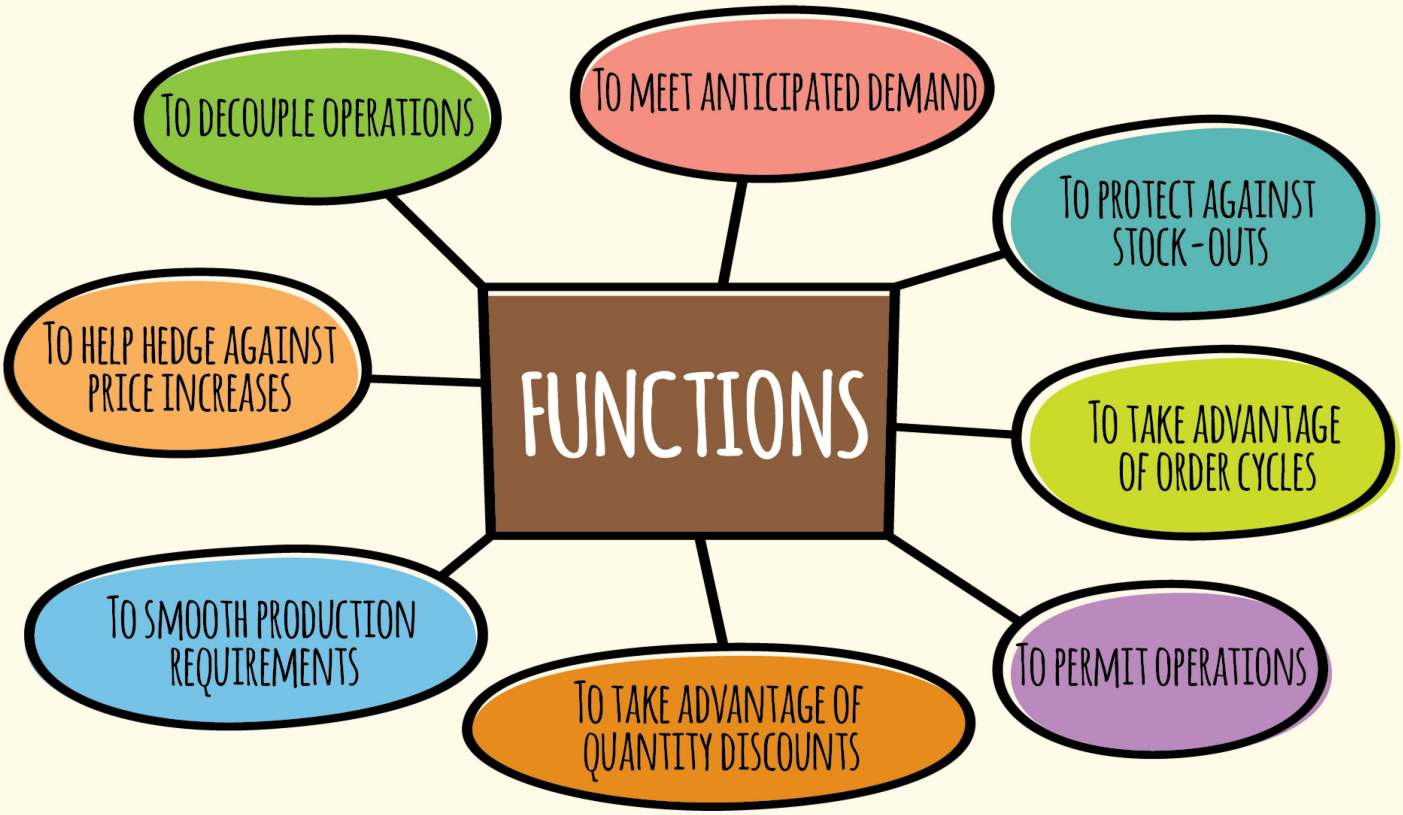


Figure 3.1: Functions of inventory

Disadvantages of Inventory

i. Higher costs
   - Item cost (if purchased)
   - Ordering (or setup) cost
   - Costs of forms, clerks' wages etc.
   - Holding (or carrying) cost
   - Building lease, insurance, taxes etc.

ii. Difficult to control

iii. Hides production problems

Objective of Inventory Control

i. To achieve satisfactory levels of customer service while keeping inventory costs within reasonable bounds

ii. Level of customer service

iii. Costs of ordering and carrying inventory

Inventory Models Based on Demand

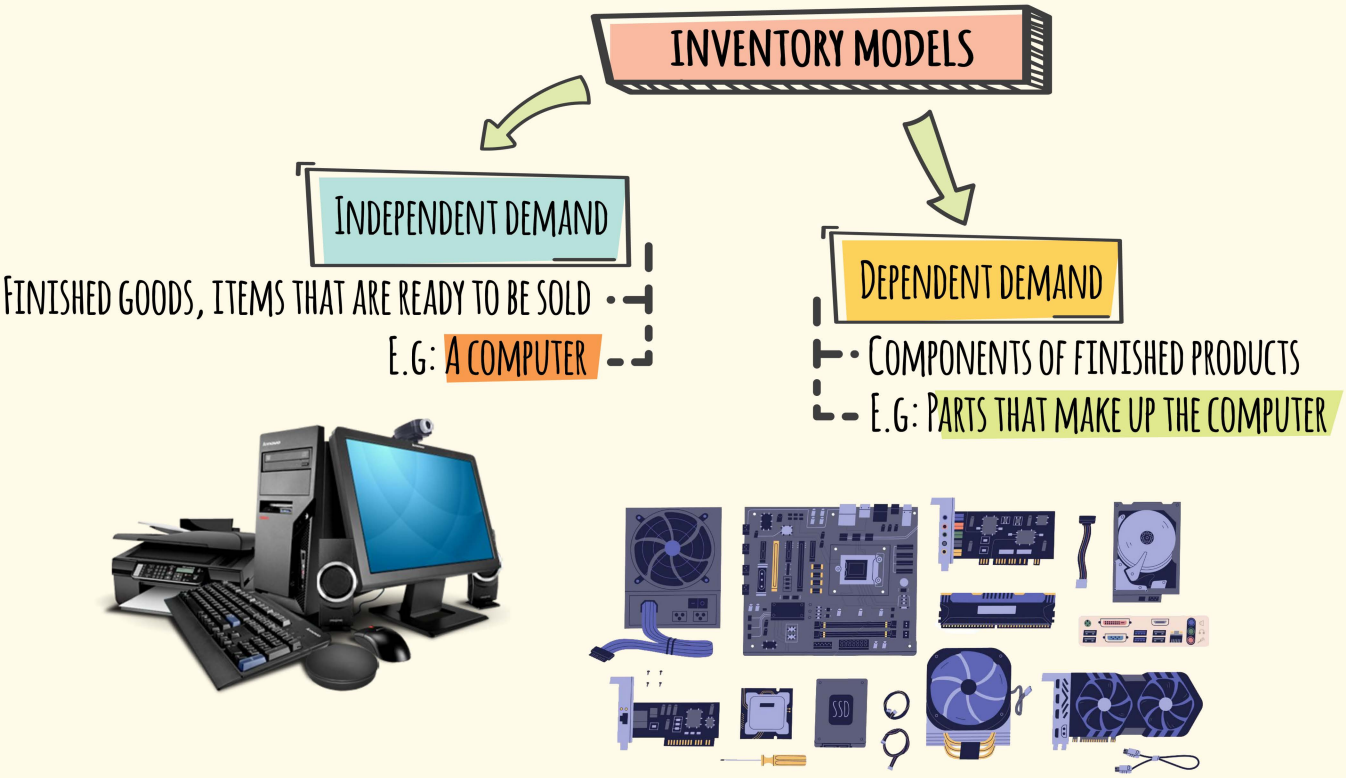


Figure 3.2: Inventory models

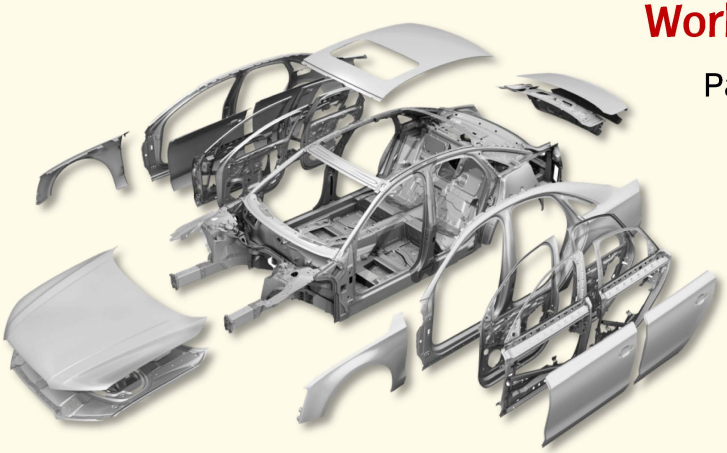
TYPES OF INVENTORY

Raw Material Inventory

The basic material from which a product is made such as rubber, metals, etc

Work-in-process Inventory (WIP)

Partially completed goods called work in progress



Maintenance/repair/operating (MRO) Supply Inventory

Replacement parts, tools, & supplies

Finished Goods Inventory

Goods-in-transit to warehouses or customers

CHARACTERIZE INVENTORY USING INVENTORY MANAGEMENT METHOD

Inventory Counting Systems

i. **Periodic System**

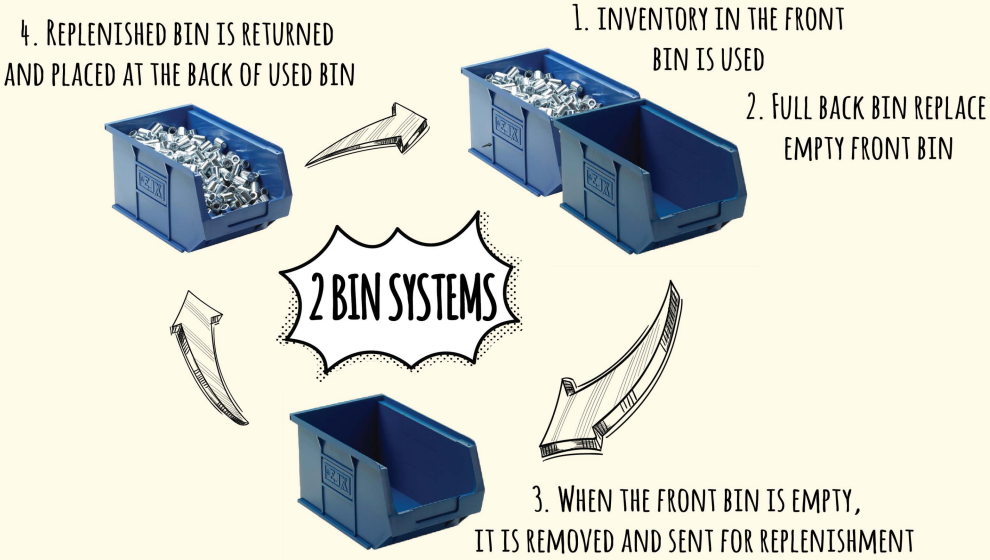
Physical count of items made at periodic intervals

ii. **Perpetual Inventory System**

System that keeps track of removals from inventory continuously, thus monitoring current levels of each item

