Colecția "MANAGEMENT"

ACTUAL CHALLENGES IN LOGISTICS AND MAINTENANCE OF INDUSTRIAL SYSTEMS

Handbook

Vol. 1 – Text and cases

The handbook "Actual Challenges in Logistics and Maintenance of Industrial Systems" is intended to support the activities of students and lecturers, which will be carry out during the Erasmus Intensive Programme with the same name, but can be use by others interested to develop their knowledge in the field.

The handbook presents a strong multidisciplinary approach due to the support functions of logistics and maintenance, which are considered key functions in actual global environment.

The handbook offers different learning instruments, such as text and cases, exercises and problems to be solved/proposed for solving, simulations and enterprise games, key speakers session, with the possibility to debate the key problems of the topics proposed, forms for discussions and reporting the enterprises issues identified by the students in their visits in companies.

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Project:
ACTUAL CHALLENGES IN LOGISTICS AND MAINTENANCE OF INDUSTRIAL SYSTEMS

A Lifelong Learning Programme, Erasmus Intensive Programmes (IP)

Coordinated by "Politehnica" University of Timisoara

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NORTH UNIVERSITY of BAIA MARE, Romania
VILNIUS GEDIMINAS TECHNIKAL UNIVERSITY, Lithuania
POZNAN UNIVERSITY OF TECHNOLOGY, Poland
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Content

Introduction

The handbook **“Actual Challenges in Logistics and Maintenance of Industrial Systems”** is realized in the frame of Lifelong Learning Programme (LLP), ERASMUS Intensive Programme (IP), intended to support the activities which will be carry out during the programme.

The IP programme want to create a frame for internationally teaching and learning in the IP topic bringing together 35 student from 5 different countries and 7 universities, and 9 professors which will teach/work and learn together for two weeks in an internationally environment.

The project and the handbook presents a strong multidisciplinary approach due to the modern issue of support function that consist of related and strong connected topics of **internal and external logistics** (every resources used by the companies to make products and/or services that are requested by the customers, activities such as transports, manipulation, flow of materials/products, stocks, inventory, production control, forecasting, planning and scheduling, supply chain management) and **maintenance** (referring at products/equipments availability, maintainability, reliability, accessibility, service, continuous improvement).
The “logistics and maintenance” problems are critical in a globalised environment, where competition is fierce, clients’ needs/exigencies has risen very much. Cost reduction in every activity is a must now for industrial system (see current global crises), there is a need for shorter cycle times, due times, terms and deadlines. The function of logistics and maintenance can fulfill these needs more easily than as separate functions.

The IP project allows the exchange of good practices in teaching and learning activities at European level, with different innovative practices in education and training, with different teaching materials and educational tools, different approaches to this interdisciplinary topic of the IP project. Each staff/student will bring to their home university the new/different teaching and learning approaches that is not available in a single institution.

The IP will develop activities in cooperation between universities and industry as follows: three enterprises visits (that have an object of activity related to the topic of IP) with presentation of the current situation and problems from the key personnel in charge of logistics and maintenance, and with comparative case analysis and possible solutions given by the students; one key speakers session with invited experts in the field of logistics and maintenance that will present also the current problems and with debates on the theme, brainstorming session for ideas/solutions finding. In this way, both the enterprises key personnel and student/teachers can gain experience from the dialog, ideas exchanges, and best practice sharing in the field.

The handbook is organise in concordance with the IP work activities, in 12 modules, which will take place during the two weeks of the programme. The topics/modules are mutually agreed among partner’s lecturers. The aim is to give the students a tool for their lifelong education, for their future possible career in the domain of logistics and maintenance.

05.05.2011 IP Team

Module M01

Company simulation – Turbix game

Pascal DUVAL
D'Artois University, IUT of Béthune - France

Learning objectives:
According to a daily order book (duration : 8 hours) - meet the customers' requirements regarding delivery time (>90 %) - reduce the volume of stocks (valuation of stocks simulated twice a month)

Description of the module:

Scenario through a business game where each participant has a role to play in this virtual enterprise (8 hours).

The simulation of this company aims to sensitize students to the problem:
- Inventory Management
- Organizing, scheduling and control workshop
- The transmission of information between functions
- The sales forecast

This is a company that assembles and sells 8 references different finished products
- From 8 components manufactured in another company shop
- From 5 components purchased from outside

The company manufactures:
- 2 references on stock (Production Plan)
- The other 6 are launched on order (Order Management)

This assembly plant is composed of:
- 3 assembly stations (Collection of various finished products)
- A testing station (Lab)
- Three stores (2 of raw materials and 1 for finished products).

Students aim to:
According to a daily backlog (duration: 6:00)
- Satisfy the customer in terms of time (> 90%)
- Reduce the volume of stock (inventory valuation simulated 2 times per month)

COMPANY PROFILE

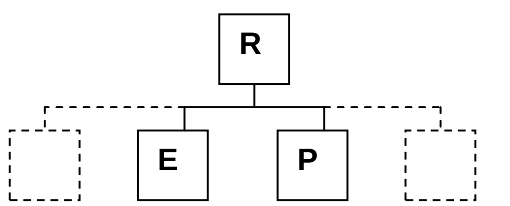
NAME : TURBIX

ACTIVITIES : Production and marketing of mechanical parts for a high voltage hydroelectric power station.

STAFF : 50
TURNOVER : 24 000 000 €
CATALOGUE : 8 finished products
PRODUCTION : Assembling and testing of components

DESCRIPTION OF THE PRODUCTS

The structure of a finished product is as follows :



The TURBIX catalogue includes 8 finished products named R1 to R8.

The sale prices are as follows (in thousands of Euros)

R1	R2	R3	R4	R5	R6	R7	R8
30	40	80	40	100	60	50	50

Machined components : E1, E2, E3, E4, E5, E6, E7, E8

They are made from forgings in another workshop of the TURBIX group.
.

Purchased components : P1, P2, P3, P4, P5

COMPOSITION OF PRODUCTS

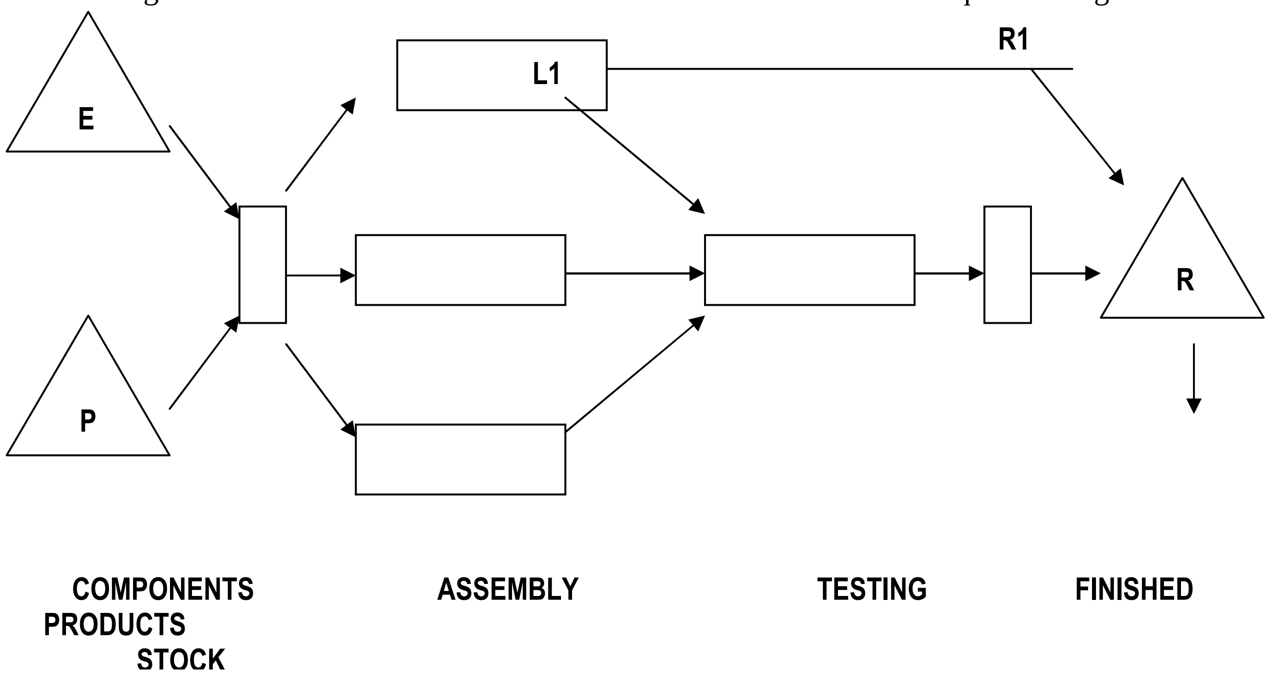
	E1	E2	E3	E4	E5	E6	E7	E8	P1	P2	P3	P4	P5
R1	1				1				2				1
R2	1					1							
R3	1						2			3	1		
R4		1			1								
R5		1	2					1				1	
R6			1	3									
R7	1				1					2			
R8						1			1	1			1

PATTERN OF PRODUCTION

During the simulation, players will be in charge of the assembly workshop as well as the components and finished products stores (the machining workshop is considered as an external supplier).

The assembly workshop consists of : - 3 assembly lines L1, L2, L3
- 1 line for testing named L4.

Each assembly line specializes in the assembly of specific products.
The testing line is versatile. However it should be noted that R1 does not require testing.



THE OBJECTIVES OF THE COMPANY

1 – TO MEET CUSTOMERS'REQUIREMENTS (deadlines and quality)

Meeting deadlines has not been a priority for TURBIX so far. Last year, one order in ten on average has not been delivered in time.

Mr Dessange, the Marketing Director, receives many complaints regarding this problem. He fears that the most loyal customers turn away from TURBIX despite the undeniable technical qualities of the products.

2 – TO MANAGE ITS RESOURCES EFFECTIVELY

(Using the lowest inventory level and avoiding wastes)

On January 1, the company holds an inventory which amounts to 1 033 000 € regarding only the stocks of components for assembly and finished products.

The CFO, Mr. Bourgeois, required that efforts be undertaken to reduce inventory. According to him, a reduction in stocks would reduce cash flow and increase the company's investment capacities.

INVENTORY VALUE

FINISHED PRODUCTS

		01/01		10/01		20/01	
NAME	UNIT COST	QTY IN STOCK	COST OF STOCK	QTY IN STOCK	COST OF STOCK	QTY IN STOCK	COST OF STOCK
R1	19	10	190				
R2	17	8	136				
R3	37	0	0				
R4	20	0	0				
R5	48	1	48				
R6	32	0	0				
R7	19	0	0				
R8	18	0	0				
TOTAL (K€) :			374				

The quantities to be recorded in the "STOCK" column include components, products in progress and finished goods.

The values in the "UNIT COST" column are the standard costs of products in thousands of Euros (K€), as reflected in the calculation of cost prices.

To simplify the calculation of inventory:

- Products in the process of being assembled are valued at the cost of their respective components.
- Products in the process of being tested are valued at the cost of finished products.

COMPONENTS AND RAW MATERIALS

		01/01		10/01		20/01	
NAME	UNIT COST	QTY IN STOCK	COST OF STOCK	QTY IN STOCK	COST OF STOCK	QTY IN STOCK	COST OF STOCK
E1	3	30	90				
E2	6	5	30				
E3	9	8	72				
E4	5	12	60				
E5	6	20	120				
E6	6	12	72				
E7	9	4	36				
E8	9	6	54				
P1	2	40	80				
P2	1	20	20				
P3	1	5	5				
P4	3	4	12				
P5	0.3	27	8				
TOTAL (K€) :			659				
GENERAL TOTAL (K€)			1 033				

Module M02

1. Kanban simulation – Redix game

Pascal DUVAL
D'Artois University, IUT of Béthune - France

Learning objectives:
-to familiarise the students with the Pull Flow System -to compare the Pull Flow System to the Push Flow System This simulation will be followed by practical sessions allowing to set up the management parameters of the system.

Description of the module:

Flow simulation from using the Kanban game (8 hours)

Since the beginning of last century, many working methods have been implemented as Taylorism, Fordism: first methods that used the line work.
Then, with the Toyotism, we used methods from the client's request, so we had to use tools such as Kanban to run these methods.

Kanban considers that "*Making prematurely is as bad as making late. All stocks are enemies for financial reasons and adaptation to demand*." In a workshop production, this means that an upstream station must produce what is requested by its downstream position itself must produce what is asked by his own position and so downstream more ... the position as far downstream as not to produce to meet customer demand.
In this context, the production is pulled downstream from controls.
KANBAN is a mechanism to enslave the production or supply of a component to the consumer that is made.

This step aims to:
- Educate students to "pull" flow
- To compare the pull flow and the push flow

This simulation will be followed by tutorials for calculating the parameters of system management.

THE REDIX COMPANY

The company was founded around 1936, with the creation of a small mechanical subcontracting workshop by a production worker.

But it really began expanding in 1952, when the founder's son filed a patent on a sun gear drive.
The company took at that time the name of REDIX, and since then has specialized in the manufacture and the sale of speed reduction mechanisms used in the handling, construction and public works industries.

Today REDIX employs 120 people in its plant situated in Villeneuve (Aveyron), France.
Its turnover amounts to 12 000 000 € and has been steadily growing by 10% per year.

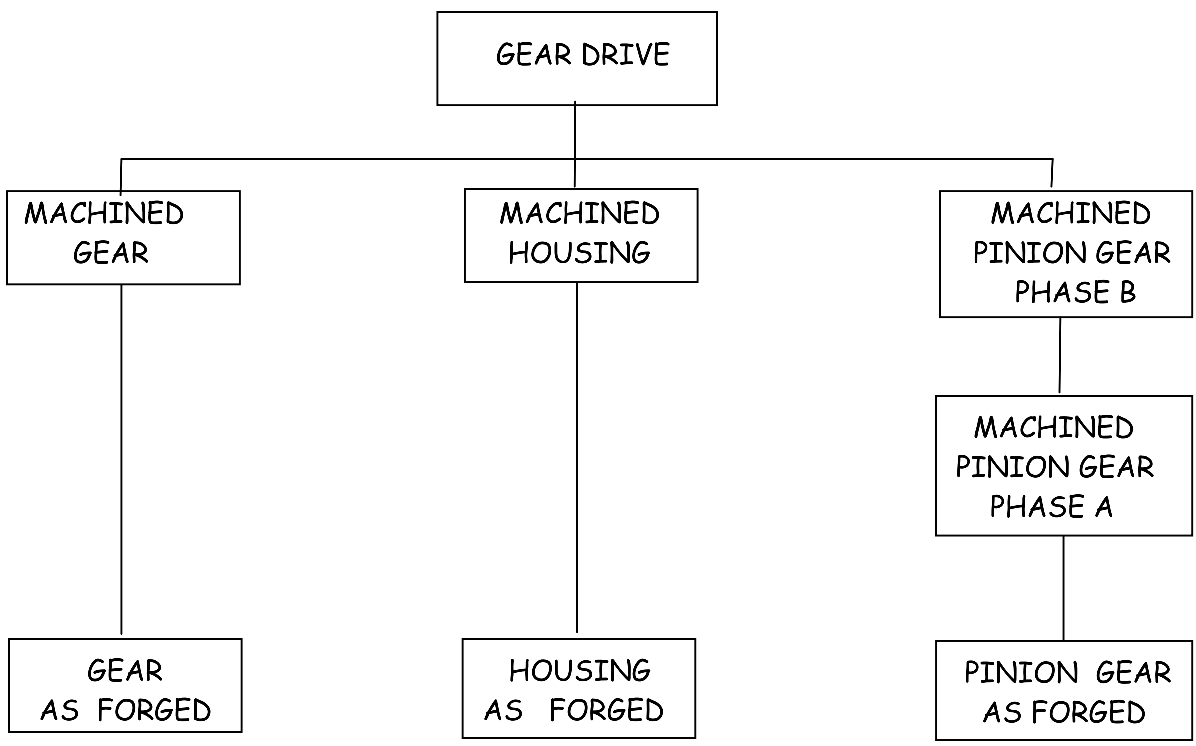
The only workshop of the factory involved in production is the one which produces the low power gear drives.

Note: To make it simpler, only 6 finished products have been considered. The production process has also been simplified.

Sales: The market on which REDIX is evolving concerning low power gear drives is a standard market. Sales are made from stock for spare parts and made to order for gear drives. Production is determined according to sales forecasts and / or firm orders.

1 –PRODUCTS

All the finished products have the same structure, represented by the nomenclature below.



The products are available in 6 references, each of them resulting from the assembly of different components. Each reference corresponds to a different gear drive.

Gear : Yellow or White
Housing : Red or Blue
Pinion gear : White, Green or Red

The way the components are combined to form the final products is shown in the table below.

MACHINED GEAR DRIVES

	R1	R2	R3	R4	R5	R6
GEAR	YELLOW	YELLOW	YELLOW	WHITE	WHITE	WHITE
HOUSING	RED	RED	RED	RED	BLUE	BLUE
PINION GEAR	WHITE	GREEN	RED	WHITE	GREEN	RED

SPARE PARTS
Only WHITE PINION GEARS IN PHASE A

The three types of components are represented by tokens of different shapes whose colours show the different alternatives.

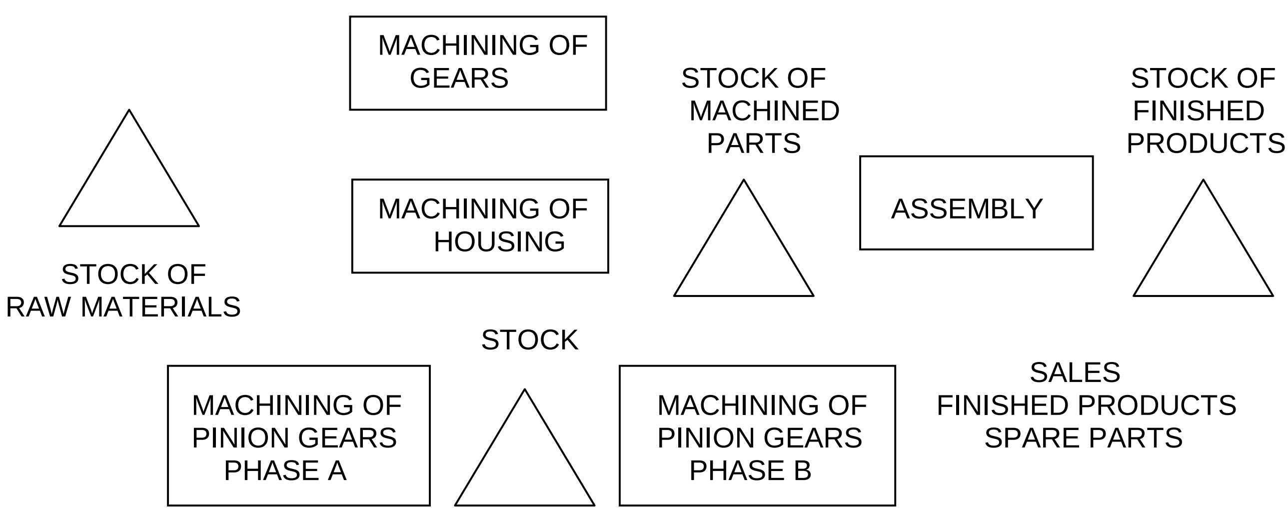
Costs of the products :
- Machined gear : 3.80 €
- Machined housing : 8.40 €
- Machined pinion gear phase A : 1.40 €
- Machined pinion gear phase B : 1.50 €
- Gear drive : 15 €

Sales prices of products:
- Each product is sold : 23 €
- Spare part : 4.60 €

2 – THE MANUFACTURING PROCESS

The workshop consists of 1 assembly and 4 machining workstations.
Once the parts have been machined, they are placed in a store which is located near the assembly area.
The machined pinion gears (phase A) are also stored, waiting to be taken into phase B.
The finished goods inventory is held in a store near the assembly line.
Each component is first machined from in-stock raw materials and then assembled into the finished product.
Semi-finished parts which are intended for the spare market are also sold.

The only component concerned by this sale is the «white pinion gear-phase A ».



3 – PRODUCTION LABOURFORCE AND MACHINES

A total of 20 people work 8 hours a day and 5 days a week at the 5 workstations in the workshop.

The 5 workstations are :

- Gears
- Housings
- Pinion gears (phase A)
- Pinion gears (phase B)
- Assembly

The machine organization is designed to comply with a satisfactory balance between the installed capacity and the sales.

The average production rate over a period of time may differ from the instantaneous rate.

We need to take into account new run set ups, machine breakdowns and other incidents that could slow down production.

Producing a new reference makes it necessary for the machines to be set up for the new run.

2. PRODUCTION ACTIVITY CONTROL
THE KANBAN METHOD

Pascal DUVAL
D'Artois University, IUT of Béthune - France

HISTORY

A JAPANESE METHOD DEVELOPED BY M. OHNO FROM THE TOYOTA MOTOR COMPANY AFTER THE SECOND WORLD WAR.

FROM THE FOLLOWING FACT :

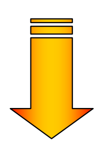
HE TRIED TO FIND A WAY TO PRODUCE :

IT BEGAN TO BE OPERATIONAL IN 1958.

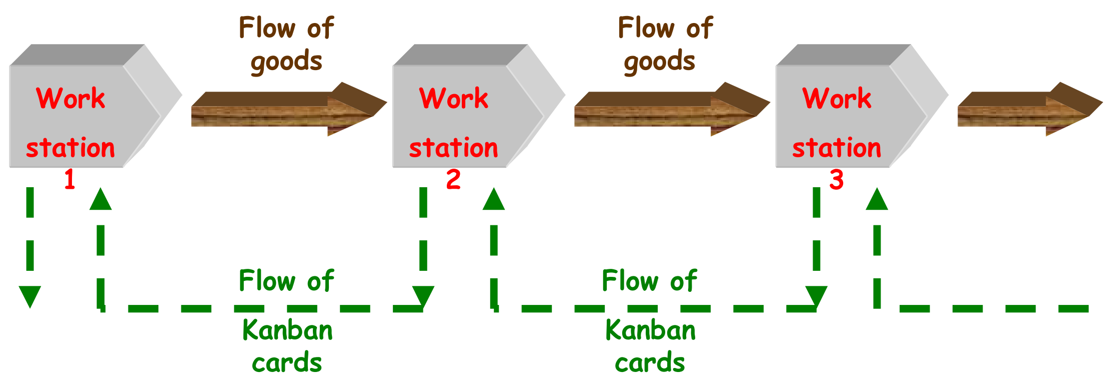
Principle - Problem

PRINCIPLE

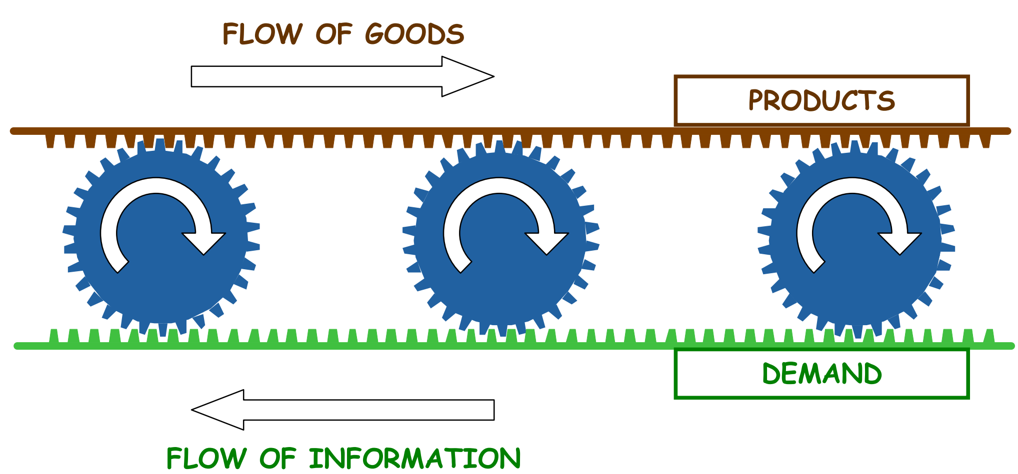
PROBLEM



HOW THE SYSTEM OPERATES



HOW THE SYSTEM OPERATES



HOW THE SYSTEM OPERATES

HOW THE SYSTEM OPERATES

- THE FLOW IS MORE OR LESS TENSE ACCORDING TO THE NUMBER OF KANBAN CARDS IN THE SYSTEM
- NO CONTAINER CAN BE PRODUCED WITHOUT A KANBAN CARD
- THE NUMBER OF CONTAINERS OF A REFERENCE WAITING AT A WORKSTATION CAN'T EXCEED THE NUMBER OF KANBAN CARDS
- THE VOLUME OF THE FLOW IS GOVERNED BY THE NUMBER OF KANBAN CARDS
- REDUCING THE NUMBER OF KANBAN CARDS AUTOMATICALLY REDUCES THE MAXIMUM LEVEL OF IN-PROCESS ITEMS OF THE REFERENCE

HOW THE SYSTEM OPERATES

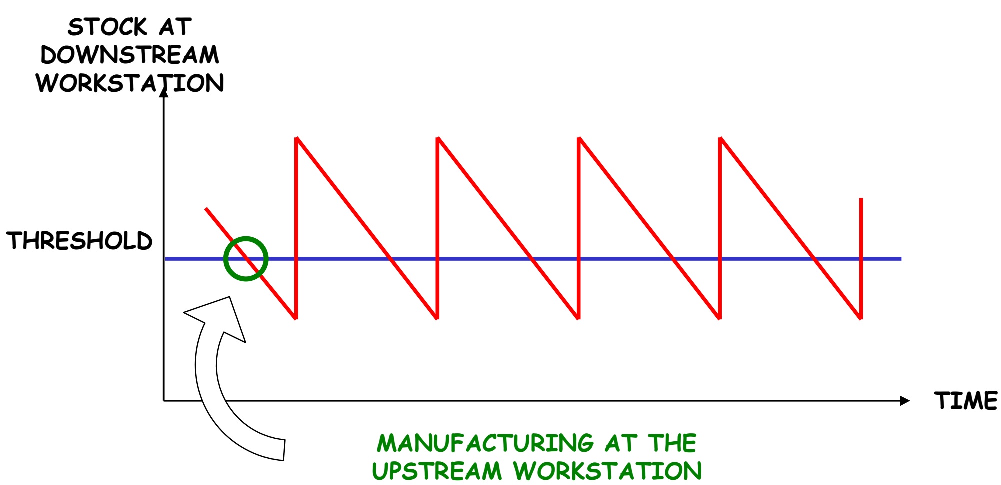
IF THE KANBAN METHOD IS CONSIDERED AS A METHOD FOR MANAGING THE STOCK WAITING AT THE DOWNSTREAM WORKSTATION, THEN THE KANBAN METHOD IS AN INVENTORY MANAGEMENT ORDER POINT METHOD.

CONCERNING THE KANBAN METHOD, EFFICIENCY IS ACHIEVED THANKS TO THE SPECIFIC QUALITIES OF THE (RE)ORDER POINT PRINCIPLE.

SHORT REPLENISHMENT LEAD TIMES

THE STOCK SUPPLIER (UPSTREAM WORKSTATION) PERMANENTLY KNOWS ITS CUSTOMER STOCK (DOWNSTREAM), AND THEREFORE CAN CHOOSE ITS PRIORITIES IN ORDER TO ANTICIPATE THE NEEDS.

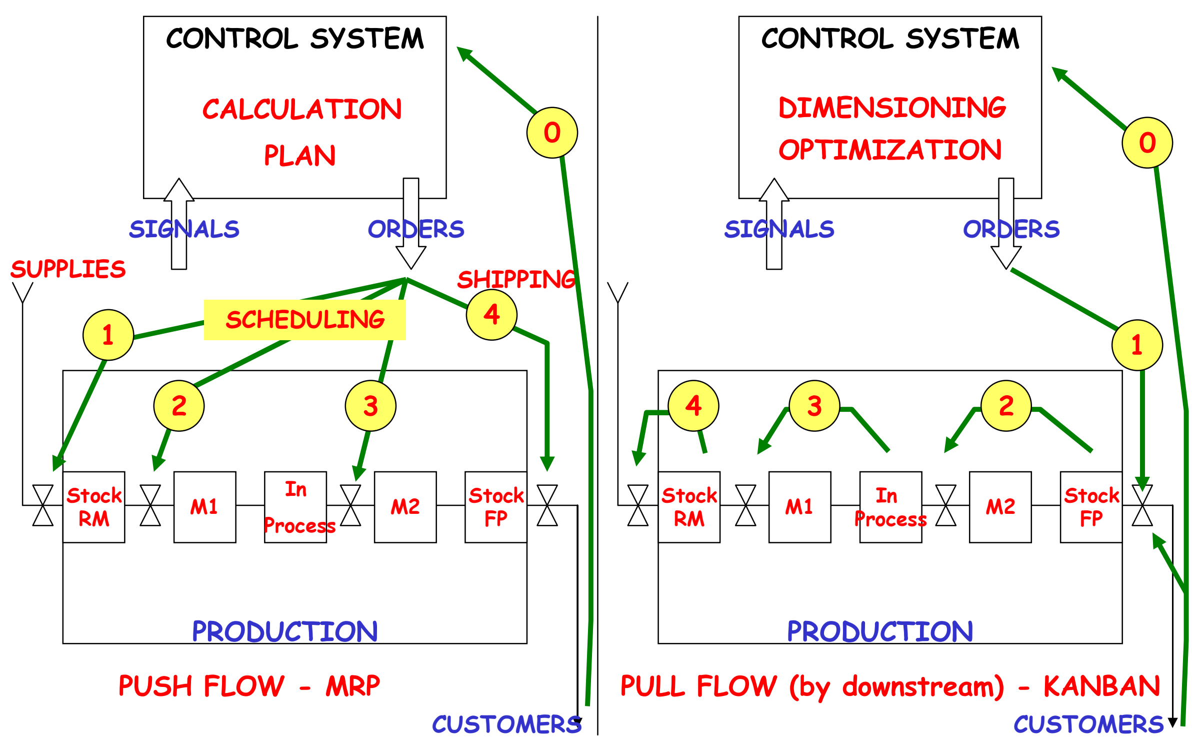
HOW THE SYSTEM OPERATES



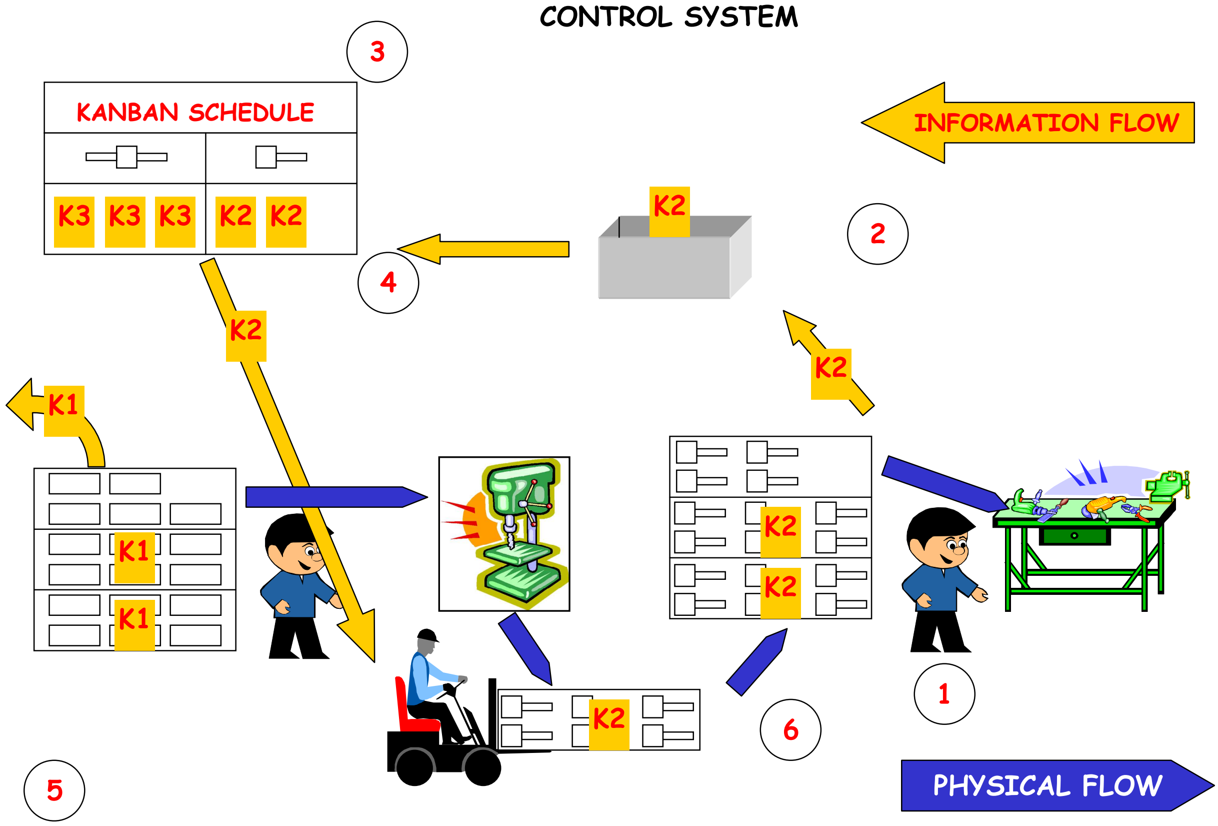
HOW THE SYSTEM OPERATES

THE UPSTREAM WORKSTATION LAUNCHES A MANUFACTURING ORDER WHEN THE DOWNSTREAM STOCK-THAT IT SUPPLIES- DECREASES BELOW A CERTAIN THRESHOLD.

THAT MANUFACTURING ORDER IS AT THE MOST EQUAL TO THE QUANTITY NECESSARY TO REPLENISH THE STOCK UP TO A DETERMINED LEVEL.