Two-Bin System

Two containers of inventory; reorder when the first is empty



Universal Bar Code

Bar code printed on a label that has information about the item to which it is attached

A B C Analysis

i. Divides on-hand inventory into 3 classes which is A class, B class, C class.

ii. Basis is usually annual RM volume (RM volume = Annual demand x Unit cost)

iii. Policies based on ABC analysis

iv. Develop class A suppliers more

v. Give tighter physical control of A items

vi. Forecast A items more carefully

vii. Classifying inventory according to some measure of importance and allocating control efforts accordingly.

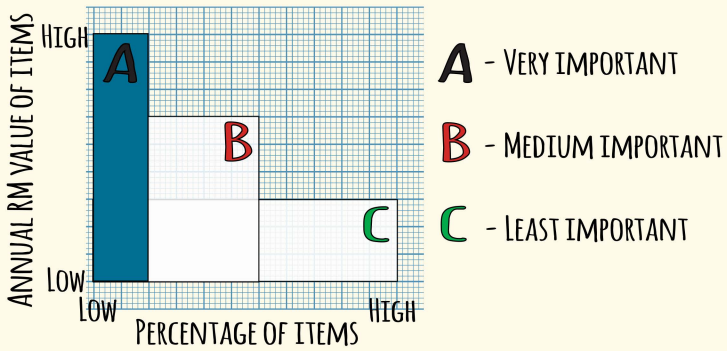


Figure 3.3: Inventory models

Example 3.1 ABC Analysis

Hong Seng Enterprise has the following 10 items in Table 4. Classify these items into ABC classifications

Item	Annual Cost	Item	Annual Cost
A2	10	H2	12
G2	7	I5	10
F3	15	J8	15
C7	4	B8	12
D1	8	E9	17

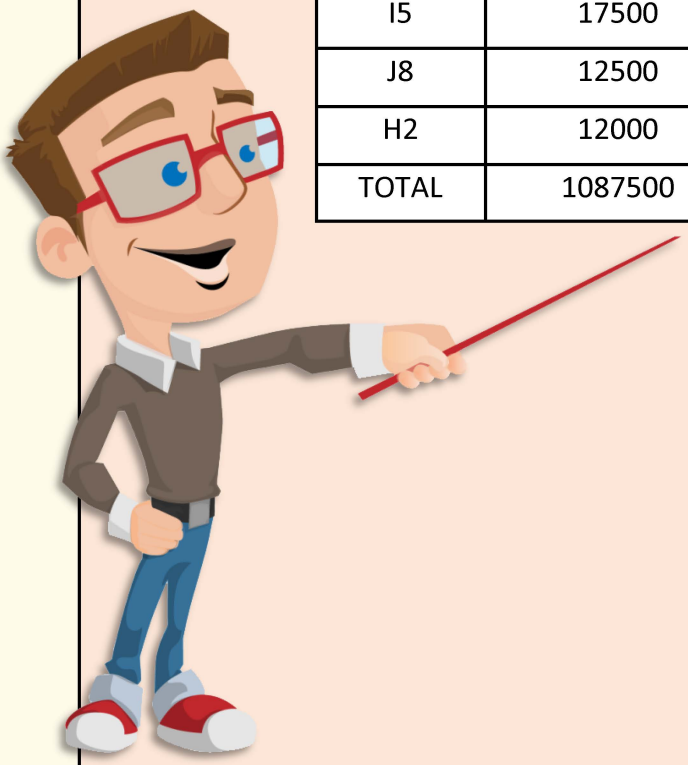
Example 3.1 ABC Analysis

Arrange annual cost from highest cost to lowest cost
Total annual cost
Calculate % each of annual cost
Using ABC analysis method, add % and classify into the **ABC** classification

A – 80% B – 15% C – 5%

Solution

ITEM	ANNUAL COST RM	PERCENTAGE %	CLASS	
G2	450000	41.4	78.2	**A**
F3	250000	23		
A2	150000	13.8		
C7	67500	6.2	16.1	**B**
D1	60000	5.5		
B8	48000	4.4		
E9	20000	1.8	5.7	**C**
I5	17500	1.6		
J8	12500	1.2		
H2	12000	1.1		
TOTAL	1087500			



Inventory Accuracy

Inventory accuracy is usually stated as a percentage, as in "we have 95 percent inventory accuracy." Many people might think this means 95 percent of the on-hand balance records are correct. But to be a true measure of accuracy, the company needs four factors to be right:

i. On-hand balance totals must be accurate.

ii. Locations and location counts must be correct.

iii. Item or bin labels and identification must be present.

iv. If the company uses serial or lot number tracking, the inventory record must also correctly identify the lot or serial numbers on hand by location.

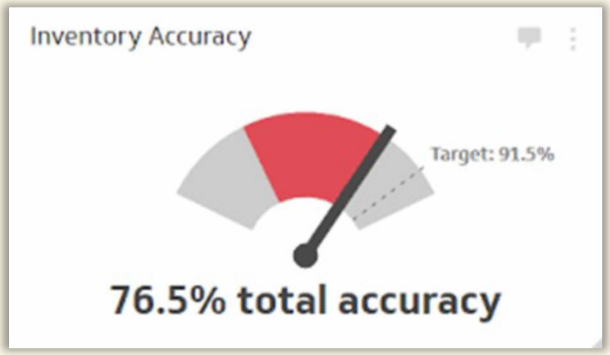


Figure 3.4: Inventory accuracy model

To calculate inventory accuracy, **divide the number of counted items that perfectly match every aspect of the record by the total number of items counted**. The resulting number is your inventory balance accuracy.

INVENTORY MODEL AND COST

Inventory Management Cost

Inventory cost are all costs associated with ordering, holding and managing the inventory or stock of an operation. These inventory costs include ordering costs, holding costs and shortage costs.

$$Total\ cost = Annual\ carrying\ cost + Annual\ ordering\ cost$$

$$TC = \frac{Q}{2}H + \frac{D}{Q}S$$

Inventory Models for Independent Demand

Economic Order Quantity (EOQ) Models

i. The order size that minimizes total annual cost
ii. Economic production model
iii. Quantity discount model

Assumptions of EOQ Mode

i. Only one product is involved
ii. Annual demand requirements known
iii. Demand is even throughout the year
iv. Lead time does not vary
v. Each order is received in a single delivery
vi. There are no quantity discounts

The Inventory Cycle

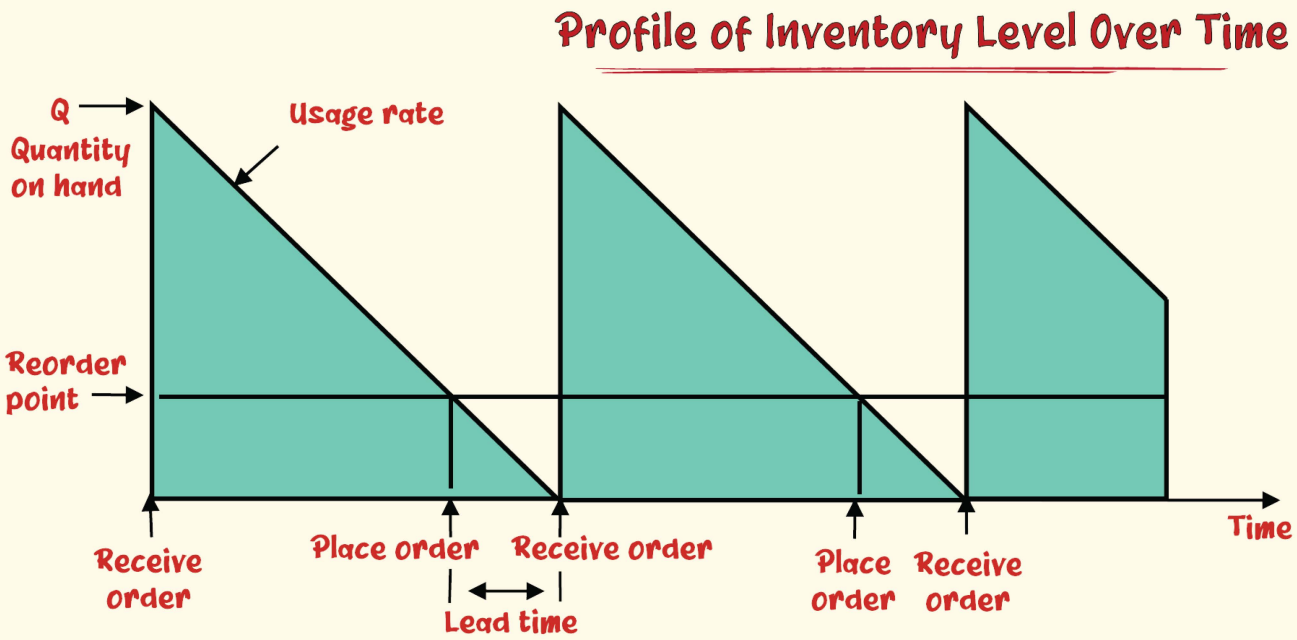


Figure 3.5: Inventory level over time

EOQ Model Equations

$$Optimal\ Order\ Quantity = Q^* = \sqrt{\frac{2 \times D \times S}{H}}$$

$$Expected\ Number\ of\ Orders = N = \frac{D}{Q^*}$$

$$Expected\ Time\ Between\ Orders = T = \frac{Working\ days/Year}{N}$$

$$d = \frac{D}{Working\ days/Year}$$

$$ROP = d \times L$$

$D = Demand\ per\ Year$

$S = Setup\ (order)\ cost\ per\ Year$

$H = Holding\ (carrying)\ cost$

$d = Demand\ per\ day$

$L = Lead\ time\ in\ days$

When to Reorder with EOQ Ordering

Reorder Point

- When the quantity on hand of an item drops to this amount, the item is reordered

Safety Stock

- Stock that is held in excess of expected demand due to variable demand rate and/or lead time

Service Level

- Probability that demand will not exceed supply during lead time

Figure 3.6: EOQ ordering point

Determinants of the Reorder Point

i. The rate of demand
ii. The lead times
iii. Demand and/or lead time variability
iv. Stockout risk (safety stock)

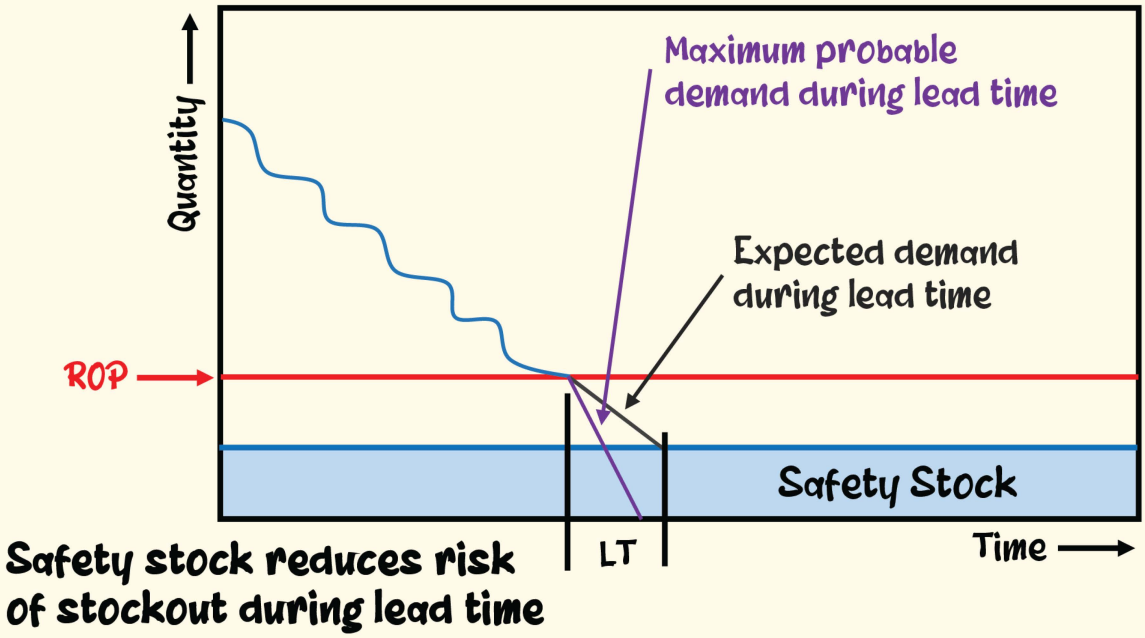


Figure 3.6: EOQ reorder point

Example 3.2	EOQ Model

The JSK Company which supplies the S type stove model has received a demand of 2500 units for this year. The model cost is RM 120.00 per unit. The order cost is RM10.00 and the holding cost is 1% of the model cost. Assuming that they work for 250 days per year and the lead time is 4 working days. Calculate EOQ, N, T, Tc & ROP

Given,

D = 2500 per year

H = 1% from RM120 = RM10

S = RM10

Example 3.2 EOQ Model

Solution

i. EOQ

$$Q^* = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(2500)(10)}{1.2}} = 204.1\ units \approx \underline{204\ units}$$

ii. Number of orders per year

$$N = \frac{D}{Q^*} = \frac{2500}{204} = \underline{12.3\ orders}$$

iii. Expected number between orders

$$T = \frac{250}{12.3} = 20.3 \approx \underline{20\ days}$$

iv. Total cost

$$T_C = \frac{DS}{Q^*} + \frac{Q^*H}{2}$$

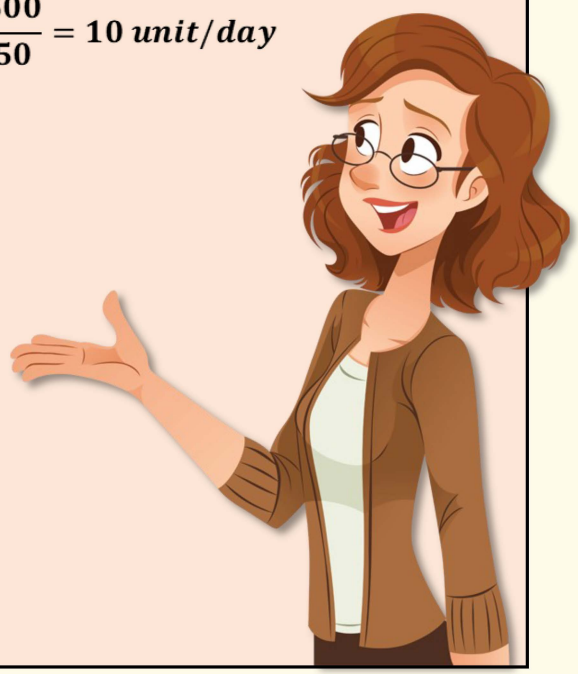
$$= \left(\frac{2500(10)}{204}\right) + \left(\frac{204(1.2)}{2}\right)$$

$$= 122.55 + 122.4 = \underline{RM244.95}$$

v. Reorder point

$$ROP = d \times L \qquad d = \frac{2500}{250} = 10\ unit/day$$

$$= 10 \times 4 = \underline{40\ units}$$



Fixed-Time Period Models

i. Orders are placed at fixed time intervals
ii. Order quantity for next interval?
iii. Suppliers might encourage fixed intervals
iv. May require only periodic checks of inventory levels
v. Risk of stockout
vi. Fill rate – the percentage of demand filled by the stock on hand

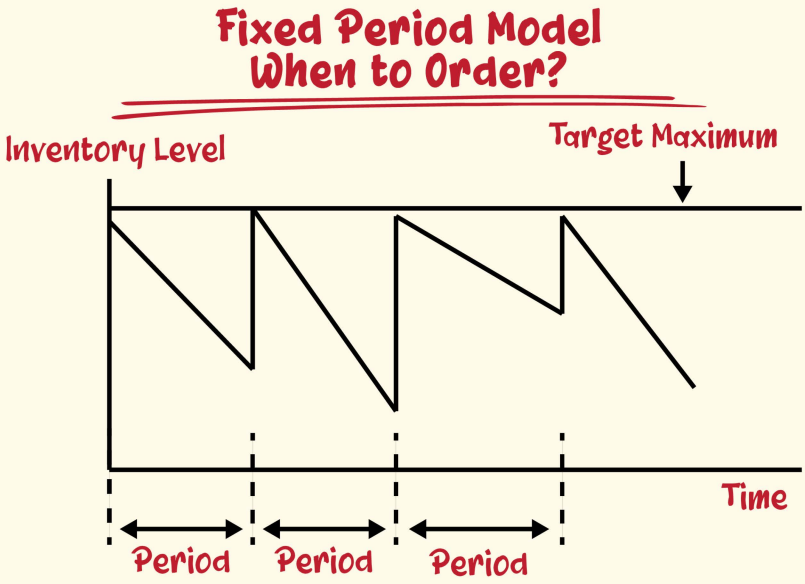


Figure 3.6: Fixed period model

Fixed-Interval Benefits

i. Tight control of inventory items
ii. Items from same supplier may yield savings in:
   - Ordering
   - Packing
   - Shipping costs
iii. May be practical when inventories cannot be closely monitored

Disadvantages

i. Requires a larger safety stock
ii. Increases carrying cost
iii. Costs of periodic reviews Tight control of inventory items

Quantity Discount Models

i. Answers how much to order & when to order
ii. Allows quantity discounts
iii. Reduced price when item is purchased in larger quantities
iv. Other EOQ assumptions apply
v. Trade-off is between lower price & increased holding cost