CONTROL SYSTEM



THE KANBAN SCHEDULE

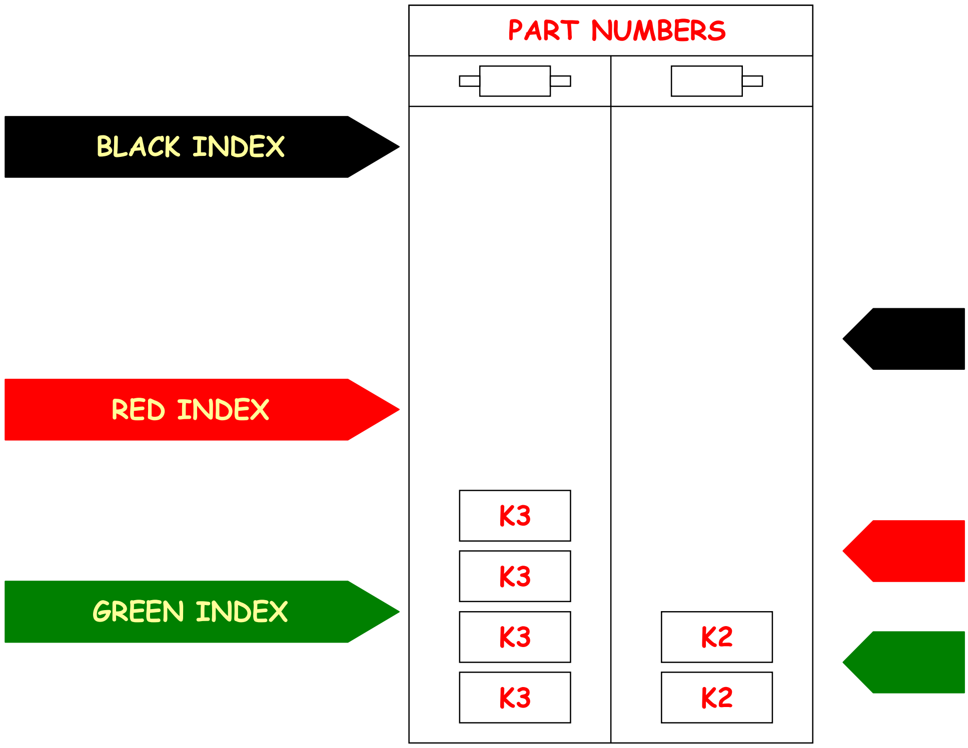
THE PRODUCTION UNIT IS THE CONTAINER

EACH FULL CONTAINER IS ACCOMPANIED WITH A KANBAN CARD

EACH KANBAN CARD ON THE SCHEDULE CORRESPONDS TO AN EMPTY CONTAINER

THE KANBAN CARDS ON THE SCHEDULE GIVE INFORMATION ABOUT :

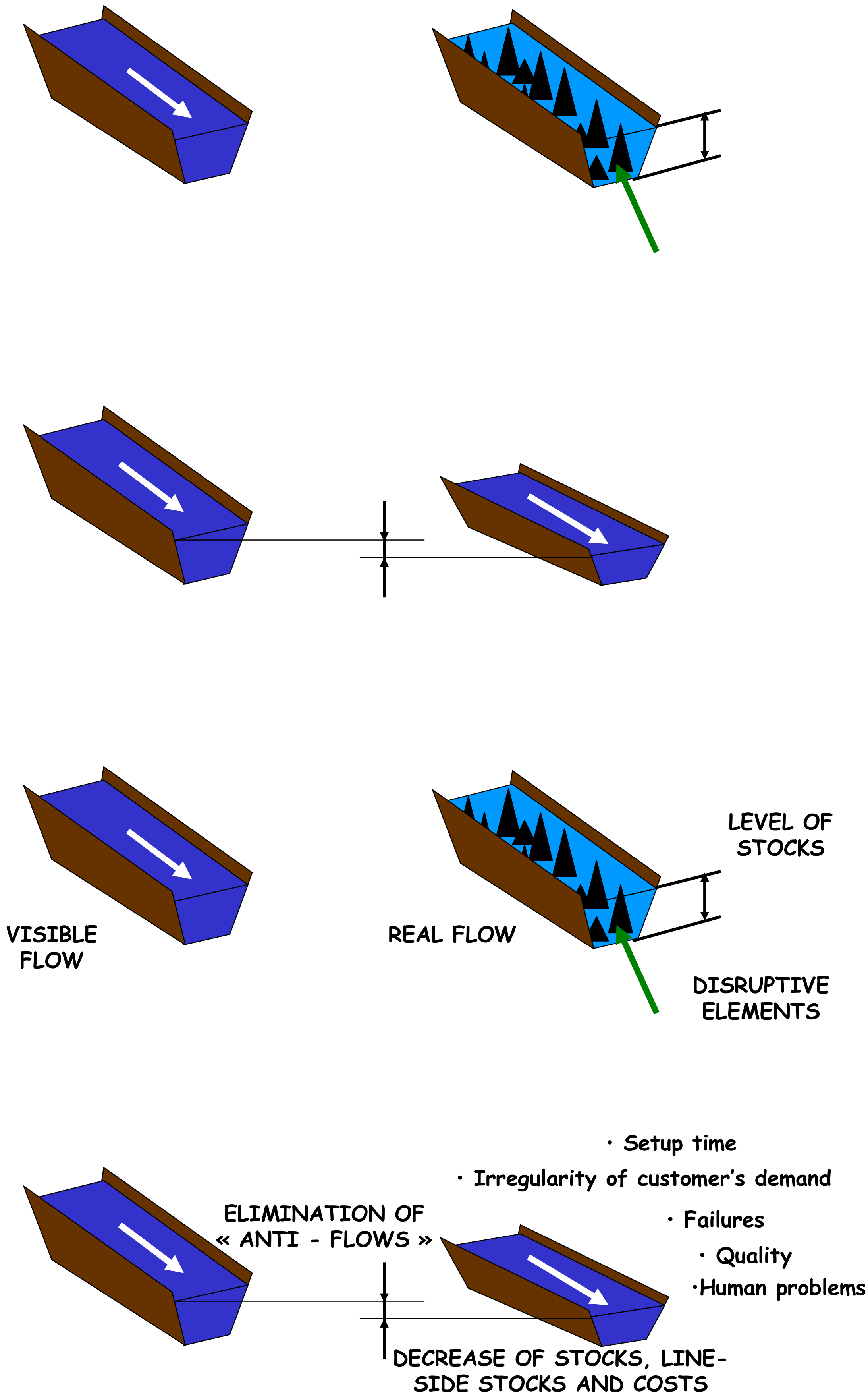
CONCEPT :

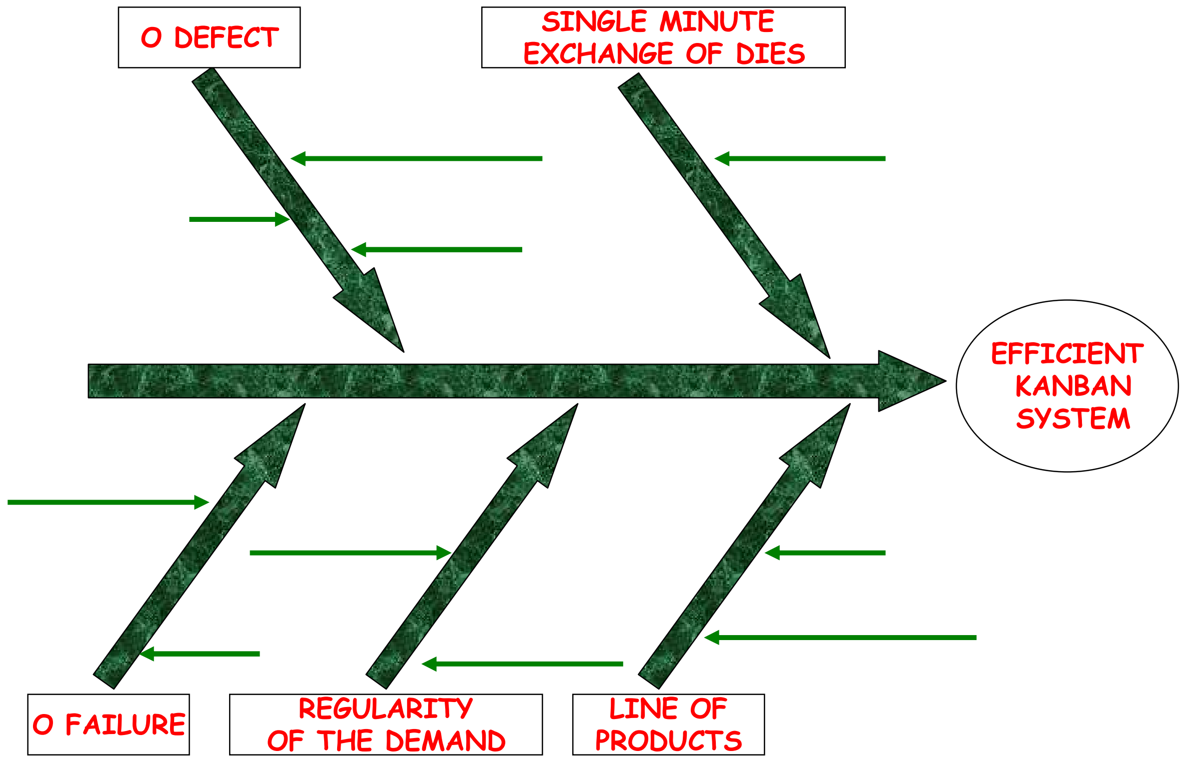


EXAMPLE OF A KANBAN CARD

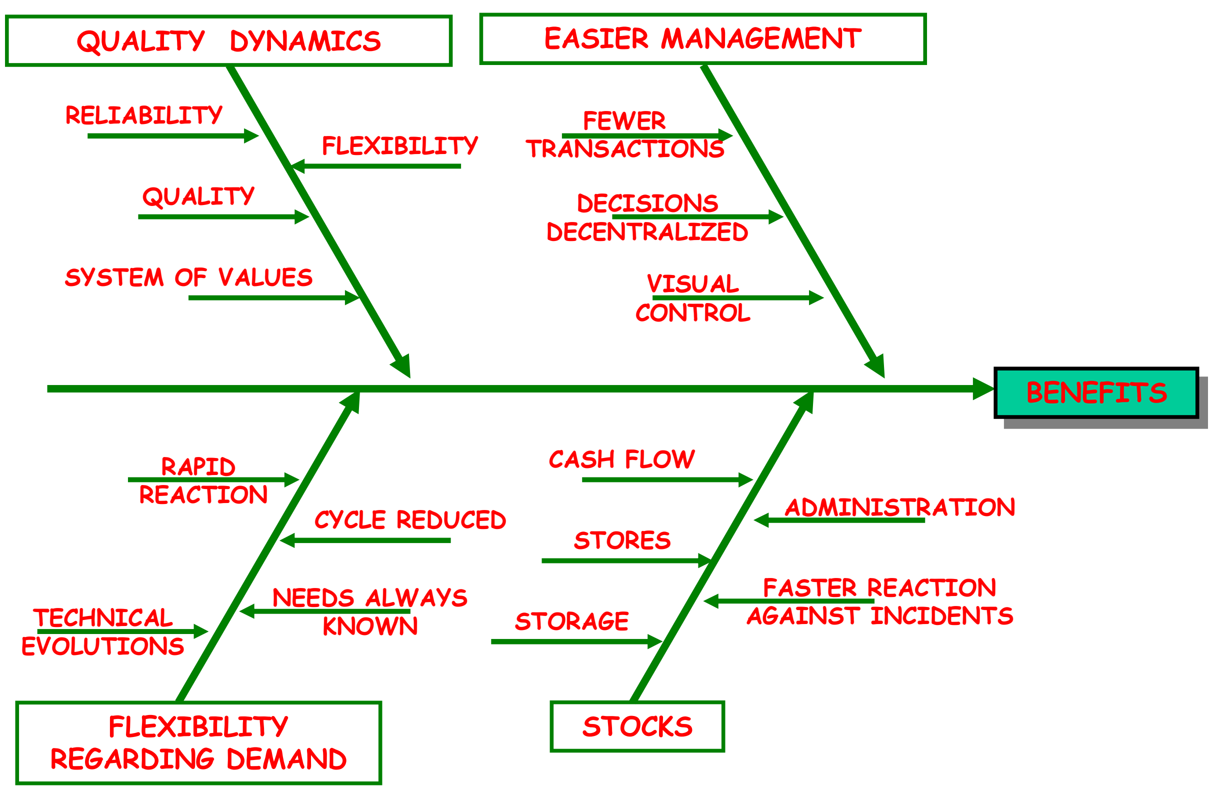
<table>
<tr><td colspan="3">COMPANY XYZ</td><td colspan="3">FX 02 33 A14
PART NUMBER</td></tr>
<tr><td colspan="6">PART NAME
CAMSHAFT</td></tr>
<tr><td colspan="3">SHIPPING WORKSTATION
(UPSTREAM)
TURNING TU 12</td><td colspan="3">RECEIVING WORKSTATION
(DOWNSTREAM)
MILLING ML 11</td></tr>
<tr><td colspan="2">QTY PARTS/CONT
50</td><td colspan="2">TYPE OF
CONTAINER
BOX 45 lts</td><td colspan="2">SPECIFIC
TOOLS
TO X23</td></tr>
</table>

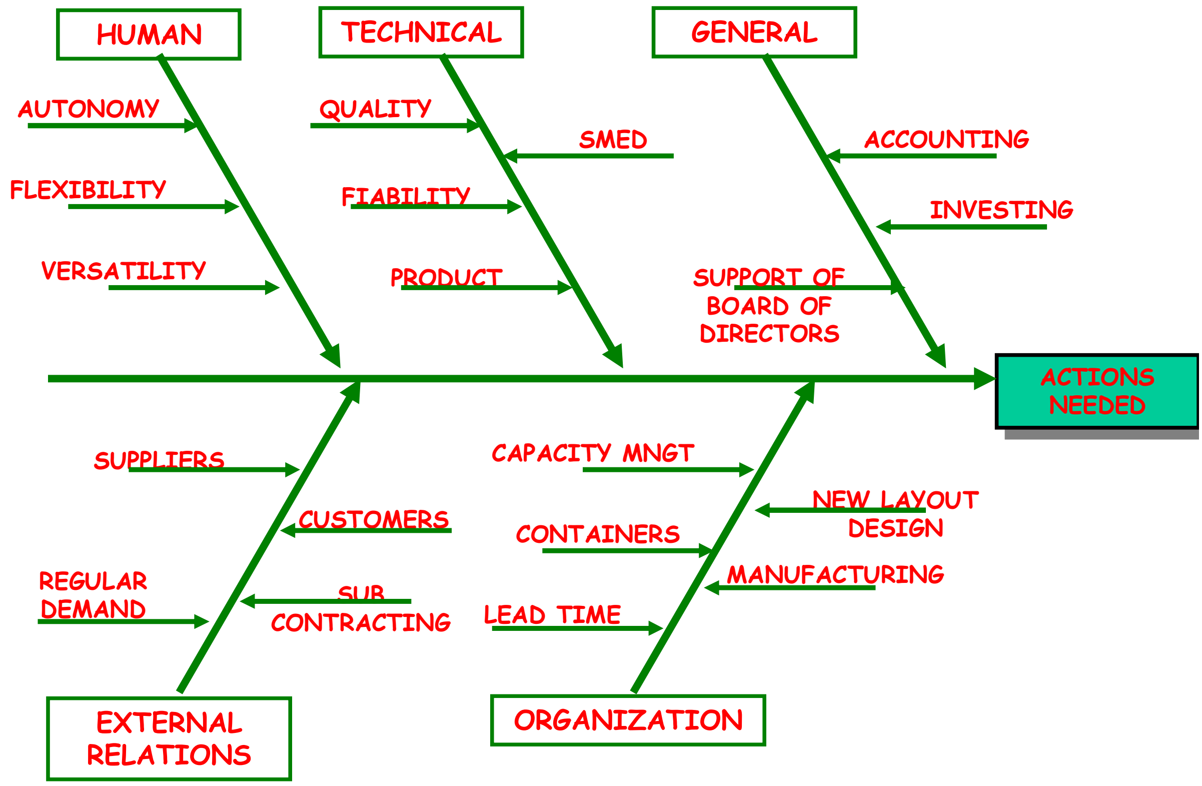
IMPROVEMENTS BROUGHT IN BY ITS IMPLEMENTATION





THE BENEFITS OF THE KANBAN METHOD




HUMAN
TECHNICAL
GENERAL
AUTONOMY
FLEXIBILITY
VERSATILITY
QUALITY
SMED
FIABILITY
PRODUCT
ACCOUNTING
INVESTING
SUPPORT OF BOARD OF DIRECTORS
ACTIONS NEEDED
SUPPLIERS
CUSTOMERS
REGULAR DEMAND
SUB CONTRACTING
CAPACITY MNGT
NEW LAYOUT DESIGN
CONTAINERS
MANUFACTURING
LEAD TIME
EXTERNAL RELATIONS
ORGANIZATION

<u>Module M03</u>

Scheduling Methods and Techniques

Ilie Mihai TĂUCEAN
“Politehnica” University of Timişoara - Romania

Learning objectives:
⇒ to identify the different steps of production activity control
⇒ to identify the scheduling issues in manufacturing environments
⇒ to identify the queue management issues
⇒ to get familiar with splitting and overlapping methods
⇒ to know and use the different scheduling methods

1. PRODUCTION ACTIVITY CONTROL

1.1. MANAGING UNCERTAINTY

Prevision, planning, control, there are management functions from Henri Fayol (1841 - 1925), a French engineer, from Frederick Taylor's *The Principles of Scientific Management* (1911).
We used to consider these functions indispensable for business running.