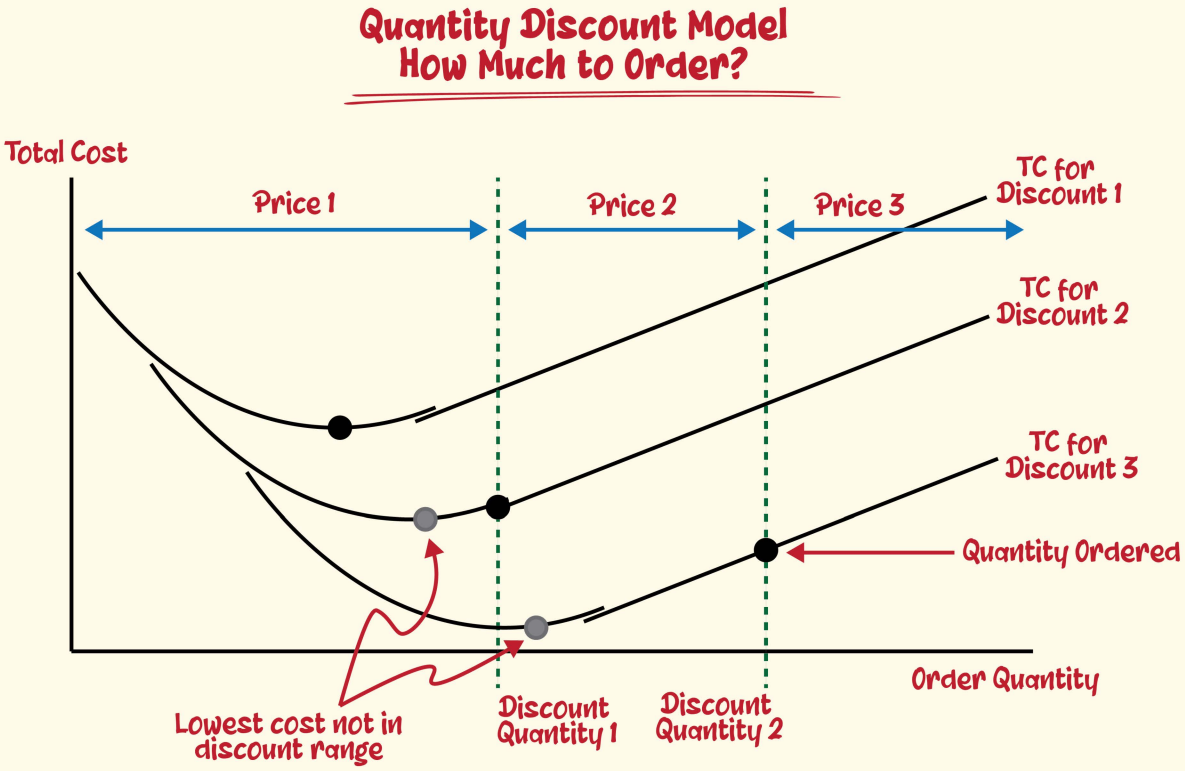


Figure 3.6: Fixed period model

Key Inventory Terms

i. Lead time: time interval between ordering and receiving the order

ii. Holding (carrying) costs: cost to carry an item in inventory for a length of time, usually a year (insurance / interest / warehouse / extra staff)

iii. Ordering costs: costs of ordering and receiving inventory (supplies / forms / order processing/ clerical support)

iv. Setup costs: cost to prepare a machine or process for manufacturing an order (clean-up / re-tooling / adjustment)

Effective Inventory Management

i. A system to keep track of inventory

ii. A reliable forecast of demand

iii. Knowledge of lead times

iv. Reasonable estimates of

- Holding costs
- Ordering costs
- Shortage costs

v. A classification system

Exercises

1. Explain the inventory management term below:
   i. ABC Analysis
   ii. Economic Order Quantity
2. Explain THREE (3) types of inventory.
3. Construct Re-Order Point (ROP) graph.
4. Pali Enterprise has the following 10 items in Table 4. Classify these items into ABC classifications

ITEM	ANNUAL COST	ITEM	ANNUAL COST
G2	450000	B8	48000
F3	250000	E9	20000
A2	150000	I5	17500
C7	67500	J8	12500
D1	60000	H2	12000

5. The ABH Company is a large manufacturer of car toys in Kedah. An investigation of the company's manufacturing facility presented in the table below. How would the plant classify these items according to an ABC approach?

Item	Volume	Unit Cost (RM)	Item	Volume	Unit Cost (RM)
#111	500	1020	#161	700	200
#121	300	120	#171	200	150
#131	90	70	#181	500	20
#141	150	1400	#191	6000	10
#151	100	102	#101	825	300

6. Based on the table below, arrange the stock units to groups by using ABC Analysis with 80%, 15% and 5% for class A, B and C respectively.

Stock Units	Average Demand per Unit	Sale Price per Unit
X12	800	130
Y27	600	300
S12	350	10
T30	200	110
H09	400	20
G16	500	60

Exercises

7. Ray's Satellite Emporium wishes to determine the best order size for its best-selling satellite dish (model TS111). Ray has estimated the annual demand for this model at 1,000 units. The cost to carry one unit is RM100 per year per unit, and he has estimated that each order costs RM25. It takes about 5 days for an order to arrive and the demand for 1 week is 120 units (this is a corporate operation, and there are 250 working days per year). Using the EOQ model calculate:
   i. Optimal number of orders per year
   ii. Optimal number of days in between any two orders
   iii. Total annual cost
   iv. Reorder point (ROP)

8. The PPP Company which supplies the cooking stove has received a demand of 25000 units for this year. The stove cost is RM 100 per unit. The order cost is RM10.00 and the holding cost is 10% of the model cost. If they work for 250 days per year and the lead time is 4 working days. Apply Economic Order Quantity (EOQ) method to obtain:
   i. EOQ?
   ii. The expected number of orders?
   iii. The annual cost

9. The annual demand for this baby doll model is 1000 units. Carrying cost is $100 per year per unit, and order cost $25. It takes about 5 days for an order to arrive and the demand for 1 week is 120 units (this is a corporate operation and there are 250 working days per year). Using the EOQ model calculate:
   i. Optimal number of orders per year
   ii. Optimal number of days in between any two orders

10. The JSK Company which supplies the S type gas stove model has received a demand of 25000 units for this year. The model cost is RM120 per unit. The order cost is RM10 and the holding cost is 5% of the model cost. Assuming that they work for 250 days per year and the lead time is 4 working days. Calculate:
    i. EOQ
    ii. Then expected time between orders
    iii. The annual inventory cost
    iv. Reorder Point (ROP)

4 Productivity and Capacity Planning

Productivity is a rate of performance that compares the amount of goods and services produced with the amount of inputs used to produce those goods and services. Each manufacturing companies has its own capacity based on each logistic. Capacity is the maximum rate of output of a process or a system. Capacity decisions related to a process need to be made in light of the role the process plays within the organization and the supply chain as a whole, because changing the capacity of a process will have an impact on other processes in the chain.

In this chapter student will learn about (i) productivity in production performance, (ii) how to calculate workers' productivity and (iii) schedule capacity planning using decision trees.

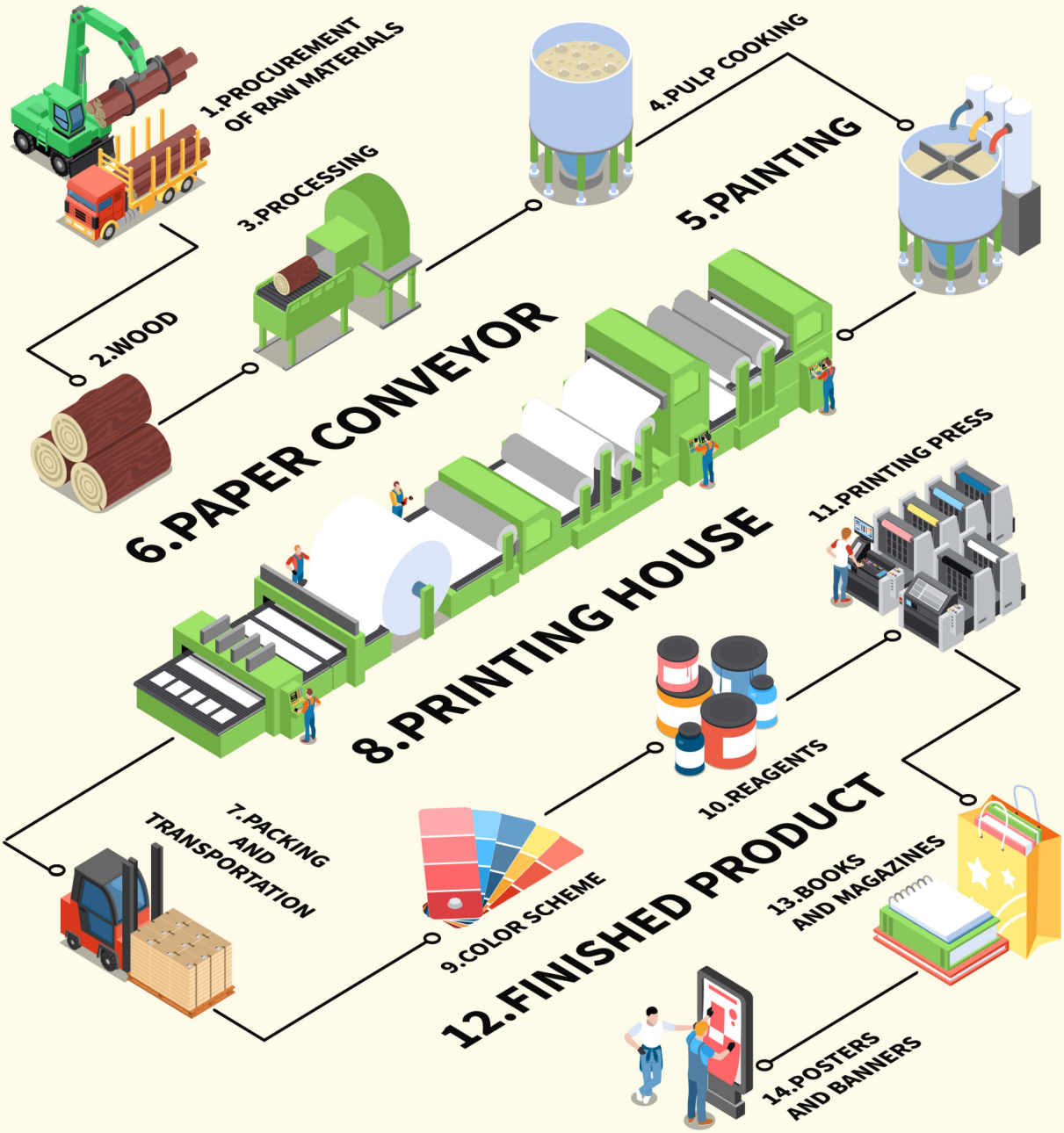
PRODUCTIVITY IN PRODUCTION PERFORMANCE

Productivity Definition

i. The ratio of outputs (goods and services) divided by one or more inputs (such as labour, capital or management).

ii. Is a measure of output based on input

iii. Usually calculated as a productivity ratio Higher costs



Paper Production: Designed by Macrovector / Freepik

Figure 4.1: Paper production

Factors Influencing The Productivity

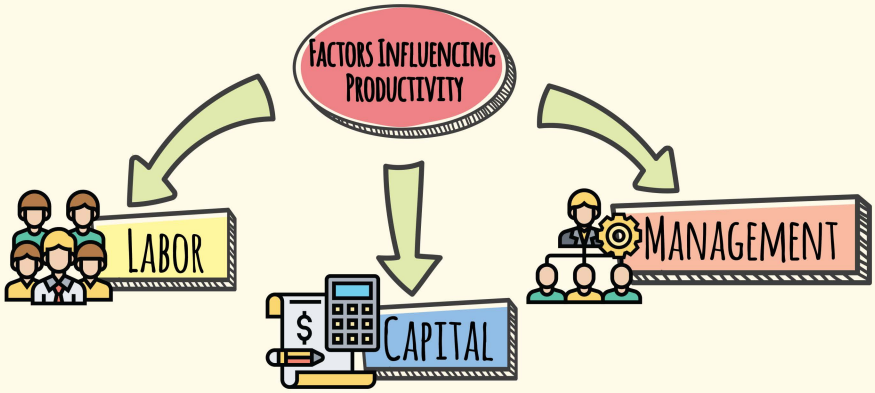


Figure 4.2: Factors influencing productivity

Labor

i. Which contributes about 10% of the annual increase
ii. Basic education appropriate for an effective labor force.
iii. Diet of the labor force (healthier).
iv. Social overhead that makes labor available such as transportation and sanitation.