“The only thing we do know for sure is that in near future we don’t know anything for sure!” (Business manager)

In this crisis time, planning became almost impossible, and the illusion of planning very dangerous. If the only certainty is uncertainty, what should we do?

First, planning for shorter time range (or very short range) is a must. But we shouldn’t neglect strategic time horizon.
We do know further that we have to be more flexible. We have to take decisions when it’s needed, to have the power and authority to act when situation ask for it.

1.2. PRODUCTION PLANNING

Product positioning strategies are **make-to-stock**, **assemble-to-order**, and **make-to-order**.
Production processes are classified as **flow shop**, **job shop**, and **fixed site**.
Product positioning strategies and production process design are both influenced by **product volume**. Products with high volume and standard design tend to be make-to-stock and are usually made in flow shops. Products with low volume and/or high customization tend to be make-to-order and usually are made in job shops or batch flow shops. Most organizations have some variety in both the product positioning and production process dimension. The most common situation is an organization that fabricates components in a job shop area and assembles finished products in a final assembly area. The organization makes its most popular products to stock and assembles less popular alternatives to order.

There are critical technological choices all companies must make. Your company must lay out a clear plan for where it wants to be in 5 years (strategic time horizon) and look at the space, people, and equipment required getting there. Systems must be evaluated after an understanding and agreement is reached about what company's needs it will be over the next 5 years.
The specific actions common to all manufacturers are forecasting, long-range planning to manage plant and major equipment matters, medium-range planning to manage staffing and materials management matters, short-range planning to schedule production activities, and production control activities to ensure that the plans are met.

The MOST approach
This approach involves statement of the mission, quantification of the goals to be achieved in a strategic time span (let's say five years) and to prioritize the issues addressed in order to formulate optimal strategies.

<table>
<tr><td>Mission</td><td rowspan="2">What company wants to do.</td></tr>
<tr><td>Objectives</td></tr>
<tr><td>Strategies</td><td rowspan="2">How the company will achieve the mission and objectives.</td></tr>
<tr><td>Tactics</td></tr>
</table>

Figure 1. MOST Model

Planning

For every action there was a planned intent. The ability to clearly establish a plan the results in cohesive action is an art, not a science. Planning is the first step in the management of any process. When done correctly, it consists of selecting measurable objectives (think of SMART model) and deciding how to achieve them. Planning is a Prerequisite for action and control. Without plans there is no basis for action and no basis for evaluating the results achieved. Planning not only provides the path for action, it also enables management to evaluate the probability of successfully completing the journey.
Action is the carrying out (Performance) of plans. Control is comparing actual results with desired results and deciding whether to revise objectives or methods of action (see in figure 2 the PDCA model).
Planning, action, and control are iterative processes that should occur continuously. Initiation of control does not require that plans actually be executed – only that their results be simulated and evaluated. Thus, at times it is difficult to identify an activity as uniquely planning or uniquely control. However, describing planning, action, and control separately leads to a better understanding of these activities.

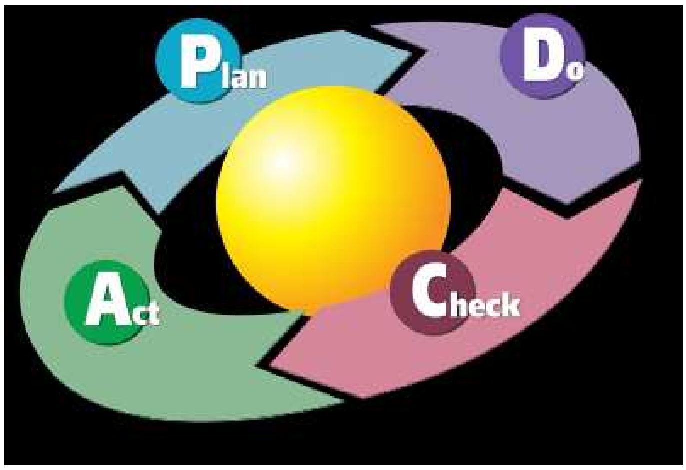


Figure 2. PDCA model

Length of the Planning Horizon

Plans can be **long range**, **medium range**, or **short range** depending on the time required to complete the action. The time spans of these different ranges depend on the operational environment of the organization.

The **long range planning** horizon should exceed the time required to acquire new facilities and equipment. This may require 10 years or longer for organizations involved in the extraction process where new mines must be developed. It may be as short as 18 months for the machine shop where facilities and equipment are catalog items.

Medium-range planning is the development of the aggregate production rates and aggregate levels of inventory for product groups within the constraints of a given facility. Expansion of capacity within the medium range planning period is limited to increasing personnel or shifts, scheduling overtime, acquiring more efficient tooling, subcontracting, and perhaps adding some types of equipment that can be obtained on short notice. Medium-range planning usually covers a period beginning 1 to 2 months in the future and ending 12 to 18 months in the future. Its exact boundaries depend on the time constraints for changing levels of production in a particular situation. The planning horizon for medium-range planning is usually at least as long as the longest product lead time. In this context, we define lead time as the time from recognizing that an order for material must be placed until that material is present in a finished good. If medium-term planning uses a horizon shorter than this, material planning cannot properly be performed.

There is no precise definition for the length of the **short term planning** horizon. Although detailed schedules and assignments of people and machines to tasks usually do not occur until well within the short-range period, the development of the production schedule frequently bridges the medium and short-range planning periods. Planning is a continuous activity, and refinement of medium range forecasts and plans to the detail required in preparing the first draft of a short range version of the production schedule may take place gradually over a number of weeks.

1.3. PRODUCTION ACTIVITY CONTROL

PAC, Production Activity Control, is concerned with converting plans into action, reporting the results achieved, and revising plans and actions as required achieving desired results. Thus, PAC converts plans into action by providing the required direction. This requires the appropriate prior master planning of orders, work force personnel, materials, and capacity requirements.

While there are better methods available via JIT and other strategies, PAC is an essential system for managing in relation to specific orders that must be properly launched, when material and labor

resources, and equipment are properly timed to be delivered or allocated for the completion of those orders.
Order release, dispatching, and progress reporting are the three primary functions of PAC.
The function of order sequencing is to determine that the sequence in which tasks are to be performed is consistent with their relative priority. Sequencing decisions arc executed by order releases and the dispatch list. The dispatch list, this includes jobs in or soon to arrive in a department and their relative priorities, is the term commonly used to identify the report used to transmit priorities to the production unit.
Dispatching is the activation of orders per original plans. Dispatching decisions are affected by queue management, I/O control, and priority control principles and techniques that are intertwined and mutually supportive. They are useful in the management of lead-time, queue length, work center idle time, and scheduled order completion.
Reports on the status of orders, materials, queues, tooling, and work center utilization are essential for control. Many report types with various informations are possible. Examining a given situation will reveal which reports and information are required. Reports of actual departmental output, which reveal actual capacity and anticipated late completion of specific jobs, provide the feedback that “closes the loop”. This enables management to exercise control by taking the necessary corrective action.
The time arrive when plans must be executed, when material requirements planning and capacity requirements planning have been completed and the detail purchasing and production schedules must be determined and released for execution. The function of production activity control (PAC) - often called Shop Floor Control (SFC) - is to have activities performed as planned, to report on operating results, and to revise plans as required to achieve desired results. Figure 3 shows the sequence of the various planning and control activities.

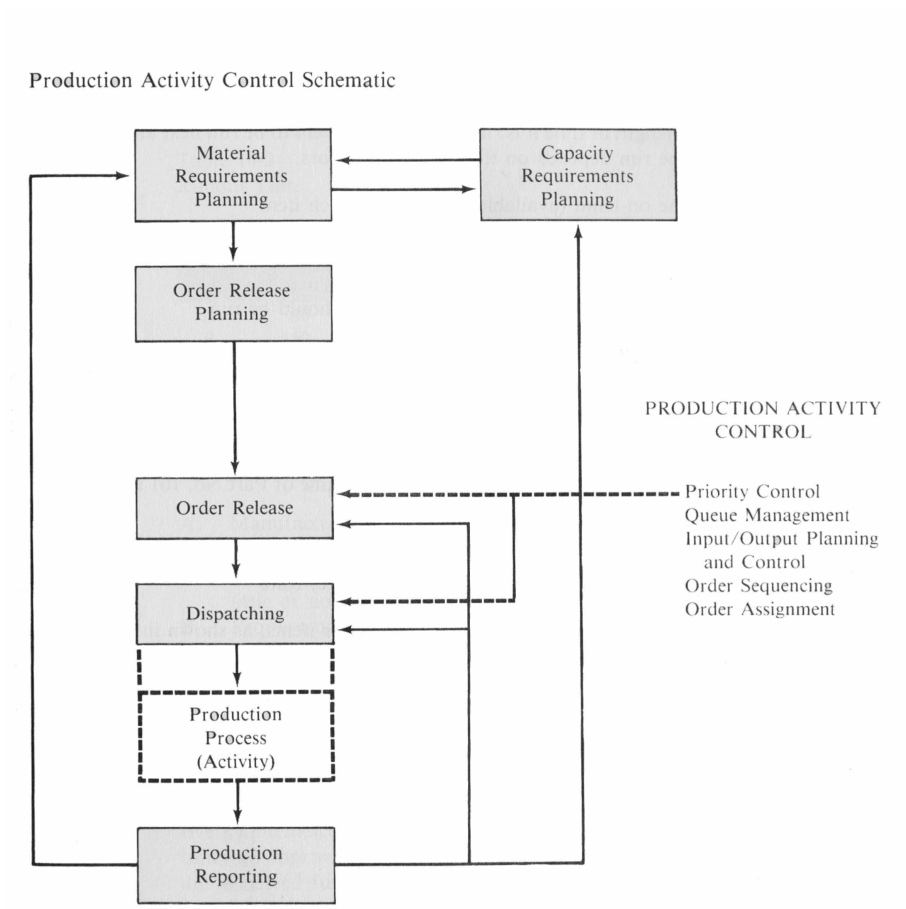


Figure 3. The sequence of the various planning and control activities

Input/Output Planning and Control: Completion of the MPS, MRP, and CRP processes with a schedule of requirements within capacity constraints leads to order release planning. Order release controls the work in process and lead times by controlling the flow of work into the shop.

Just-In-Time Manufacturing: The term "Just-in-Time" was introduced in connection with high-volume, repetitive manufacturing. Just-in-Time is an approach to manufacturing that involves eliminating all waste and making the production worker an important part of the decision-making process. Just-in-Time involves not only the production and inventory management function, but many other aspects of a business. Manufacturers that are not high-volume, repetitive manufacturers are finding that the philosophy of continually striving to eliminate waste has much to offer their operations as well.

Total Quality Control and Preventive Maintenance: For Just-in-Time manufacturing to function, machines must not break down at critical times, nor can they produce defective parts. Thus, total quality control and preventive maintenance are prerequisites to Just-in-Time system success.

1.4. SCHEDULING IN MANUFACTURING ENVIRONMENTS

Scheduling for Batch Flow Lines

Batch flow lines exist in beverage companies, ice cream manufacturers, soap powder packaging facilities, and pharmaceutical plants. Typically, a group of similar items is manufactured on the batch line. A family of items may be produced in batch quantities on the same line with some changes in the setup, a cleaning of the equipment, and changes in incoming materials. (If no time is required for switching from one item in the family to another, then the different items can be mixed in the same run and a mixed model line exists.) Thus, a primary production management objective is to reduce and eventually eliminate the time required for changing between items in a group. The smaller the changeover time, the greater the scheduling flexibility and the smaller will be the scheduling problem.
The quantity of an item produced depends on that item's production rate and the length of time it is run. Deciding the item to be run next and the quantity to be run depends on the following factors:

A. The on-hand (available) quantity of each item
B. The demand rate of each item
C. The times required to change between different items
D. The production rate of each item
F. The sequence, if any, in which items should be run

When the setup (changeover) times are relatively small and independent of the sequence in which the items are produced, the decision is relatively simple: the item with the smallest run-out time is run first.
Run-out time is the period where existing inventory will last given forecast usage. For example, if a company uses (or sells) 20 printed circuits, each day and has 80 of them in stock, the run-out time is four days. Run-out time (R) is calculated as follows:

$$R = \frac{\text{Units in Inventory}}{\text{Demand (Usage) Rate}}$$

If the setup times for the items in a group are relatively short and the production lot quantities are small due to relatively low demand rates and low setup costs, there is no problem. Sufficient time usually will exist to manufacture all items on schedule.
The purpose of this example is to point out that:

A. Manufacturing engineering should reduce the setup times and, thus, improve the production run quantities and time. (How?)

B. Proper timing of order releases is as important as the quantity decision.

When sufficient inventory is available, personnel may be used for preventive maintenance, methods analysis, and setup time reduction to reduce lead time and improve quality rather than to produce unneeded parts.

Job Shop Scheduling

The physical layout of a job shop usually groups equipment performing similar functions in the same area. Typically, there are many different orders being processed in the plant at the same time and relatively few have the same routing (the department-by-department path through the plant). Scheduling is the assigning of starting and completion times to orders (jobs) and frequently includes the times when orders are to arrive and leave each department. Sequencing is the assigning of the sequence in which orders are to be processed, for example, do Order C first, then B, followed by D, and so on. However, in practice and in the literature, scheduling frequently refers to both the time schedule and the sequence of orders or jobs. The selection of a scheduling system, approach, or technique depends on the objectives of the schedule and the criteria by which its results will be measured.
Management mission, policies and objectives are the basis for scheduling decisions. However, production management may define multiple and conflicting scheduling objectives in different ways, such as: minimize average lateness of orders, minimize maximum lateness, minimize manufacturing lead time (minimum average flow time), minimize work in process, and maximize utilization of bottleneck work centers. Fortunately, many of the objectives are mutually supportive. For example, reducing manufacturing lead time reduces work in process and increases the probability of meeting due dates.
Achievement of these scheduling objectives depends on the flexibility of the manufacturing equipment and personnel. The importance of achieving flexibility through methods improvement, facility layout, setup reduction, worker cross training, and the development of manufacturing cells cannot be overemphasized.

Priority Control

Many methods (sometimes called priority rules) exist for establishing the priority of orders. The priority, often expressed numerically, is used to determine the sequence in which the orders should be processed. The rules described in the following are probably the most common, but many variations and combinations of these methods exist. The list below provides a good overview of the basic rules and their objectives.
To show how these rules are used to determine the priority of orders, let's consider a specific example. Say we have a table that shows data concerning four orders in a manufacturing plant. All orders were in the same department, which we call Department 7. The simplest priority rule to implement is earliest due date. For this example, the manufacturing sequence would be A, B, C, D. These jobs have due dates of 130, 132, 136, and 138, respectively (see table 1).

Table 1. Scheduling Priority

Scheduling Priority, Department 7, Day 125
(All times are in days.)

Order	Due Date	Current Operation Time	Total Operation Time Remaining	Manufacturing Lead Time Remaining*	Number of Operations Remaining	Slack Time	Critical Ratio
A	130	1.5	3.0	6.0	3	2.0	0.83
B	132	1.0	4.5	9.5	5	2.5	0.74
C	136	2.0	4.0	8.0	4	7.0	1.38
D	138	3.5	7.0	9.0	2	6.0	1.44

Includes planned queue time

Slack time (ST) is found by subtracting the present date (say, Day 125) and the total operation time remaining from the due date. That is:

ST = Due Date - Present Date - Total Operation Time Remaining

For Order A: ST = 130 - 125 - 3.0 = 2.0

The critical ratio (CR) equals the difference between the due date and the present date divided by the manufacturing lead time remaining:

$$CR = \frac{\text{Due Date - Present Date}}{\text{Manufacturing Lead Time Remaining}}$$

Table 2. Priority Rules

Rule	Objective
FCFS – First Come, First Served or **FIFO** – First In First Out	Run the orders in the sequence in which they arrive at the work center. This "fairness" rule is especially appropriate in service organizations where most customers often either need or desire the completion of the service as soon as possible
SPT, SOT – Shortest Processing (Operation) Time	Run the orders in the inverse order of the time required to process them (smallest time first) in the department. This rule usually results in the lowest work in process, the lowest average job completion (manufacturing lead time), and average job lateness. Unless this rule is combined with a due date or slack time rule, jobs (orders) with long processing times can be extremely late.
STPT – Shortest Total Processing Time Remaining	Run the orders in the inverse order of the total processing time remaining. The rationale of this rule is similar to the preceding one. It accomplishes similar objectives when most jobs follow a common process.
EDD – Earliest Due Date	Run orders with the earliest due date first. This rule works well when processing times are approximately the same.
FO - Fewest Operations	Run first the orders with the fewest operations remaining. The logic of this rule is that fewer operations involve less queue time and, as a result, the rule reduces average work in process, manufacturing lead time, and average lateness. However, jobs with a relatively large number of

	operations can take excessively long if another rule is not combined with this one.
ST – Slack Time	Run first the order with the smallest slack time and continue the sequence in the ascending order of their slack times. Slack time equals the due date minus the remaining processing time (setup plus run time). This rule supports the achievement of due date objectives. The slack time remaining per operation is a variation of this rule.
CR - Critical Ratio	For orders not already late (overdue), run first those orders with the lowest critical ratio. The critical ratio equals the due date minus the present date divided by the normal manufacturing lead time remaining.