Challange

- Maintaining and enhancing the skill of labor (cause by expending technology and knowledge)
- Better utilized labor with stronger commitment (motivation, team building, training etc.)

Capital

i. Which contributes about 38% of the annual increase
ii. Human being are tool

Challange

- Taxes and inflation increase that cost of capital.

Management

i. which contributes about 52% of the annual increase
ii. Responsible for ensuring the labor and capital are effectively use to increase productivity.

Challange

- Knowledge society – a society in which much of the labor force has migrated from manual work to work base on knowledge.

Productivity Terms

i. Capital Usage

- Used in investment decision making of business firms
- Used in estimating production function and productivity

ii. Workers Productivity

- Knows as labour productivity
- Values of services produced in a period of time, divided by a hours of labor

iii. Yield

- Is the number of acceptable pieces at the end of a process divided by the number of starting pieces
- Used only to measure a single process

iv. Throughput Yield (TPY)

- Is the number of acceptable pieces at the end of a process divided by the number of starting pieces
- Used only to measure a single process

CALCULATE WORKERS PRODUCTIVITY

Single Productivity

Single Productivity is a measure of output against specific input. Partial productivity is concerned with efficiency of one class of input. Its significance lies in its focus on utilization of one resource. Labor productivity is a single productivity measure. The equation for a single productivity is as follows:

$$\boldsymbol{Productivity = \frac{Unit\ produce}{Input\ used}}$$

Example 4.1 Single Productivity

2 machines produce 82 usable pieces in 2 hours.

Solution

$$\boldsymbol{Machine\ Productivity = \frac{Output}{Input} = \frac{82}{(2 \times 2)}}$$

$$\boldsymbol{= \underline{20.5\ pieces/hour}}$$

Multifactor Productivity

Multifactor productivity is a measure of economic performance that compares the amount of output to the amount of combined inputs used to produce that output. Combinations of inputs can include labor, capital, energy, materials, and purchased services cost.

$$Productivity = \frac{Output}{Labor + Material + Energy + Capital}$$

Example 4.2 Single Productivity

Develop a productivity measure for a product utilizes labor machine time, raw materials and purchased materials. Assume 10,000 units are produced in 500 hours and are sold for RM10/unit. The labor rate RM9/hour, the cost of the raw materials is RM5,000 and the cost of purchased materials is RM 25,000

Solution

$$Output = 2000\ rolls \times RM\ 1\ = RM\ 2000$$

$$Input = Labor + Material + Overhead$$

$$= RM\ 160 + RM\ 50 + RM\ 320$$

$$= RM\ 530$$

$$Multifactor\ Productivity = \frac{Output}{Input} = \frac{2000}{530}$$

$$= \underline{3.77\ rolls\ output/ringgit}$$

SCHEDULE CAPACITY PLANNING USING DECISION TREES

It's a strategic planning process designed to help you determine if the organization has the production capacity required to meet demand. It looks at resource availability at the skill set/team level. Then it facilitates the decision-making process to hire resources or defer/approve/cancel projects.

A decision tree is a diagram that models the alternatives being considered and the possible outcomes. Decision trees help by giving structure to a series of decisions and providing an objective way of evaluating alternatives.

Design Capacity

The theoretical maximum output of a system in a given period under ideal conditions.

Effective Capacity

The capacity a firm can expect to achieve, given its product mix, method of scheduling, maintenance, and standards of quality.

Utilization

Actual output as a percent of design capacity.

Capacity Planning

Capacity planning is the process of determining the production capacity needed by an organization to meet changing demands for its products.

Three (3) types of capacity planning

i. **Long range capacity**

   (More than 1 year) – a function of adding facilities and equipment that have a long lead time.

ii. **Intermediate range capacity**

   (3 – 18 months) – add equipment, personnel and shift, subcontract and can build or use inventory.

iii. **Short run capacity**

   (up to 3 months) – concerned with scheduling jobs and people and allocating machinery.

Decision Trees for Capacity Decisions

A decision tree is a diagram that models the alternatives being considered and the possible outcomes. Decision trees help by giving structure to a series of decisions and providing an objective way of evaluating alternatives. Decision trees contain the following information:

i. **Decision points**. These are the points in time when decisions, such as whether or not to expand, are made. They are represented by squares, called "nodes."

ii. **Decision alternatives**. Buying a large facility and buying a small facility are two decision alternatives. They are represented by "branches" or arrows leaving a decision point.

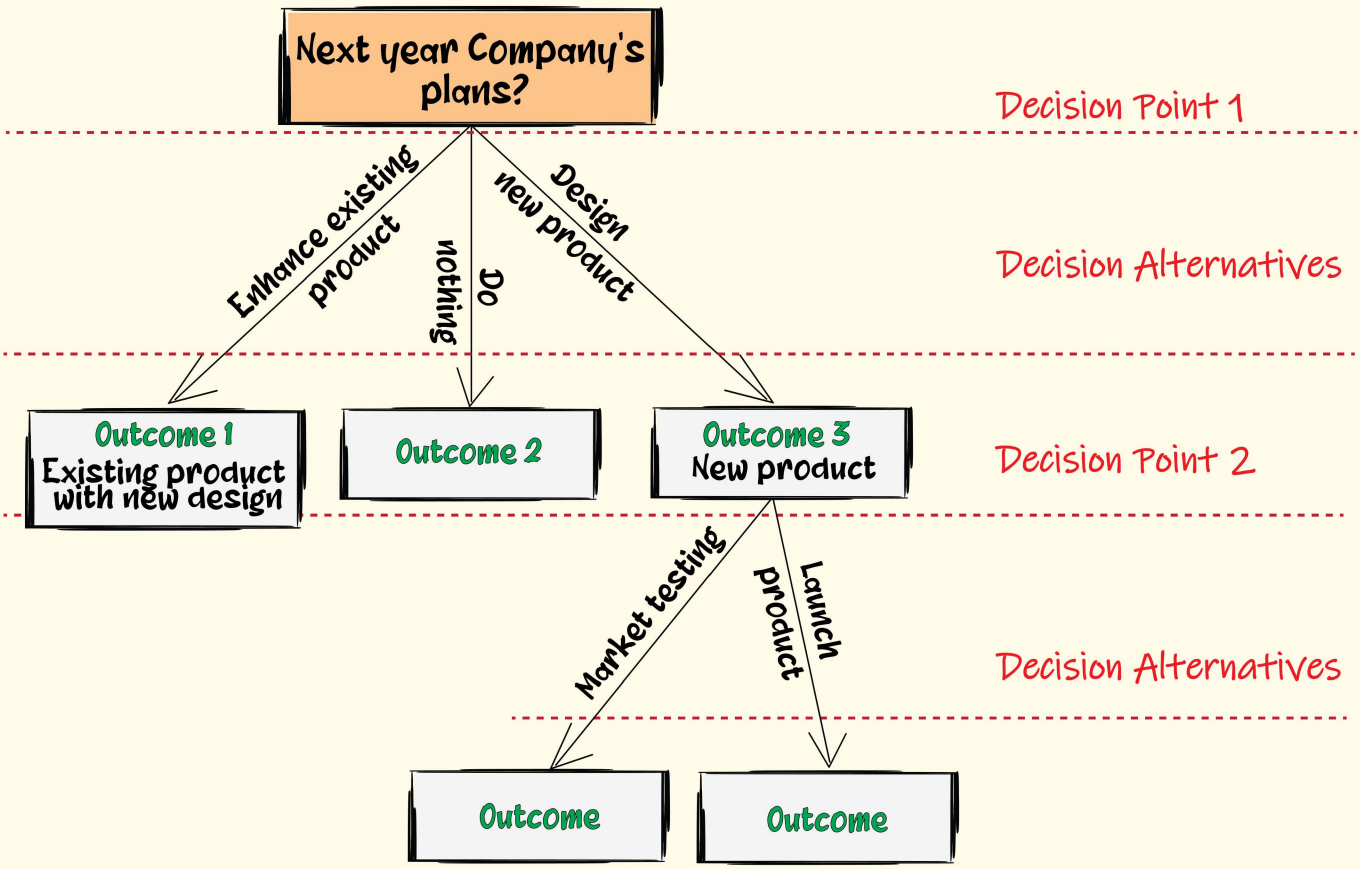


Figure 4.3: Decision tree model

Exercises

1. List five (5) factors that influence the productivity.
2. Give five (5) factors that affect productivity.
3. Define capital usage and worker's productivity.
4. Explain three types of capacity planning.

5. Siti Sarah is currently working a total of 12 hours per day to produce 240 dolls. She thinks that by changing the paint used for the facial features and fingernails she can increase her production rate to 360 dolls per day. The total material cost for each doll is approximately RM3.50. She has to invest RM20 in the necessary supplies per day. The energy costs are assumed to be only RM4.00 per day and she thinks she should be making RM10 per hour for her time. Calculate:
   i. Current productivity before changing to a new paint.
   ii. Productivity after using new paint. Explain THREE (3) types of inventory.

6. Altel company plans to produce 10000 unit of hand phones in June 2022 with 50 employees. They will be working for 8 hours per day and the number of working days is 20 days. In July 2022, productivity increases to 15000 unit hand phones whereby 10 contract employees were employed. They worked for 8 hours per day for 20 days in that month. Calculate employee's productivity for June and July.

7. Table below shows the production and annual working hour for three firms.

FIRM	OUTPUT	WORKER	WORKING HOUR	ANNUAL WORKING
Alpha	43200	35	22	250 day
Beta	75625	40	20	250 day
Gama	58450	45	21	250 day

   i. Calculate the productivity for each firm
   ii. Choose which firm is the most productive one

Exercises

8. The SEJ Company produced 22000 units of product E in November 2022 with 20 workers. The company increased production of product E to 25000 units in December 2022 after adding employees 5 contract worker. All employees work for 8 hours per day for 25 days per month. Calculate the company productivity for November 2022 and December 2022.

9. A company that processes fruits are produce 2500 units of canned peaches in five hours with 10 workers for January 2023. The company decided to hire 5 more workers in February 2023 and they successfully increase their production to 4000 units for that month.
   i. Calculate the labour productivity for January
   ii. Calculate the labour productivity for February

10. If the company produce 10000 pieces of cake yearly, calculate the multifactor productivity for January based on the combined inputs as follow:

    Labour: RM1000

    Materials: RM520

    Overheads: RM2000

5 Material Requirements Planning (MRP)

Material requirements planning (MRP) is a computerized information system developed specifically to help manufacturers manage dependent demand inventory and schedule replenishment orders. The key inputs of an MRP system are a bill of materials database, a master production schedule, and an inventory record database. Using this information, the MRP system identifies the actions planners must take to stay on schedule, such as releasing new production orders, adjusting order quantities, and expediting late orders.

In this chapter student will learn about (i) basic concept of MRP, (ii) element for process of MRP, (iii) organize inventory using MRP and (iv) analyze MRP table for inventory control.

DEFINE BASIC CONCEPT OF MRP

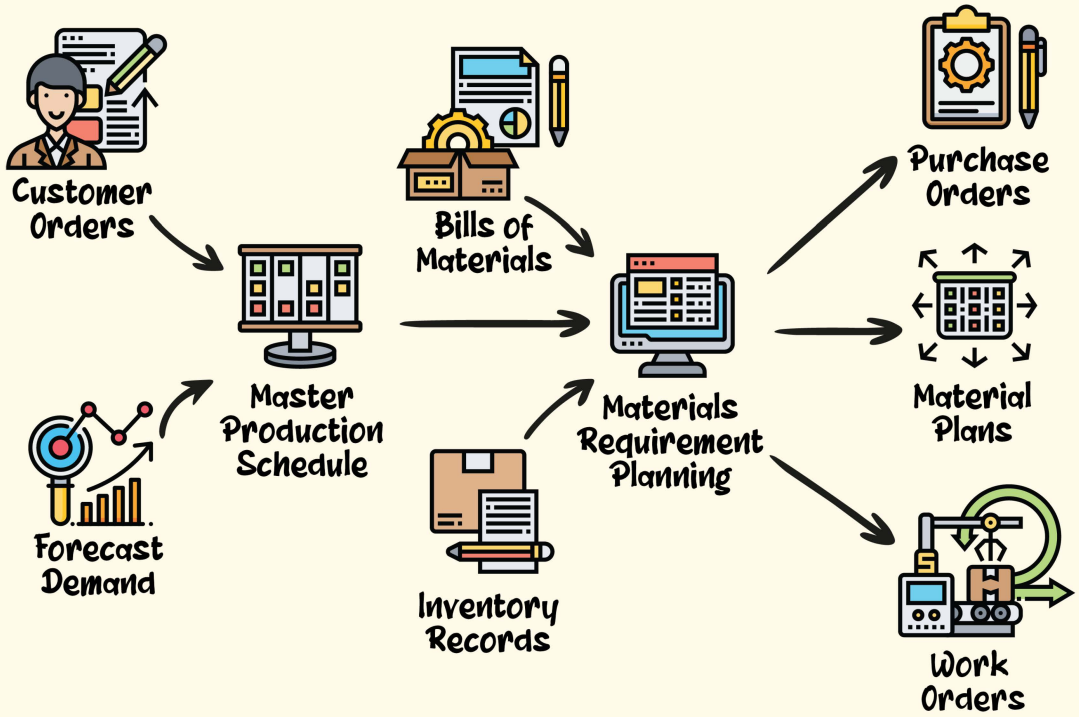


Figure 5.1: MRP concept

Material requirement planning (MRP) is a system for calculating the materials and components needed to manufacture a product. It consists of three primary steps: taking inventory of the materials and components on hand, identifying which additional ones are needed and then scheduling their production or purchase.

MRP is a production planning and inventory control system used to manage manufacturing processes. MRP is a tool to deal with these problems. It provides answers for several questions:

i. What items are required?
ii. How many are required?
iii. When are they required?

The Major Objectives of MRP

i. Ensure the availability of materials, components and product for planned production & for customer delivery
ii. Maintain the lowest possible level of inventory
iii. Plan manufacturing activities, delivery schedules & purchasing activities.

MRP Steps and Processes

The MRP process can be broken down into four major steps:

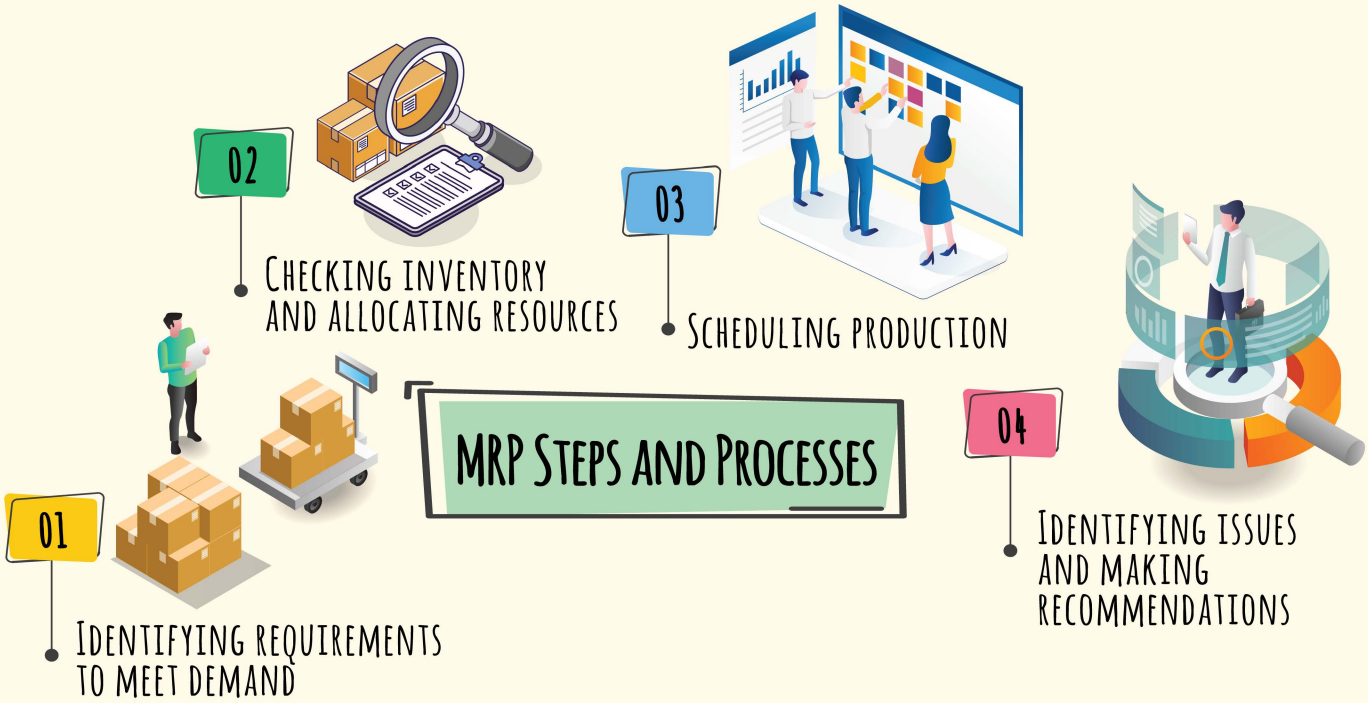


Figure 5.2: MRP steps and processes

i. Identifying requirements to meet demand

The first step of the MRP process is identifying customer demand and the requirements needed by inputting customer orders and sales forecasts.

Using the bill of materials required for production, MRP disassembles demand into the individual components and raw materials needed to complete the build while accounting for any required sub-assemblies.

ii. Checking inventory and allocating resources

Utilizing the MRP to check demand against inventory and allocating resources accordingly. MRP show status of items that are already allocated into another build as items not yet physically in the warehouse that are in transit, or on order. The MRP then moves inventory into the proper locations and prompts reorder recommendations.

iii. Scheduling production

By using the master production schedule, the system determines how much time and labor are required to complete each step of each build and when they need to happen so that the production can occur without delay.

The production schedule also identifies what machinery and workstations are needed for each step and generates the appropriate work orders, purchase orders and transfer orders.

iv. Identifying issues and making recommendations

MRP links raw materials to work orders and customer orders and automatically alert when items are delayed and make recommendations for existing orders.

THE ELEMENT FOR PROCESS OF MRP

MRP systems use four key pieces of information to determine what exactly needs to be ordered. These four information sources include:

i. Production schedules
ii. Material specs
iii. Production cycle times
iv. Supplier lead times

ORGANIZE INVENTORY USING MRP

Product Tree Structure

Product structure is an illustration of how the parts of a product fit together and interrelate with one another, usually arranged in levels of detail according to the structure. It delivers a hierarchical sorting of the items forming a product.