For Order D,

$$CR = \frac{138 - 125}{9.0} = 1.44$$

A CR of 1.0 indicates that the order is right on schedule; a CR greater than 1.0 indicates that the order is ahead of schedule; and a CR smaller than 1.0 indicates that the order is behind schedule. The smaller the CR, the higher is the priority of the order. The CR index - as most priority criteria - should be used in conjunction with one or more other criteria.
For example, Order X has 2 days left to delivery and 1 day of manufacturing lead time remaining; thus, its CR is 2.0(2 + 1). Suppose Order Y has a 1.11 CR: it has 10 days left until its due date and 9 days of manufacturing lead time remaining. On the basis of CR's, Order Y has the higher priority. Both have the same slack time, one day. However, the nearer due date of Order X argues strongly for giving it first priority. In addition, the CR is not a good priority index for orders whose due date has passed.
Applying each of the priority rules from our list above, (except FCFS) to the four orders in our earlier example, gives the following processing sequences:

EDD (Earliest Due Date): A, B, C, D
SOT (Shortest Operation Time): B, A, C, D
STPT (Shortest Total Processing Time Remaining): A, C, B, D
P0 (Fewest Operations): D, A, C, B
ST (Stack Time Remaining): A, B, D, C
CR (Critical Ratio): B, A, C, D

Although applying priority rules to any four orders at a given time in a specific department will produce different results, the above results are not unusual. Different rules produce different sequences, but certain patterns tend to appear in most. For example, Orders A and B are scheduled first or second by most rules. One factor that also should be considered is the status of the work center to which each order goes next. There would be little point in scheduling Order A first if its next operation was in a work center overloaded with higher priority orders.
An advantage of the SOT rule is that the data required to use it is readily available to the immediate supervisor, as should be the due date data. Operation and order due dates are very popular for establishing order priorities because of their simplicity, ease of understanding, and direct relationship to a primary objective of management-on time delivery. The other rules require calculations and considerably more data. Thus, they usually require a computerized shop floor control system that performs all calculations and prepares daily lists showing job priority.
Planning (determining) the priority of orders is a prerequisite to effective production activity control. Priorities must reflect actual needs and be consistent among items going into the same assembly. Changing order priorities frequently will destroy their credibility.

Overdue Orders and Priority Indices: Overdue orders are of special interest because management is interested in minimizing the cost of late orders. Special priority indices are often used to manage overdue orders because, among other reasons, the CR technique gives confusing information when applied to overdue orders.

Table 3. Critical Ratio for overdue orders

(Present date is Day 35.)

Order	Date Due	Actual Time Remaining	Manufacturing Lead Time Remaining*	CR	Days Behind or Ahead of Schedule
A**	40	5	2	2.5	+3
B	35	0	10	0.0	−10
C	35	0	8	0.0	−8
D	25	−10	4	−2.5	−14
E	25	−10	8	−1.25	−18

**Includes planned queue time*

***Not overdue*

The concept of slack time, the time ahead of or behind schedule, can be used to aid in determining priority for overdue orders. Slack time may be computed by different methods; manufacturing lead-time and processing time remaining are the two most widely used. Managers may wish to minimize the number of late orders and decide to have one job very late. In this case, jobs that can be delivered on time are not delayed to process a job that already is late.

The manufacturing lead-time remaining (MLTR) method of computing slack time computes the number of days ahead of or behind schedule by subtracting the manufacturing lead time from the actual lead time remaining. The priority is then computed based on the number of days behind or ahead of schedule.

The processing time remaining (PTR) method of computing slack time computes the number of days behind or ahead of schedule by subtracting the processing time remaining from the actual time remaining.

For **overdue orders**, two priority rules are:

1. Run those orders first that have the greatest total of days behind schedule plus manufacturing lead time remaining.
2. Run those orders first that have the greatest total of days behind schedule plus processing time remaining.

Orders for safety stock and made-to-stock items should have lower priority than items being manufactured to fill a customer order with the same due date. This is in keeping with the philosophy that the customer always comes first. In addition, safety stock and finished goods stock are manufactured to meet probable but uncertain demands, while an actual order is a certainty.

Performance Measures

Criteria for evaluating a priority control system can include the following:

1. Percentage of on time orders to a) customers; b) the assembly line
2. Average tardiness
3. Work in process
4. Idle time
5. Minimizing setup time

One or two of the foregoing may be dominant over a short period. The planner must be able to recognize shifting criteria, or even different criteria in different parts of the plant, and to organize dispatch lists accordingly. A *dispatch list* is a document that lists the jobs in a work center and indicates the priority of each.

1.5. QUEUE LENGTH MANAGEMENT

Queues consist of those items waiting to be processed at a work center. They usually are measured in hours of work required in the work center, that is, the length or size of the queue. The lengths of queues directly affect the value of work-in-process inventory and manufacturing lead times. In an ideal situation there are no queues and also no idle time: an item arrives exactly at the time scheduled for its processing and the work center has just become available to perform the operation. However, ideal conditions rarely exist in job shops and queues are planned to compensate for the uneven flow of incoming work and the variations in work center processing times.
The objective of queue length management is to control lead time and work in process and to obtain full utilization of bottleneck work centers. Material queues of only an hour's work or so may be planned in a flow line process to avoid downtime. In a job shop environment, determining the nature of queues at the critical work centers should be the first step. Meaningful queue length goals then can be established.
We will investigate operation overlapping and operation splitting, two methods of managing queues and lead times.

Operation Overlapping (Transfer Batches)

Operation overlapping, is a technique used to reduce the total lead time of a production order by dividing the lot into two or more batches and linking at least two successive operations directly (one is performed immediately after the other). Operation overlapping is a common practice in manufacturing cells when setup is required.
Operation overlapping consists of the following:
1. A lot of parts is divided into at least two batches (transfer batches).
2. As soon as the first batch completes operation A, it is moved to operation B for immediate processing.
3. While A is being performed on the second batch, B is being performed on the first batch.
4. When A has been completed on the second batch, it is moved immediately to B.
If operation B requires substantially shorter time per piece than operation A, the first batch should be sufficiently large to avoid idle time at operation B. Calculation of this minimum batch size is straightforward:

$$Q = Q1 + Q2$$

$$Q1 \times PB + TAB + SB \geq Q2 \times PA + TAB$$
(assuming Q2 is to be at operation B before operation B is completed on Q1)

where Q = total lot size
Q1 = minimum size of first batch
Q2 = maximum size of second batch
SB = setup time of Operation B
PA = processing time per unit, Operation A
PB = processing time per unit, Operation B
TAB = transit time between Operations A and B

Solving the above equations for Q1, gives:

$$Q1 \geq \frac{Q \times PA - SB}{PB + PA}$$

For example, if:
Q = 100 units
PA = 10 minutes

PB = 5 minutes
SB = 40 minutes
TAB = 30 minutes

then:

$$Q1 \geq \frac{100 \times 10 - 40}{10 + 5} = \frac{960}{15} = \mathbf{64}$$

The result is checked easily. The time required to process 64 units in operation B is 320 (64 x 5) minutes of run time plus 40 minutes for setup, a total of 360 minutes. This is exactly the time required to process the second batch of 36 units at Work Center A. Move time is the same for both. If fewer than 64 units were in the first batch, Work Center B would be idle awaiting arrival of second batch.

If operation B can be set up prior to the arrival of parts, consideration of setup time drops out of the equation defining the minimum size of the first batch. For example:

$$Q1 \geq \frac{100 \times 10}{10 + 5} = 66.7 = \mathbf{67\ units}$$

Reduction of total manufacturing lead time by the reduction of the throughput time for operations A and B is the **benefit** of operation overlapping, as illustrated in figure 4.

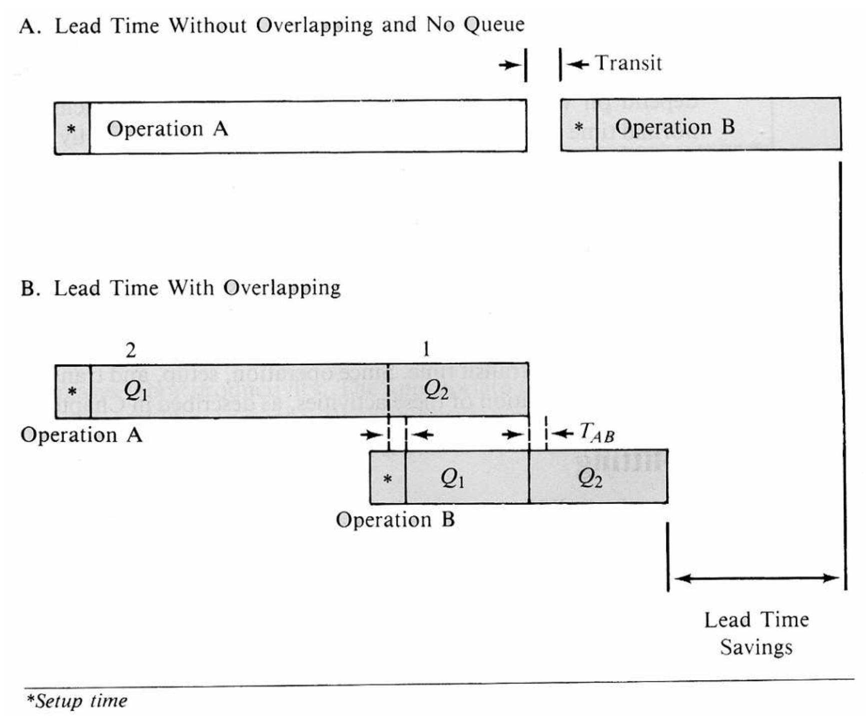


Figure 4. Comparison of lead time without and with overlapping

The **disadvantages** are the added cost of increased planning and control required by doubling the number of batches and material movements, plus the requirements that the first batch be moved immediately upon completion and that capacity is available at Work Center B when the first batch arrives. Time lost by not meeting these latter two requirements decreases the savings in lead time.

The manufacturing lead time (MLT) without overlapping and no queue equals the total time for operation A (setup and run) plus transit time plus the total time for operation B (setup and run). Thus:

MLT = 80 + 100 x 10 + 30 + 40 + 100 x 5 = 1,650 min

The MLT with overlapping and prior setup of operation B equals the time for operation A on Batch 1 (setup and run) plus transit time from operation A to operation B plus the total time for operation B (run only) on Batches 1 and 2. Batch 2 completes operation A and is moved to operation B while Batch 1 is being processed in B. Thus:

MLT = 80 + 67 x 10 + 30 + 100 x 5 = 1,280 min

The difference between the two conditions in lead times is 370 minutes (1,650- 1,280), approximately a 22 percent reduction.

The actual savings depend on whether parts are required to set up the machine as well as the normal time an order would wait between processes. Usually the major savings from overlapping come from the elimination of queue time between operations, frequently several times greater than total processing time.

When the processing time of operation B is greater than that of operation A, similar calculations can be performed to determine the batch sizes required to maximize lead time savings under the constraint of only one additional movement (dividing the lot into no more than two batches).

Operation Splitting

Operation splitting reduces total lead time by reducing the run time component. A production lot is divided into two or more batches and the same operation is then performed simultaneously on each of these sub-lots. Operation splitting reduces the processing (run time) component of manufacturing lead time at the cost of an additional setup. Conditions conducive to lot splitting include a relatively high ratio of total run time to setup time, idle duplicate equipment or work force personnel, and the feasibility of an operator running more than one machine. These conditions frequently exist. For example, in the cutting of large diameter ring gears, the setup time is small in comparison with the run time of a lot of 20 or more.

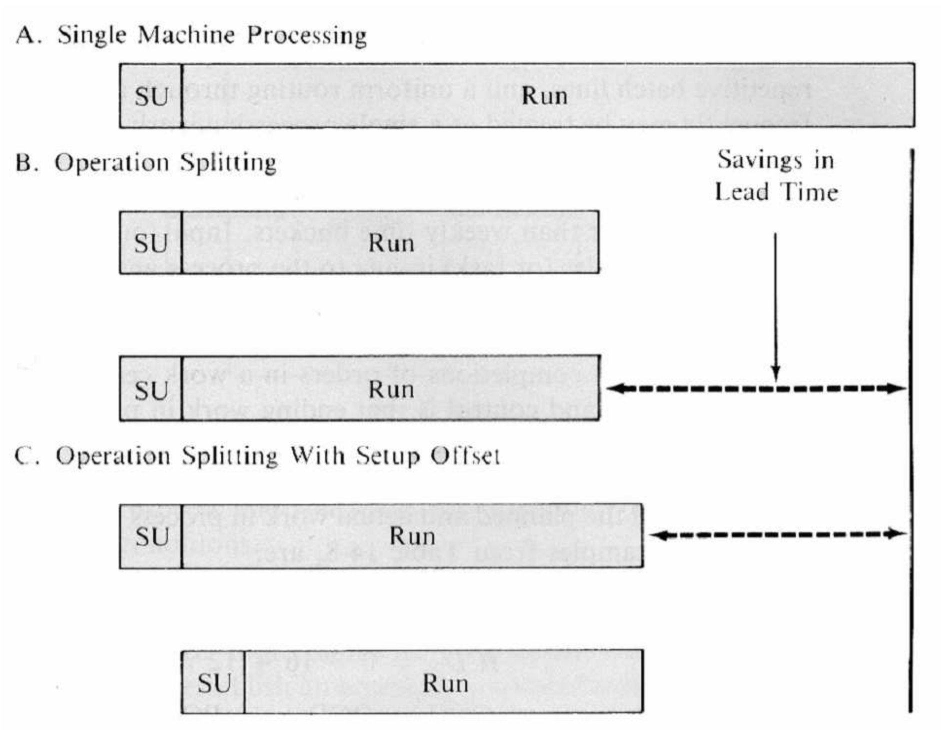


Figure 5. Operation splitting impact on manufacturing lead time

Lots also may be split in a “setup offset” manner. After the first machine is set up and running, the operator sets up the second machine. For this approach to be feasible, the time required to unload one part and load the following part must be shorter than the run time per part. In addition, shop practices (and the labor contract) must allow an individual to run more than one machine. This approach reduces lead time and increases labor productivity. The appropriate mix of parts to equalize runout or to meet cycle assembly requirements is committed as a group. Both overlapping and lot splitting are normal procedures in manufacturing cells.

1.6. INPUT/OUTPUT CONTROL

Input/output (I/O) planning and control is an integrated process that includes (1) planning the acceptable input and output performance ranges per time period in each work center, (2) measuring and reporting actual inputs and outputs (feedback), and (3) correcting out-of-contro1 situations.
Input/output control is an effective technique for controlling queues, work in process, and manufacturing lead time (the time from the release of an order to its completion). This section analyses actual inputs, outputs, and work in process. Input/output control enables the planner to determine what action is necessary to achieve the desired output, work in process, and manufacturing lead time objectives. We will examine the case of a single processing center and then the more complicated case of multiple work centers and many orders with different routings.

Single Work Center Processes

Some manufacturing processes have only one work center; others have a dominant (bottleneck) work center that is the focal point for controlling input and output to the entire process. In addition, gateway work centers, continuous and repetitive batch lines, and a uniform routing through a group of work centers frequently may be treated as a single processing work center for input/output analysis purposes.
Input/output is a short-range control technique; it usually is performed using daily rather than weekly time buckets. Input/output analysis compares the scheduled order (or task) inputs to the process and the scheduled outputs to the actual inputs and the actual outputs. This information comes from production schedules and reports of actual order releases, arrivals of orders in a work center, and completions of orders in a work center. The basic concept of I/O planning and control is that ending work in process equals beginning work in process plus input minus output, as illustrated by figure 7. Further computations can provide the cumulative input deviation, the cumulative output deviation, and the planned and actual work in process (WIP).

$$\text{Lead Time} = \frac{\text{Work in Process}}{\text{Output Rate}}$$

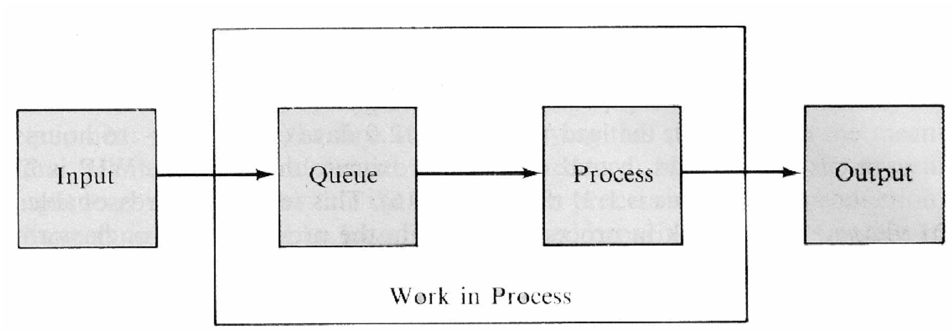


Figure 6. Input/Output relationship of a continuous process or single operation process

Management must develop various measures of process performances, including an acceptable level of input and output deviation and the acceptable level of WIP. The following examples illustrate three different situations:
(1) a process in control,
(2) the use of input/output to control and reduce work in process and lead time, and
(3) input/output controls under out-of-control conditions.

Typical out-of-control situations, possible causes, and corrective actions include the following:
1. Queues exceed upper limits. Possible causes include equipment failure, inefficient processing, and excessive input. Decreasing input or increasing process output is necessary to correct the situation.
2. Output is below the lower limit. Possible causes include equipment failure, inefficient processing, inadequate input, or the wrong input at assembly work centers.
Equipment failure and inefficient processing are manufacturing engineering problems. Inadequate, excessive, or the wrong inputs are I/O problems that should be rectified by dispatching. I/O control is essential at critical (bottleneck) work centers whether they are gateway, intermediate, or the final work centers.

The principles of input/output control are:
1. The planned output should be realistic and should represent labor and equipment capacity.
2. A planned or actual input greater than the realistic output wilt increase WIP, hinder production, and increase manufacturing lead time.
3. All significant deviations from planned input and planned output indicate operational problems that must be identified and solved.

Multiple Work Centers

Work flow through multiple work centers is often represented schematically. Two formats are commonly used, the flow-by-order format and the rate-of-flow format. Figure 7 is a schematic representation of four possible order flow patterns in a job shop with ten work centers. Work Centers Al and A2 are gateway work centers. The first operation is performed in one of these two work centers. Work Centers B1, B2, B3, Cl, C2, and C3 are intermediate work centers, and Dl and D2 are the finishing or final work centers. (All work centers in which processing is performed following processing in a given work center are called downstream work centers. Those work centers in which processing is performed prior to a given work center are upstream work centers.) We wilt examine I/O control at each type of work center.

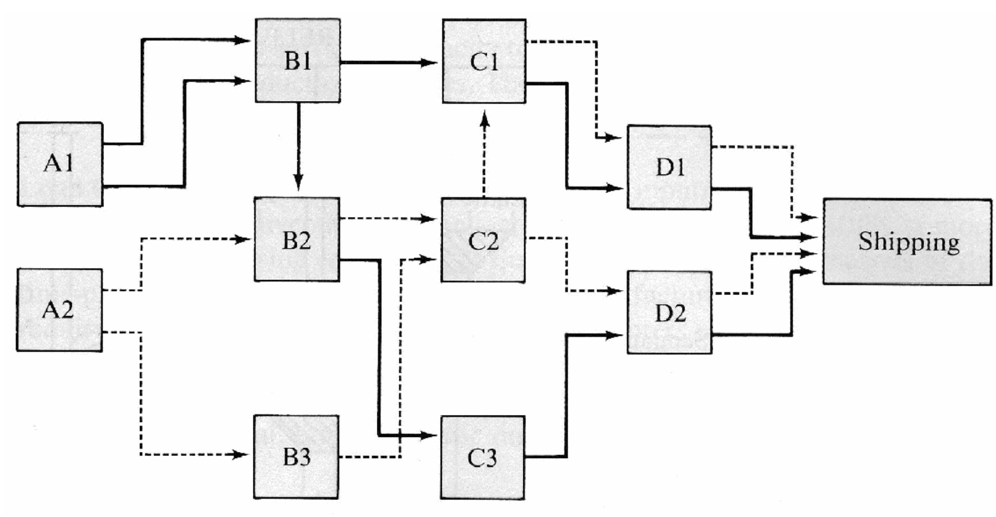


Figure 7. Flow Patterns in a job shop

Gateway Work Center Control: Management of the release of orders controls the input, queues, and WIP at gateway work centers. If the work center is running smoothly, output also is controlled. The input to the gateway work centers also influences inputs to downstream work centers. There is little reason to have a long queue at a gateway work center. Keeping gateway queues at a minimum enables the dispatcher to use the latest available information when establishing order priorities. It also reduces WIP and expediting.

Downstream Work Center Control: The input and queues at downstream work centers are controlled by dispatching (order sequencing) at upstream work centers in the process flow. For example, if Work Center C3 in figure 7, is running short of work, while there is a relatively large queue at Work Center C2, priority in Work Center B2 should be given to orders going to C3 next. This requires that order release decisions recognize the needs of downstream work centers as welt as gateway work centers. Of course, other factors such as due dates and manufacturing inventory not required must also be considered.

Final Work Center Control: The output of final work centers influences shipments, due date commitments, billings, accounts receivable, and cash flow, Final output usually is one of the dominant measures of production management performance. Controlling final work center input is necessary to achieve the desired output. This involves coordinating the flow of parts, items, and sub-assemblies required in final assemblies. Dispatching is concerned with achieving control of the volume and specific items entering the final work centers. In some complex job shops, large-scale computer simulations are used to provide completion oriented priority control that extends backward from the final work center to gateway operations (Lankford 1978).

Bottleneck Work Centers: When the capacity required exceeds the capacity available, a bottleneck exists. Often this condition either is short lived or can be solved by using the flexibility of the work force and the equipment to increase capacity. Eliminating bottlenecks with flexible capacity is one of the primary objectives of the JIT approach and is necessary to compete in world markets. Chronic bottlenecks can occur even with the best planning and, therefore, should receive the special attention of planners. A bottleneck work center limits output, and an hour lost at such a work center is an hour of output lost. Thus, the scheduling of work in bottleneck work centers is critical to achieving production objectives. As a result, measures should be taken to provide flexible and sufficient capacity to eliminate bottlenecks when designing and developing production facilities. The objective of the theory of constraints is to manage bottlenecks.

Load Order Manufacturing Control: This is an input/output control method developed at the University of Hannover and implemented successfully at more than 20 manufacturing companies in Europe. It uses statistical analysis of the time-phased relationships of order releases, manufacturing process work center requirements, and loads at downstream work centers to develop order release priority rules and guidelines for specific environments. It has had noteworthy success in reducing queues, work in process, and manufacturing lead time in an orderly, practical, and systematic manner (Bechte 1988, Wiendahi 1987).

Order Release

Order release initiates the execution phase of production; it authorizes production and/or purchasing. The planned order becomes a released (open) order. Placement of a purchase order or the initiation of manufacturing follows shortly. Order release planning may take place until the moment of order release. Authorization of order release is based on the planned orders in the MRP output, the current priority, the availability of materials and tooling, and the loads specified by I/O planning. Release of an order triggers the release of the following:

1. Requisitions for material and components required by the order. If some of these items are not required immediately and have not been allocated previously, they are allocated now.
2. Production order documentation to the plant. This documentation may include a set of both engineering drawings and manufacturing specifications and a manufacturing routing sheet.
3. Requisitions for tools required in the first week or so of production. Tooling, including tapes for numerically controlled machines, required in later operations is reserved for the appropriate period. Tooling can be included in the master production schedule and the bill of material. Its availability is thus coordinated with material and equipment availability.

The time required to deliver production order documentation, tooling, and materials to the first operation is included in the normal planned lead time for the order. An order is released by adding it to the dispatch list.

Production Reporting

Reports describing actual production status are necessary for control. Dynamic response to changing conditions is possible only if timely, accurate, and adequate information is available. The information must enable management to take meaningful corrective action concerning production schedules.
The production environment influences the design of the production reporting system. Reporting in a line flow environment with long production runs, may take place on an exception basis with feedback occurring only when the output rate falls below an acceptable level. In a custom design and manufacturing environment, that has project management and fixed site manufacturing, emphasis is on reporting the status of activities on the critical path. All reporting systems should have an exception reporting capability to inform management whenever machine failure, material shortages, or similar events threaten planned output.
Parts fabrication in a job shop environment requires more data collection for control than continuous processes or repetitive manufacturing of discrete parts. Once a flow process is initiated, it will continue smoothly unless machine failure, employee absenteeism, scrap, a materials shortage, or production inefficiencies occur. Exception reporting usually works well in these circumstances. Flow in a job shop is more complex, and order status estimates are less certain. Thus, the processing and movement of orders does not automatically follow their release into the production stream as do orders in a flow process. Control in a job shop usually requires information concerning the following:

1. The release of orders
2. The beginning and completion of operations
3. The movement of orders
4. The availability of processing information, tooling, and material
5. The queues in each work center

Exception reporting is frequently adequate for controlling the availability of information required for processing, tooling, and material. Reporting both the beginning and completion of operations is appropriate when the total operation times are relatively long. For example, if the estimated completion time of processing a lot of parts through a particular operation is four days, reporting initiation of the operation makes sense. On the other hand, if an operation requires only an hour and a half, reporting its completion should be sufficient.

1.7. SCHEDULING

Master Scheduling

Figure 8 illustrates how master scheduling and rough cut capacity planning relate to the corporate and operations planning.

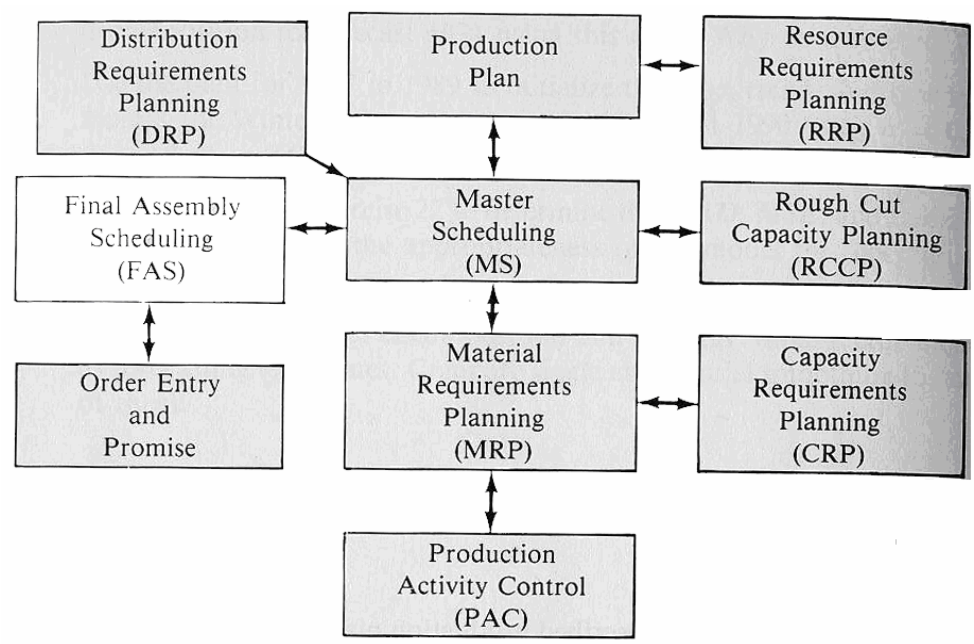


Figure 8. Relationship of Master Scheduling to other manufacturing planning and control activities

Master Scheduling & the MPS

The master schedule (MS) is a presentation of the demand, including the forecast and the backlog (customer orders received), the master production schedule (the supply plan), the projected on hand (POH) inventory, and the available-to-promise (ATP) quantity. The master production schedule (MPS) is the primary output of the master scheduling process. The MPS specifies the end items the organization anticipates manufacturing each period. End items are either final products or the items from which final assemblies (products) are made. Thus, the MPS is the plan for providing the supply to meet the demand.

Make-to-Stock

The competitive strategy of make-to-stock emphasizes immediate delivery of reasonably priced off-the-shelf standard items. In this environment the MPS is the anticipated build schedule of the items required to maintain the finished goods at the desired level. Quantities on the schedule are based on manufacturing economics and the forecast demand as well as desired safety stock levels. An end item bill of material (BOM) is used in this environment. Items may be produced either on a mass production (continuous or repetitive) line or in batch production. Case I in figure 9 represents this situation. Note that the MPS is the same as the final assembly schedule (FAS) in this case.

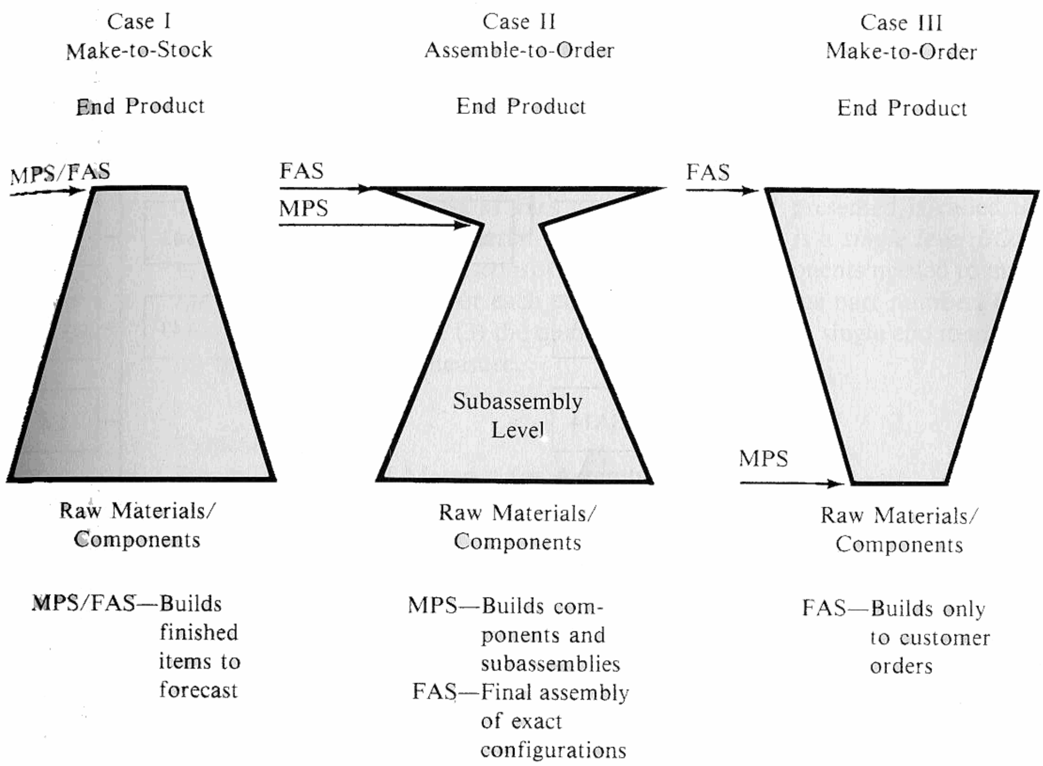


Figure 9. Make-to-stock, Assemble-to-order and Make-to-order cases

Assemble-, Finish-, or Package-to-Order

In this environment, options, subassemblies and components are either produced or purchased to stock. The competitive strategy is to be able to supply a large variety of final product configurations from standard components and subassemblies within a relatively short lead time. For example, an automobile may be ordered with or without air conditioning, an option, and a fast-food restaurant will deliver your hamburger with or without lettuce. This environment requires a forecast of options as well as of total demand. Thus, there is an MPS for the options, accessories, and common components as well as final assembly schedule (FAS). This is Case II in figure 9.
The advantage of this approach is that many different final products can be produced from relatively few subassemblies and components. This reduces inventory substantially.

Custom Design & Make-to-Order

In many situations the final design of an item is part of what is purchased. The final product is usually a combination of standard items and items custom designed to meet the special needs of the customer. Combined material handling and manufacturing processing systems are an example, special trucks for off-the-road work on utility lines and facilities are another. Thus, there is one MPS for the raw material and the standard items that are purchased, fabricated, or built to stock and another MPS for the custom engineering, fabrication, and final assembly. Case III in figure 9 represents this situation.

Scheduling

In manufacturing systems with a wide variety of products, processes, and production levels, production schedules can enable better coordination to increase productivity and minimize operating costs. A production schedule can identify resource conflicts, control the release of jobs to the shop, and ensure that required raw materials are ordered in time. A production schedule can determine whether delivery promises can be met and identify time periods available for preventive maintenance. A production schedule gives shop floor personnel an explicit statement of what should be done so that supervisors and managers can measure their performance.

Production scheduling can be difficult and time-consuming. In dynamic, stochastic manufacturing environments, managers, production planners, and supervisors must not only generate high-quality schedules but also react quickly to unexpected events and revise schedules in a cost-effective manner. These events, generally difficult to take into consideration while generating a schedule, disturb the system, generating considerable differences between the predetermined schedule and its actual realization on the shop floor. Rescheduling is then practically mandatory in order to minimize the effect of such disturbances in the performance of the system.

Because production scheduling activities are common but complex, there exist many different views and perspectives of production scheduling. Each perspective has a particular scope and its own set of assumptions. Different perspectives lead naturally to different approaches to improving production scheduling.

Scheduling is an important tool for manufacturing and engineering, where it can have a major impact on the productivity of a process. In manufacturing, the purpose of scheduling is to minimize the production time and costs, by telling a production facility what to make, when, with which staff, and on which equipment. Production scheduling aims to maximize the efficiency of the operation and reduce costs.
Production scheduling tools greatly outperform older manual scheduling methods. These provide the production scheduler with powerful graphical interfaces which can be used to visually optimize real-time work loads in various stages of production, and pattern recognition allows the software to automatically create scheduling opportunities which might not be apparent.
Companies use backward and forward scheduling to allocate plant and machinery resources, plan human resources, plan production processes and purchase materials. **Forward scheduling** is planning the tasks from the date resources become available to determine the shipping date or the due date. **Backward scheduling** is planning the tasks from the due date or required by date to determine the start date and/or any changes in capacity required.