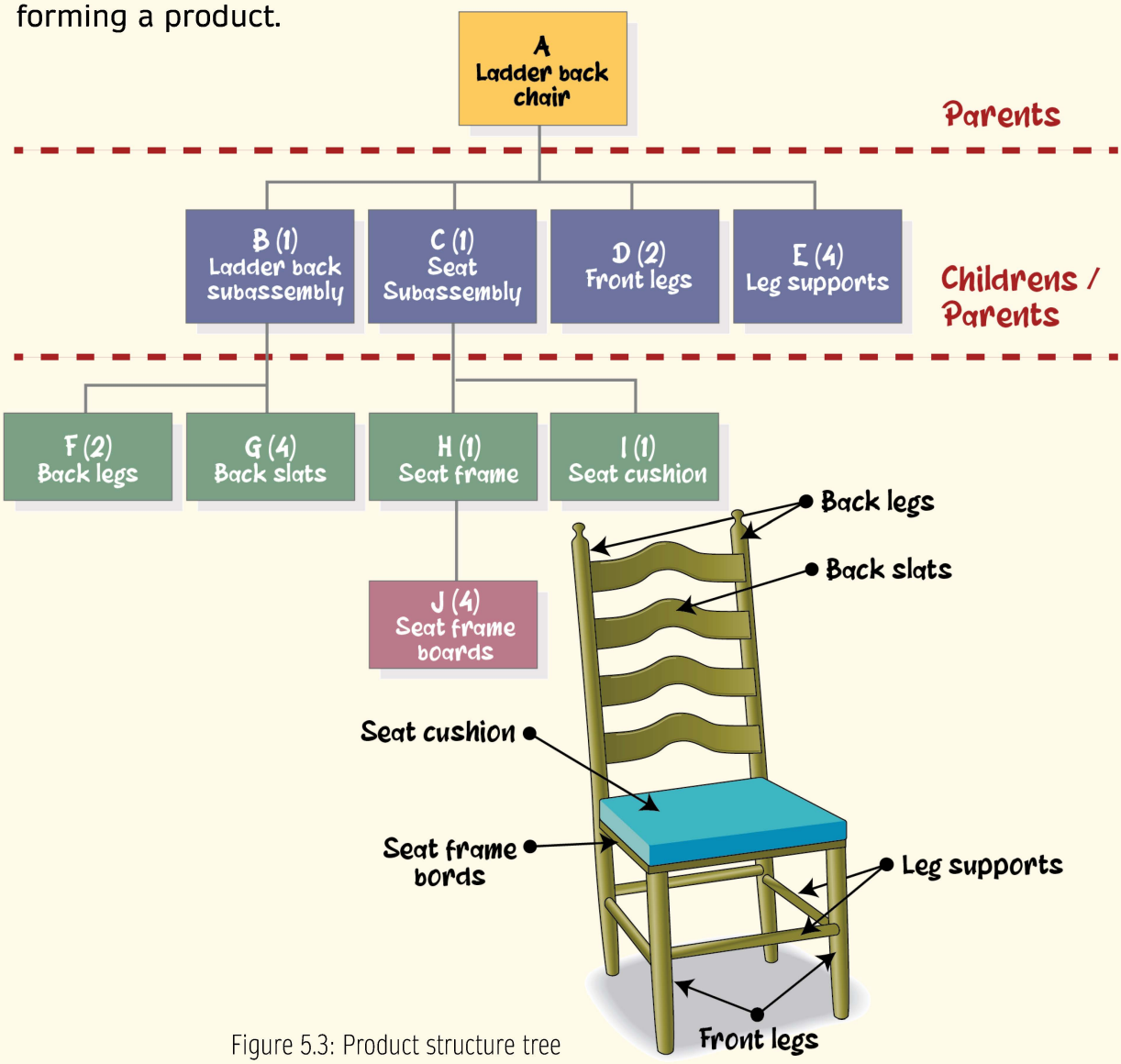


Figure 5.3: Product structure tree

In manufacturing the product structure tree provides a hierarchical classification of the items which form a product. With the product structure, the understanding of the components which compose a product as well as their attributes, can be presented. For product tree structure diagram, items above any level are called 'parents' and items below any level are called 'children'.

Time phase structure

The planning process time-phases material requirements and expresses future demand, supply, and inventories by time period. **Time-phasing delays release of orders for components until they are needed and offsets the requirements by item lead time (lead time offset)**. The time phased product structure, unlike the bill of material, adds the concept of lead times.

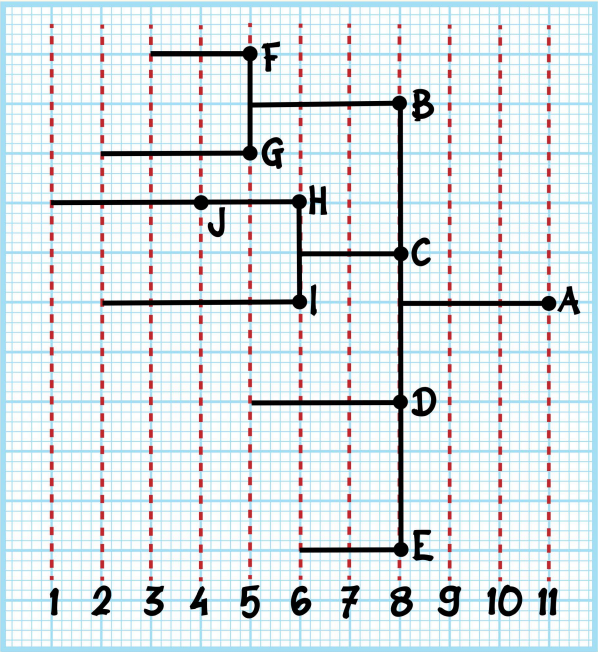


Figure 5.4: Time phase structure

Bill of material

A bill of materials (BOM) is a comprehensive inventory of the raw materials, assemblies, subassemblies, parts and components, as well as the quantities of each needed to manufacture a product. It is also defining as a list of the component, their description and the quantity of each required to make one unit of a product. Individual drawings describe not only physical dimensions but also any special processing as well as the raw material from which each part is made.

Item	Code	Quantity
Ladder back chair	A	2
Ladder back frame	B	2
Seat	C	2
Front leg	D	4
Leg support	E	8
Back legs	F	4
Back slats	G	8
Seat frame	H	2
Seat cushion	I	2
Seat frame boards	J	8

Figure 5.5: Bill of materials

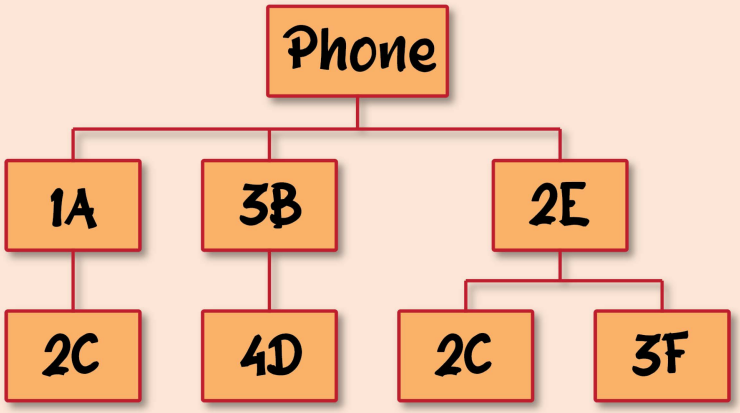
Example 5.1 Product Structure Tree / Bill of Materials

Based on the table below, sketch the product tree structure. Then calculate the number of components required to produce 20 units of phones.

Item	Components
Phone	A(1), B(3), E(2)
A	C(2)
B	D(4)
C	-
D	-
E	C(2), F(3)
F	-

Solution

Product Structure Tree



Bill of Material (BOM)

ITEM	QUANTITY (unit)
Phone	20
A	20
B	(3x20) = 60
C	(2x1x20) + (2x2x20) = 120
D	(4x3x20) = 240
E	(2x20) = 40
f	(3x2x20) = 120

MRP Table

MRP is a dynamic system that uses **a computerized system that allows manufacturers to plan, manage, and control their inventories more efficiently**. MRP consists of three basic steps:

i. **Identifying the Quantity Requirements**

   Determine what quantity is on hand, in an open purchase order.

ii. **Planned for manufacturing**

   Committed to existing orders.

iii. **Forecast**

These requirements are specific to each company and each company location and change with the date.

Assumptions of EOQ Mode

i. **Gross requirements –** Demand for an item by time period.

ii. **Net requirements –** Number of items to be provided and when.

iii. **Planned order receipts –** Net requirements adjusted for lot size.

iv. **Planned order releases –** Planned order receipts offset for lead times.

v. **Stock/projected on hand –** Expected ending inventory.

vi. **Lead time –** The time from when an order is placed to when it is received.

Example 5.2 MRP

Product A will be delivered on week 12. Based on table below:

Item	Component	Lead Time	On Hand
A	B(1), C(2)	1	50
B	D(1), E(1)	2	20
C	F(2), G(1)	2	20
D	-	1	5
E	-	1	10
F	-	1	0
G	E(2)	3	10

Example 5.2 MRP

i. Develop the product tree structure

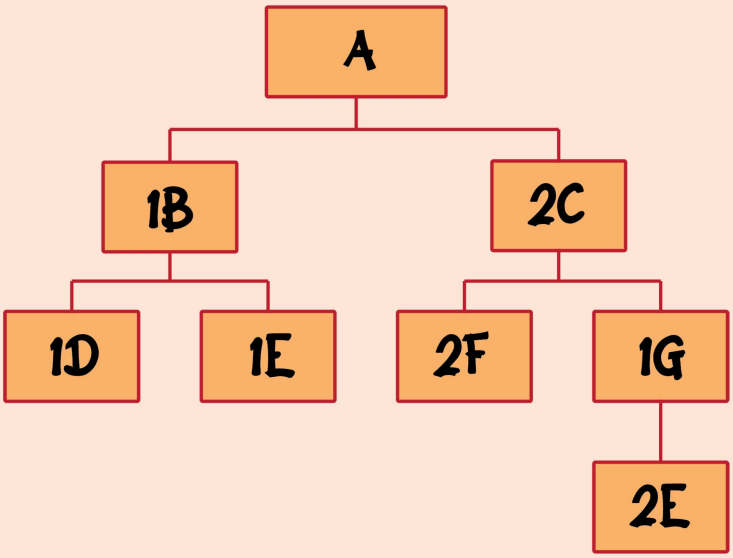
ii. Construct time phase product structure

iii. Develop the MRP table if the gross requirement for A is shown in table below:

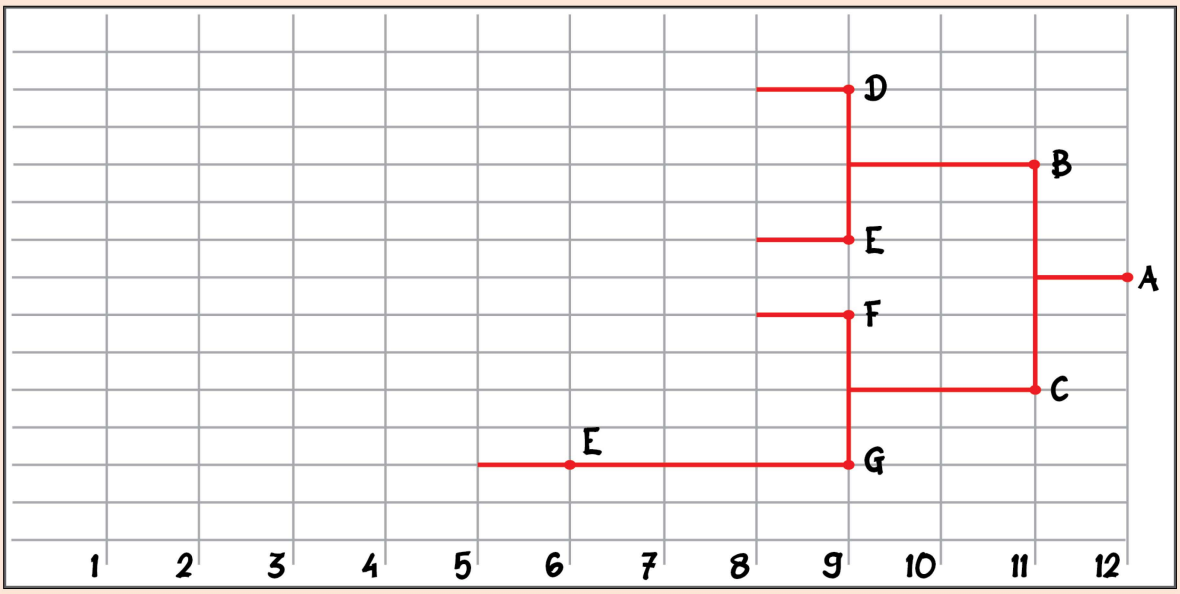
Week	7	8	9	10	11	12
Gross Requirement						100

Solution

Product Structure Tree



Time Phase Product Structure



Example 5.2 MRP

MRP Table

ITEM	INVENTORY		Week 1	2	3	4	5	6	7	8	9	10	11	12	Lead Time
A	Gross Requirement		100	100	100	100	100	100	100	100	100	100	100	100	1
	On Hand	50												50	
	Net Requirement													50	
	Receipt Order													50	
	Release Order												50		

ITEM	INVENTORY		Week 1	2	3	4	5	6	7	8	9	10	11	12	Lead Time
B	Gross Requirement												50		2
	On Hand	20											20		
	Net Requirement												30		
	Receipt Order												30		
	Release Order										30				

Example 5.2 MRP

ITEM	INVENTORY		Week 1	2	3	4	5	6	7	8	9	10	11	12	Lead Time
C	Gross Requirement												100		2
	On Hand	20											20		
	Net Requirement												80		
	Receipt Order												80		
	Release Order										80				

ITEM	INVENTORY		Week 1	2	3	4	5	6	7	8	9	10	11	12	Lead Time
D	Gross Requirement										30				1
	On Hand	5									5				
	Net Requirement										25				
	Receipt Order										25				
	Release Order									25					

ITEM	INVENTORY		Week 1	2	3	4	5	6	7	8	9	10	11	12	Lead Time
E	Gross Requirement							140			30				1
	On Hand	10						10			0				
	Net Requirement							130			30				
	Receipt Order							130			30				
	Release Order						130			30					

Example 5.2 MRP

ITEM	INVENTORY		Week 1	2	3	4	5	6	7	8	9	10	11	12	Lead Time
F	Gross Requirement										160				1
	On Hand	0									0				
	Net Requirement										160				
	Receipt Order										160				
	Release Order									160					

ITEM	INVENTORY		Week 1	2	3	4	5	6	7	8	9	10	11	12	Lead Time
G	Gross Requirement										80				3
	On Hand	10									10				
	Net Requirement										70				
	Receipt Order										70				
	Release Order							70							

Exercises

1. Explain dependant demand and independent demand.
2. Explain the input and output of Material Requirement Planning (MRP) system.
3. Explain three (3) benefits of Material Requirement Planning (MRP).
4. There are six terms used in MRP. List all of the terms.

5. Explain the MRP terms;
   i. Bill of Material (BOM)
   ii. Tree Structure

6. The demand for product A is 50 units. Each A unit needs 3 units of B and 2 units of C. each B unit needs 1 unit of D and 2 units of E. each E unit needs 2 units of G and 1 unit of F. Each C unit needs 2 units of D and 3units of F. if 50 units of A require for month of May, calculate the bill of material for all components.

6. The production manager at AX's Company wants to plan the manufacturing schedule at week 8 for product X. The company will produce the new product X for 40 units. Each product X needs one component A and two components B. Each component A uses 3 components C and 2 components D. Every component B needs 3 components D and 1 component A. The lead time record is shown in table below:

   Based on the data;
   i. Sketch the time-phase structure for product X
   ii. Calculate the Bill of Material (BOM) for product X

Item	Lead Time
X	2
A	2
B	1
C	3
D	1

Exercises

8. Product A will be delivered on week 12. Based on table below:

Item	Component	Lead Time	On Hand
A	B(1), C(2)	1	50
B	D(1), E(1)	2	20
C	F(2), G(1)	2	20
D		1	5
E		1	0
F		1	0
G	E(2)	3	10

i. Develop the time-phase product structure.

ii. Develop the net material requirement planning (MRP) table if the gross requirement for A is as shown in table below.

Week	7	8	9	10	11	12
Gross Requirement		50		20		100

9. Dias Furniture Company is supplying furniture to one holiday place. The company received a demand of 80 units of furniture, A. Furniture A have been completely installed by the end of week 7. Each unit of furniture A requires 2 units of B and 3 units of C. Then every unit of B requires 2 units of D and 2 units of E. Furthermore, each unit of C requires 3 units of E and 2 units of F. Inventory record for each component is shown in Table below.

Item	On hand (unit)	Lead time (week)
A	40	1
B	20	2
C	30	1
D	10	3
E	20	2
F	10	3

Based on the data in the table above:

i. Draw the tree structure for product A

ii. Construct the net Material Requirement Planning (MRP) for product A.

Exercises

10. RBA company has received an order for 100 units of product A at week 7. The inventory records is shown in table below. Based on this record, sketch;

Item	Parent	Quantity for 1 parent	Lead Time	Stock
A	-	1	1	-
B	A	1	1	5
C	A	2	2	10
D	A	½	1	5
E	C	½	1	20
F	C	1	1	5

i. Tree structure for product A.
ii. Time phased diagram for product A.
iii. Calculate every item needed to produce 100 unit of product A.
iv. Develop the MRP table for item A, B, C and D.

MRP Table

ITEM	INVENTORY	Week												Lead Time
		1	2	3	4	5	6	7	8	9	10	11	12	
	Gross Requirement													
	On Hand													
	Net Requirement													
	Receipt Order													
	Release Order													

ITEM	INVENTORY	Week												Lead Time
		1	2	3	4	5	6	7	8	9	10	11	12	
	Gross Requirement													
	On Hand													
	Net Requirement													
	Receipt Order													
	Release Order													

ITEM	INVENTORY	Week												Lead Time
		1	2	3	4	5	6	7	8	9	10	11	12	
	Gross Requirement													
	On Hand													
	Net Requirement													
	Receipt Order													
	Release Order													

Print this page

Bibliography

Jay Heizer, Barry Render, Chuck Munson, Amit Sachan (2017) Operations Management | Twelth Edition | By Pearson

Jay Heizer, Barry Render, Chuck Munson (2020) Operations Management: Sustainability and Supply Chain Management | Thirtieth Edition | Global Edition | By Pearson

Heizer & Render (1996). Production and Operation Management, 3rd edition, Prentice Hall.

Jay Heizer & Barry Render (2006). Production and Operation Management, 8th edition, Prentice Hall.

Jay Heizer & Barry Render. (2008). Operations Management, 9th Ed. Pearson Prentice Hall, USA.

Henri Tokola (2012) Short-term Production Planning Methods from the Cost, Planning and Lead-Time Points of View. Conference: FAIM 2012 - 22nd International Conference on Flexible Automation and Intelligent Manufacturing. Aalto University

Sharizan Abdul Halim (2015) Manufacturing Control for Manufacturing Students & Problem Solving. Politeknik Seberang Perai. Perpustakaan Negara Malaysia

Lee Krajewski, Larry P. Ritzman and Manoj K. Malhotra (2013) Operation Management: Process and Supply Chains | Tenth Edition | By Pearson

Stevenson, William J.(2012) Operations management | Eleventh Edition | By McGraw-Hill/Irwin

William J. Stevenson. (2007). Operations Management, 9th edition. McGraw Hill. USA.

J.R. Tony Arnold (1998). Introduction to Materials Management, 3rd edition, Prentice Hall

Soh Keng Lin, Suhaiza Hanim, Mohamad Zailani, Noorliza Karia, Mohd Shukri Abdullah, Ishak Haji Ismail (2003). Asas Pengurusan Operasi, 2nd edition. Prentice Hall.

Suhaiza Hanim, Mohamad Zailani, Shahimi Ahmad Mohtar (2001). Prinsip Pengurusan Operasi, 2nd edition. Prentice Hall.

Wayne C. Turner, Joe H. Mize, Kenneth E. Case, John W. Nazemetz (1993). Introduction to industrial and systems engineering, Prentice Hall

https://www.netsuite.com/portal/resource/articles/inventory-management/material-requirements-planning-mrp.shtml

POLITEKNIK MALAYSIA
TUANKU SULTANAH BAHIYAH

e ISBN 978-967-2740-27-8

9 7 8 9 6 7 2 7 4 0 2 7 8

Manufacturing Control 2nd Edition