The **benefits** of production scheduling include:

- Increased production efficiency
- A production schedule can determine whether delivery promises can be met and identify time periods available for preventive maintenance.
- A production schedule gives shop floor personnel an explicit statement of what should be done so that supervisors and managers can measure their performance.
- Minimize WIP inventory, inventory, leveling
- Minimize average flow time through the system
- Maximize machine and/or worker utilization
- Minimize setup times
- A production schedule can identify resource conflicts, control the release of jobs to the shop, and ensure that required raw materials are ordered in time.
- Better coordination to increase productivity and minimizing operating costs.

Because of complexity of production scheduling there are different views of it.

Problem Solving Perspective views the scheduling as an optimization problem. It is the formulation of scheduling as a combinatorial optimization problem isolated form the manufacturing planning and control system place.

Decision making Perspective is the view where scheduling is a decision that a human must make. Schedulers perform a variety of tasks and use both formal and informal information to accomplish these. Schedulers must address uncertainty, manage bottlenecks, and anticipate the problems that people cause

Organizational Perspective: is a systems-level view that scheduling is part of the complex flow of information and decision-making that forms the manufacturing planning and control system. Such systems are typically divided into modules that perform different functions such as aggregate planning and material requirements planning

Production scheduling can be classified according to the following criteria:

1. Flow patterns
    - (a) Flow shop: All the jobs have identical process flows and require the same sequence of operations.
    - (b) Job shop: Jobs have different process flows, and may require significantly different sequence of operations.
2. Processing mode
    - (a) Unit processing: Jobs are processed one by one.
    - (b) Batch processing: A number of jobs are processed together as a batch.
3. Job release pattern (job release time is the earliest time at which processing can start)
    - (a) Static: Jobs are (or assumed to be) released to the shop floor at time zero.
    - (b) Dynamic: Jobs are (or assumed to be) released to the shop floor over time.
4. Work center configuration
    - (a) Single machine.
    - (b) Identical parallel machines.
    - (c) Uniform parallel machines.
    - (d) Unrelated parallel machines.

Difference between production planning and production scheduling

The main difference is in the resolution of the resulting plan or schedule. While the industrial planning deals with the task of finding "rough" plans for longer period of time where activities are assigned to departments etc., the industrial scheduling deals with the task of finding detail schedules for individual machines for shorter period of time. From this point of view, scheduling can be seen as a high-resolution short-term planning.

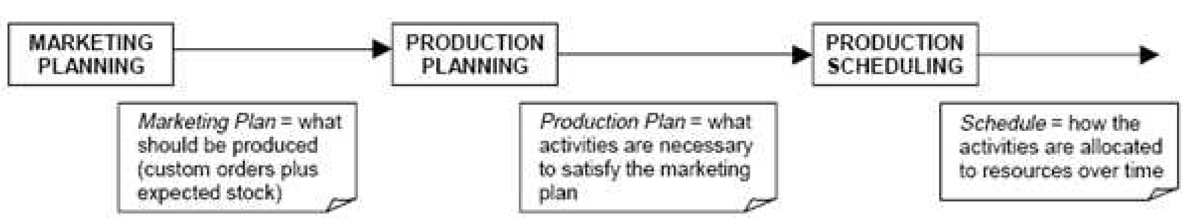


Figure 10. Production planning and production scheduling

Figure 11 show the planning and scheduling in industry.

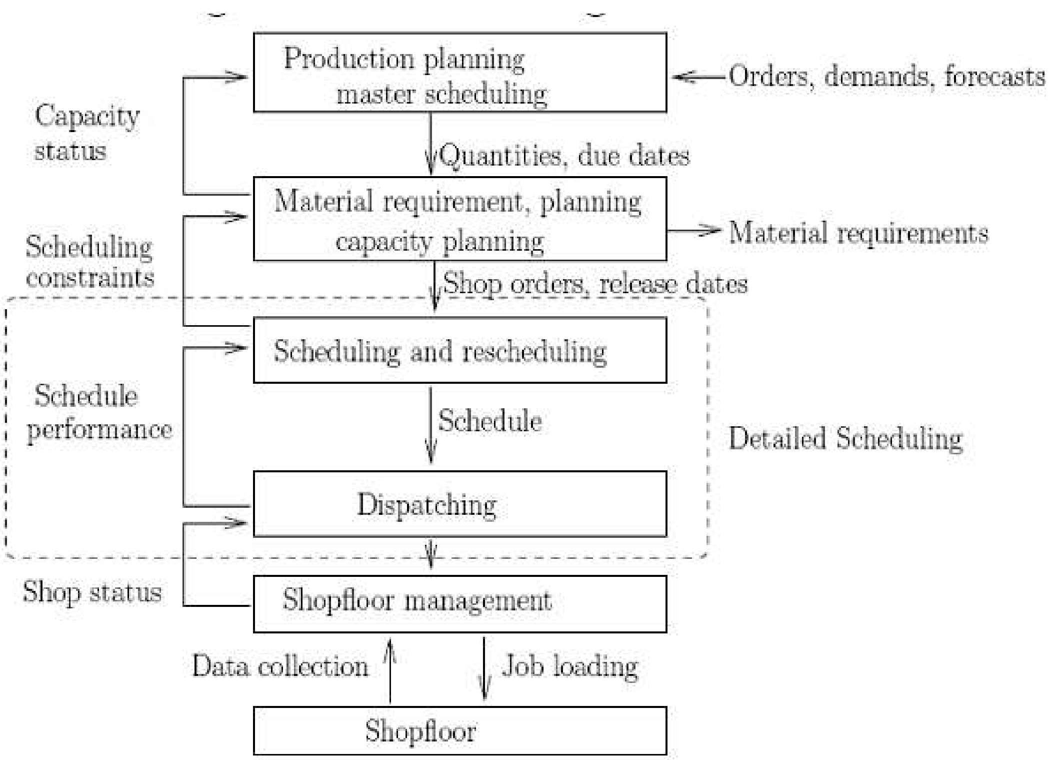


Figure 11. Hierarchical Planning

The gap between theory and practice

Wiers presented applicability of operations research and artificial intelligence techniques and their shortcomings in practice:

1. *Robustness*. Robustness refers to the extent to which a schedule will remain unchanged when the information on which a schedule is based changes. Robustness avoids nervousness in scheduling in situations with uncertainty. Most authors recognize that nervousness should be avoided as much as possible.
2. *Complexity*. In this context, complexity refers to the number of real world elements that are relevant for the scheduling problem, and the relationships between these elements.
3. *Performance measurement*. The optimization criteria of many scheduling techniques do not meet the criteria used in practice. In practice, performance is often a matter of judgment by the human scheduler, and can be subject to negotiation.
4. *Fixed vs. changeable input*. Most scheduling techniques assume that information input is a given and cannot be changed. However, in practice, the situation is often not taken for granted: inputs, such as available capacity, might be changed if judged necessary.
5. *Organizational embedding*. The relationship of scheduling decision making to other parts of an organization is generally not considered in scheduling techniques.
6. *Availability and accuracy of data*. The scheduling process predominantly depends on the availability of accurate data. If this condition is not met, the schedule will be incorrect and cannot be executed properly.
7. *Interaction with human scheduler*. It is recognized by many authors that the human scheduler will remain an indispensable factor in the scheduling process. However, many techniques do not account for interaction with the human scheduler.
8. *Learning from experience* (artificial intelligence techniques). The intelligence that is built into artificial intelligence scheduling techniques is often not stable in practice. Therefore, these systems

should learn from experience to keep their intelligence base up to date. However, most artificial intelligence scheduling techniques are not able to learn from experience, and therefore may become outdated.
9. *Availability and reliability of human experts* (artificial intelligence techniques). The intelligence of AI based scheduling systems sometimes comprises expertise that must be elicited from human experts. However, in many cases, this expertise cannot be adequately acquired.

2. Exercises – resolved and proposed

2.1. Capacity Planning vs. Finite Scheduling

Imagine you have 5 jobs to do before this time tomorrow:

Products	**Hours**	**Due-time**
A	7	24
B	12	24
C	4	24
D	5	24
E	8	24
Total	**36**	

You have work totaling an estimated 36 hours to complete in a day (24 hours). You have a problem. **Capacity planning** tells you that you have a problem by saying that you are (36÷24) 150% loaded for the day, and leaves you to resolve the problem by adding more resources or negotiating alternative due dates.

Finite scheduling, on the other hand, recognizes that the capacity of the resource is finite, and tells you that some of the jobs are going to be late, and it can also tell you:

- which jobs are going to be late
- how late they are going to be
- are they important jobs, or for important customers
- what revised delivery dates can be promised
- how all these would change if the Jobs were undertaken in a different sequence

Compared with capacity planning, finite scheduling gives you richer management information.

Products	**Hours**	**Due-time**	**Total time**	**R/D**
A	7	24	7	17
B	12	24	19	5
C	4	24	23	1
D	5	24	28	-4
E	8	24	36	-12
Total	**36**			

We can see that only three of the five jobs will be on time.

Let's see what happens when we do them in a different sequence, applying a priority rule – SPT (Shortest Processing Time).

Products	**Hours**	**Due-time**	**Total time**	**R/D**
C	4	24	4	20
D	5	24	9	15
A	7	24	16	8
E	8	24	24	0
B	12	24	36	-12
Total	**36**			

Four out of the five jobs will be on time.

2.2. Multiple Machines or Work Centers

So far we have only considered one work centre (or one worker, or one machine). For multiple work centers we could create a separate schedule for each.

Work centers	**Products**	**Hours**	**Due-time**	**Total time**	**R/D**
1	A	7	24	7	17
1	B	12	24	19	5
1	C	4	24	23	1
2	D	5	24	5	19
2	E	8	24	13	11
	Total	**36**			

All products will be on time.

2.3. Repetitive Production and Setups

So far we have accepted that a job has duration of say, 7 hours, and we haven't worried about how the 7 hours has been estimated. Let's say the first job is to set up a work centre and then produce 450 of Product A. Work Centre 1 is an old machine which runs slowly, but is quick to set up, and Work Centre 2 is a new high speed machine, but the set ups take a long time. We would describe this in tables like this:

W/C	**Set up hours**
1	1.25
2	3.00

W/C / **Product**	**Units per hour**	
	W/C 1	**W/C 2**
A	80	140
B	55	105
C	72	135

D	65	110

The schedule would look like this:

W/C	**Seq.**	**Product**	**Qty**	**Set up hours**	**Units per hour**	**Run hours**	**Total Hours**
1	1	A	550	1.25	80	5.63	6.88
1	2	B	350	1.25	55	6.36	7.61
2	2	C	750	3.00	135	5.55	8.55
2	2	D	600	3.00	110	5.45	8.45

A Set-up Matrix

Often the time it takes to set up a work centre is dependant on the previous job. For example to clean out a mixer to make white paint, after it has been used to make black paint, will take a long time, but to change to grey paint after making white won't take as long. Similar examples exist in printing and food processing and with the shut height of presses. In these industries the sequence of the jobs will affect the amount of time the work centers are being set up, and therefore the productivity of the work centers.
The set-up times between products, or product groups is expressed in a matrix as follows:

Work Centre 1

	A	B	C	D
A	-	0.50	0.50	1.25
B	2.00	-	0.75	1.00
C	2.00	2.00	-	0.75
D	2.10	1.75	1.50	-

Work Centre 2

	A	B	C	D
A	-	1.25	1.25	2.75
B	4.25	-	1.75	2.50
C	4.25	4.25	-	1.75
D	5.00	4.50	3.50	-

W/C	**Seq.**	**Product**	**Qty**	**Set-up hours**	**Units per hour**	**Run hours**	**Total Hours**
1	1	D	200	0.00	65	3.08	3.08
1	2	B	350	1.75	55	6.36	8.11
1	3	A	450	2.00	80	5.63	7.63
1	4	B	300	0.50	55	5.45	5.95
					Total	**22.16**	**26.41**
2	1	C	1500	0.00	135	11.11	11.11
2	2	D	1100	1.75	110	10.00	11.75
					Total	**21.11**	**22.86**

Try changing the sequence numbers and sorting to see if you can reduce the total set-up hours.

2.4. Jobs That Pass Through Multiple Work Centers

So far we have considered jobs assigned to Work Centre 1 or Work Centre 2, and now we shall look at jobs that pass through Work Centre 1 and then Work Centre 2. To avoid confusion lets have Work Centre 6 doing the 1st operation on the job, and Work Centre 7 the 2nd operation.

For the sake of simplicity our example will not refer to a calendar (the work centers operate 24 hours a day, 7 days a week) and we will not allow for set-up times.

Repetitive Production that Passes Through Multiple Work Centers

In the example in a section before, the 1st operation of a job had to be complete before the second operation could start. However if the job is to manufacture 5000 units, then often you don't have to wait for all of them to have gone through the 1st operation before you start the 2nd operation. When the first transfer batch (pallet load or bin full) of the product has come off the 1st work centre, it can be passed to the second work centre for the second operation to start while the product is still going through the 1st work centre.

A similar principle will apply at the end of the production run, when the last transfer batch (or part batch) of product comes off the first operation it will join a queue at the second operation. However if the second operation is faster (as in this example), then the first operation will stop, the transfer batch will be passed to the second operation, which will then stop after the transfer batch has been completed.

The rule that defines how long after the 1st operation the 2nd operation can start and stop, should be stated as the number of units in the transfer batch, but for the sake of simplicity, we will define it here as the time which the start and stop, of the next operation, lags behind the previous operation.

Start of first job: 15/6 8:00

											15/6			16/6			17/6			18/6		
W/C	**Jobs**	**Op**	**Job/Op**	**Duration Hours**	**Previous Op**	**Previous Op Row**	**Stop of Previous Op**	**Wait hours**	**Start**	**Stop**	0:00	8:00	16:00	0:00	8:00	16:00	0:00	8:00	16:00	0:00	8:00	16:00
6	A	1	A/1	19	A/0	#N/A	1/1 0:00	0	15/6 8:00	16/6 3:00		**8**	**8**	**3**								
6	B	1	B/1	22	B/0	#N/A	1/1 0:00	0	16/6 3:00	17/6 1:00				**5**	**8**	**8**	**1**					
6	C	1	C/1	17	C/0	#N/A	1/1 0:00	0	17/6 1:00	17/6 18:00							**7**	**8**	**2**			
7	A	2	A/2	8	A/1	15	16/6 3:00	19	16/6 3:00	16/6 11:00				**5**	**3**							
7	B	2	B/2	14	B/1	16	17/6 1:00	14	17/6 1:00	17/6 15:00							**7**	**7**				
7	C	2	C/2	6	C/1	17	17/6 18:00	3	17/6 18:00	18/6 0:00									**6**			
8	A	3	A/3	13	A/2	18	16/6 11:00	27	16/6 11:00	17/6 0:00					**5**	**8**						
8	B	3	B/3	11	B/2	19	17/6 15:00	15	17/6 15:00	18/6 2:00								**1**	**8.0**	**2**		
8	C	3	C/3	21	C/2	20	18/6 0:00	0	18/6 2:00	18/6 23:00										**6**	**8.0**	**7**

The next operation can start 1 hour after the start of the previous operation   Start of first job: 15/6 4:00

															15/6			16/6			17/6			18/6		
W/C	**Prod**	**Op**	**Prod/ Op**	**Qty**	**Units per Hour**	**Dur-ation Hours**	**Prev. Op**	**Prev. Op Row**	**Start of Previous Op**	**Stop of Previous Op**	**Wait hours**	**Start**	**Stop**	**Effec. Units/ Hour**	0	8	16	0	8	16	0	8	16	0	8	16
6	A	1	A/1	1500	65	23.1	A/0	#N/A	0/1 0:00	0/1 0:00	0.0	15/6 4:00	16/6 3:04	65	**260**	**520**	**520**	**200**								
6	B	1	B/1	2200	60	36.7	B/0	#N/A	0/1 0:00	0/1 0:00	0.0	16/6 3:04	17/6 15:44	60				**295**	**480**	**480**	**480**	**465**				
6	C	1	C/1	1900	75	25.3	C/0	#N/A	0/1 0:00	0/1 0:00	0.0	17/6 15:44	18/6 17:04	75								**19**	**600**	**600**	**600**	**81**
7	A	2	A/2	1500	105	14.3	A/1	14	15/6 5:00	16/6 4:04	1.0	15/6 5:00	16/6 4:04	65	**195**	**520**	**520**	**265**								
7	B	2	B/2	2200	95	23.2	B/1	15	16/6 4:04	17/6 16:44	0.0	16/6 4:04	17/6 16:44	60				**235**	**480**	**480**	**480**	**480**	**45**			
7	C	2	C/2	1900	110	17.3	C/1	16	17/6 16:44	18/6 18:04	0.0	17/6 16:44	18/6 18:04	75									**544**	**600**	**600**	**156**
8	A	3	A/3	1500	80	18.8	A/2	17	15/6 6:00	16/6 5:04	2.0	15/6 6:00	16/6 5:04	65	**130**	**520**	**520**	**330**								
8	B	3	B/3	2200	85	25.9	B/2	18	16/6 5:04	17/6 17:44	0.0	16/6 5:04	17/6 17:44	60				**175**	**480**	**480**	**480**	**480**	**105**			
8	C	3	C/3	1900	95	20.0	C/2	19	17/6 17:44	18/6 19:04	0.0	17/6 17:44	18/6 19:04	75									**469**	**600**	**600**	**231**

Although the second operation can start 1 after the first, it is faster and will quickly catch up. Work Centre 7 will then keep stopping to wait for products from the slower Work Centre 6 and that is why the effective speed in units per hour is so much less than the rated speed. This is a typical “PUSH” schedule.

2.5. Pull and Push schedule

A Pull Schedule

Let's go back to the very simple schedule. It says:
"If I start now (at hour zero), when will the last job stop?"

To turn it into a pull schedule, it should say:
“If all the jobs are required in 2 days (at hour 48), when do I need to start?”

Jobs required at hour:			48
Jobs	**Hours**	**Start**	**Stop**
A	7	12	19
B	5	19	24
C	4	24	28
D	12	28	40
E	8	40	48

You can see that each job is dependant on the one after it, and time cascades upwards.

What if we now changed the question to:
“If all the jobs are required in 1 day (at hour 24), when do I need to start?”

Change the "Jobs required at hour" from 48 to 24, and you will see that we would need to have started at hour -12, half a day ago. In this case the nature of the question changes, and reverts back to the push question:
"If I start now (at hour zero), when will the last job stop?"

What is needed is a schedule that will handle both push and pull logic, and apply the appropriate one.

Push and Pull Schedule

Here is the push logic from before section along side the pull logic. By testing the 1st start of the pull, it decides which of the two to apply:

Jobs required at hour:			32				
		Push		**Pull**		**Apply**	
Jobs	**Hours**	**Start**	**Stop**	**Start**	**Stop**	**Start**	**Stop**
A	7	0	7	-4	3	0	7
B	5	7	12	3	8	7	12
C	4	12	16	8	12	12	16
D	12	16	28	12	24	16	28
E	8	28	36	24	32	28	36

You will notice that the push logic adds the hours to get the stop, whereas the pull logic works backwards, and subtracts the hours to get the start.

Stop of last job: 15/6 23:00

W/C	Jobs	Op	Job/Op	Hours	Next Op	Next Op Row	Start of Next Op	Wait hours	Start	Stop	15/6			16/6			17/6			18/6		
											0:00	8:00	16:00	0:00	8:00	16:00	0:00	8:00	16:00	0:00	8:00	16:00
6	A	1	A/1	19	A/2	26	15/6 17:00	0	15/6 8:00	16/6 3:00		8	8	3								
6	B	1	B/1	22	B/2	27	16/6 1:00	0	16/6 3:00	17/6 1:00				5	8	8	1					
6	C	1	C/1	17	C/2	28	16/6 20:00	2	17/6 3:00	17/6 20:00							5	8	4			
7	A	2	A/2	8	A/3	29	16/6 2:00	0	16/6 17:00	17/6 1:00						7	1					
7	B	2	B/2	14	B/3	30	16/6 15:00	0	17/6 1:00	17/6 15:00							7	7				
7	C	2	C/2	6	C/3	31	17/6 2:00	5	17/6 20:00	18/6 2:00									4	2		
8	A	3	A/3	13	A/4	#N/A	17/6 23:00	0	17/6 2:00	17/6 15:00							6	7				
8	B	3	B/3	11	B/4	#N/A	17/6 23:00	0	17/6 15:00	18/6 2:00								1	8	2		
8	C	3	C/3	21	C/4	#N/A	17/6 23:00	0	18/6 2:00	18/6 23:00										6	8	7

Although the first start and the last stop is the same on both schedules, the work centers spend less time waiting between jobs on the pull schedule.

Repetitive Production through Multiple Work Centers - Pull Schedule

The next operation can start 1 h after the start of previous operation

Stop of last job: 18/6 19:04

W/C	Prod	Op	Prod/Op	Qty	Units per Hour	Hours	Next Op	Next Op Row	Start of Next Op -Lag	Stop of Next Op -Lag	Wait hours	Start	Stop	Effect. Units/ Hour	15/6			16/6			17/6			18/6		
															0	8	16	0	8	16	0	8	16	0	8	16
6	A	1	A/1	1500	65	23.1	A/2	26	16/6 0:26	16/6 19:11	0.0	15/6 4:00	16/6 3:04	65	260	520	520	200								
6	B	1	B/1	2200	60	36.7	B/2	27	16/6 19:11	17/6 21:04	0.0	16/6 3:04	17/6 15:44	60				295	480	480	480	465				
6	C	1	C/1	1900	75	25.3	C/2	28	17/6 21:04	18/6 17:04	0.0	17/6 15:44	18/6 17:04	75								19	600	600	600	81
7	A	2	A/2	1500	105	14.3	A/3	29	16/6 1:26	16/6 20:11	0.0	16/6 1:26	16/6 20:11	80				524	640	336						
7	B	2	B/2	2200	95	23.2	B/3	30	16/6 20:11	17/6 22:04	0.0	16/6 20:11	17/6 22:04	85						323	680	680	517			
7	C	2	C/2	1900	110	17.3	C/3	31	17/6 22:04	18/6 18:04	0.0	17/6 22:04	18/6 18:04	95									183	760	760	197
8	A	3	A/3	1500	80	18.8	A/4	#N/A	18/6 19:04	18/6 19:04	0.0	16/6 2:26	16/6 21:11	80				444	640	416						
8	B	3	B/3	2200	85	25.9	B/4	#N/A	18/6 19:04	18/6 19:04	0.0	16/6 21:11	17/6 23:04	85						238	680	680	602			
8	C	3	C/3	1900	95	20.0	C/4	#N/A	18/6 19:04	18/6 19:04	0.0	17/6 23:04	18/6 19:04	95									88	760	760	292

Again the entire schedule stops and starts at the same times, but the work centers don't start until they need to, and the effective run rates, in units per hour, are higher.

Push Pull Push - 3 Pass Logic

In previous section we had a series of jobs that were all required at the same time, but here we consider jobs with different required times. We will start with a simple example of job A required in 24 hours, and job B required 48 hours from now. The objective is to try and meet the due date of each job, but to start each job just in time. The logic works in 3 passes, and “shuffles” the jobs taking into consideration the following:

- the start of the schedule (hour zero)
- the length of the job in hours
- when the job is due
- the stop of the previous job
- the start of the next job

			Push 1		**Pull**		**Push 2**			Day 1			Day 2		
Jobs	**Hours**	**Due**	**Start**	**Stop**	**Start**	**Stop**	**Start**	**Stop**	0	8	16	24	32	40	48

In the first pass job A starts now, and job B starts immediately after that:

A	32	24	**0**	**32**											
B	8	48	**32**	**40**											

In the second pass each job stops when it is due, so job A would need to have started 8 h ago:

A	32	24	0	32	**- 8**	**24**									
B	8	48	32	40	**40**	**48**									

The third pass pushes job A later so that it starts at hour zero:

A	32	24	0	32	- 8	24	**0**	**32**							
B	8	48	32	40	40	48	**40**	**48**							

2.6. Johnson algorithm

Exercise 01

In one unit of an enterprise it is made 7 products (P1 to P7) on 2 machines (M1 and M2). Manufacturing times are presented in table 1.

Find the dispatching order of products that assure minimum of total manufacturing time.

Table 1.

Product / Machines	P1	P2	P3	P4	P5	P6	P7
M1	7	20	6	25	7	14	13
M2	14	15	8	4	8	20	15

Solution:

Johnson algorithm:

1. From all available operation time, pick the minimum. If the minimum corresponding to Pmin belongs to M1 line, add Pmin to end of list.
   If minimum belongs to M2 line, add Pmin to beginning of list.

2. Repeat step 1 until all product are add in optimum sequence

For our case the minimum time is 4 for P4 product for machine M2, Thus product P4 will be the last to do in our sequence. Next minimum is 6 for P3 for M1, thus P3 will be the first in our sequence. In this way the optimum sequence will be: P3, P1, P5, P7, P6, P2, P4.

Table 2.

Product / Machines	P3	P1	P5	P7	P6	P2	P4
M1	6	7	7	13	14	20	25
M2	8	14	8	15	20	15	4
Manufacturing time	14	21	15	28	34	35	29

<u>Exercise 02</u>

In one unit of an enterprise it is made 7 products (P1 to P7) on 3 machines (M1, M2 and M3). Manufacturing times are presented in table 4.

Find the dispatching order of products that assure minimum of total manufacturing time.

Table 3.

Product / Machines	P1	P2	P3	P4	P5	P6	P7
M1	17	19	20	22	18	19	20
M2	15	17	11	14	9	7	13
M3	17	14	18	12	21	21	15

Solution:

Add the times corresponding to M1 and M2 in one line (so we will have a fictive machine “M1+M2”) and the times corresponding to M2 and M3 in other line (second fictive machine “M2+M3”), like in table 4, and apply Johnson algorithm as.

Table 4.

Product / Machines	P1	P2	P3	P4	P5	P6	P7
M1 + M2	32	36	31	36	27	26	33
M2 + M3	32	31	29	26	30	28	28

The optimum sequence will be: P6, P5, P1, P2, P3, P7, P4.

<u>Proposed exercise 03</u>:

In one unit of an enterprise it is made 5 products (P1 to P5) on 3 machines (M1, M2 and M3). Manufacturing times are presented in table 5.

Find the dispatching order of products that assure minimum of total manufacturing time.

Table 5.

Product / Machines	P1	P2	P3	P4	P5
M1	6	8	4	3	5
M2	5	3	2	2	5
M3	5	7	8	11	9

2.7. Forward and Backward algorithm

<u>Exercise 04</u>

In one unit of an enterprise it is made 4 products (P1 to P4) on 5 machines (M1 to M5). Manufacturing times, liberation time for machines, operations succession, deadline for products and the cost of the products are presented in table 6.

Schedule the product execution so they meet the deadline with efficient machines utilization.

Table 6

	Liberation time	**P1**		**P2**		**P3**		**P4**	
		Succession	**Duration**	**Succession**	**Duration**	**Succession**	**Duration**	**Succession**	**Duration**
M1	15	2	5	2	15	3	10	-	-
M2	7	1	10	4	20	2	20	2	5
M3	20	5	15	-	-	1	30	1	10
M4	24	3	12	1	5	5	15	3	15
M5	3	4	20	3	15	4	10	4	20
Total product time			62		55		85		50
Deadline		237		182		160		160	
Cost		1.200		905		900		1.300	

Solution:

a) Downward algorithm

The earliest level 1 is for P1 thus we will start with P1.

We recalculate the machines liberation time:

$T_{12} = 7 + 10 = 17$
$T_{11} = \max(15; 17) + 5 = 22$
$T_{14} = \max(24; 22) + 12 = 36$
$T_{15} = \max(3; 36) + 20 = 56$
$T_{13} = \max(20; 56) + 15 = 71$

Next, the liberation time for P2 is 36, for P3 is 71 and for P4 is 71, thus we continue with P2:

$T_{24} = \max(36; 0) + 5 = 41$
$T_{21} = \max(22; 41) + 15 = 56$
$T_{25} = \max(56; 56) + 15 = 71$
$T_{22} = \max(17; 71) + 20 = 91$

Next we have P3 and P4 with the same liberation time but we continue with P4 considering the next criterion: biggest product cost (1300 vs. 900):

$T_{43} = \max(71; 0) + 10 = 81$
$T_{52} = \max(91; 81) + 5 = 96$
$T_{44} = \max(41; 96) + 15 = 111$
$T_{45} = \max(71; 111) + 20 = 131$

The last it came P3.

$T_{33} = \max(71; 0) + 10 = 81$
$T_{32} = \max(71; 0) + 10 = 81$
$T_{31} = \max(91; 81) + 5 = 96$

T_{35} = max (41; 96) + 15 = 111
T_{34} = max (71; 111) + 20 = 131

The sequence **P1-P2-P4-P3** lead to the following time reserves:
P1: 237 – 71 = 166
P2: 182 – 91 = 91
P3: 160 – 166 = –6
P4: 160 – 131 = 29

For product P3 we have a delay so the sequence is not favorable and can’t be accepted. We can propose a new sequence based on reserves in a descending order: **P3-P4-P2-P1**:

T_{33} = max (20; 0) + 30 = 50
T_{32} = max (7; 50) + 20 = 70
T_{31} = max (15; 70) + 10 = 80
T_{35} = max (3; 80) + 10 = 90
T_{34} = max (24; 90) + 15 = 105

T_{43} = max (50; 0) + 10 = 60
T_{42} = max (60; 70) + 5 = 75
T_{44} = max (105; 75) + 15 = 120
T_{45} = max (90; 120) + 20 = 140

T_{24} = max (120; 0) + 5 = 125
T_{21} = max (80; 125) + 15 = 140
T_{25} = max (140; 240) + 15 = 155
T_{22} = max (75; 155) + 20 = 175

T_{12} = max (175; 0) + 10 = 185
T_{11} = max (140; 185) + 5 = 190
T_{14} = max (125; 190) + 12 = 202
T_{15} = max (155; 202) + 20 = 222
T_{13} = max (60; 222) + 15 = 237
In this sequence there is no delay, but there is waiting time for the machines.

b) Upward algorithm

The sequence is proposed so that we have the descending order of liberation time:
P1 (237) – **P2** (182) – **P4** (160) – **P3** (160)
(P4 is before P3 because of the higher product cost)
We recalculate the machines liberation time in upstream:
T_{13} = 237 – 15 = 22
T_{15} = 222 – 20 = 202
T_{14} = 202 – 12 = 190
T_{11} = 190 – 5 = 185
T_{12} = 185 – 10 = 175

T_{22} = min (120; 0) + 5 = 125
T_{25} = max (80; 125) + 15 = 140
T_{21} = max (140; 240) + 15 = 155
T_{24} = max (75; 155) + 20 = 175

T_{45} = max (50; 0) + 10 = 60
T_{44} = max (60; 70) + 5 = 75
T_{42} = max (105; 75) + 15 = 120
T_{43} = max (90; 120) + 20 = 140

T_{34} = max (20; 0) + 30 = 50
T_{35} = max (7; 50) + 20 = 70
T_{31} = max (15; 70) + 10 = 80
T_{32} = max (3; 80) + 10 = 90
T_{33} = max (24; 90) + 15 = 105

The launching time for P3 is the same with the liberation time for M3 which is possible.

Proposed exercise 05
In one unit of an enterprise it is made 2 products (P1 and P2) on 5 machines (A, B, C, D and E). Manufacturing times and operations succession are presented in table 7. Schedule the product execution for a minimum total time. What are the waiting time for machines and waiting time for products?

Table 7

	P1		**P2**	
	Succession	Duration	Succession	Duration
A	A	4	A	2
B	B	3	D	2
C	C	1	C	4
D	D	3	B	2
E	E	2	E	2

2.8. Next-Best (NB) Algorithm

Exercise 05
In one unit of an enterprise it is made 7 products (P1 to P7) on one machine. The machine setup times for the products passing through the same machine are presented in table 8 (P1 is first product to process). What is the production launching order for a minimum total setup time?

Table 8.

Product \ **Product**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**
P1	-	1,68	1,47	1,62	1,39	1,55	1,56
P2	-	-	1,52	1,76	1,23	1,52	1,71
P3	-	1,45	-	1,73	1,41	1,46	1,83
P4	-	1,63	1,51	-	1,38	1,61	1,75
P5	-	1,59	1,41	1,85	-	1,65	1,86
P6	-	1,72	1,43	1,57	1,27	-	1,89
P7	-	1,42	1,36	1,58	1,32	1,47	-

Solution:

a) Basic NB – the next product is the one with the shortest setup time after the production of precedent product.
From the table 6 we see that P1 have the shortest setup time (1,39). We reduce the table 6 by eliminating the column of P1 and seek again for the product with shortest setup time until all products are finally in the specific order: **P1-P5-P3-P2-P6-P4-P7**.
We have for this sequence the total setup time: **9,09**.

b) NB with variable origin – analyze n-1 sequences with the any second product:

S_1: P1-P2-P5-P3-P6-P4-P7 = 9,10 (total setup time)
S_2: P1-P3-P5-P2-P6-P4-P7 = 9,31
S_3: P1-P4-P5-P3-P2-P6-P7 = 9,27
S_4: P1-P5-P3-P2-P6-P4-P7 = 9,09
S_5: P1-P6-P5-P2-P3-P4-P7 = 9,41
S_6: P1-P7-P5-P3-P2-P6-P4 = 8,93

The shortest total setup time is 8,93 for the sequence S_6.

c) **NB with columns reduction –** that means finding the shortest setup time for every column and subtracting it from each element of that column and then applying basic NB algorithm on this table. In table 9 we have the reduced columns.

Table 9

Product \ Product	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**
P1	-	0,26	0,11	0,05	0,16	0,09	0
P2	-	-	0,16	0,19	0	0,06	0,15
P3	-	0,03	-	0,16	0,18	0	0,27
P4	-	0,21	0,15	-	0,15	0,15	0,19
P5	-	0,17	0,05	0,28	-	0,19	0,30
P6	-	0,30	0,07	0	0,04	-	0,33
P7	-	0	0	0,01	0,09	0,01	-

We will have 2 sequences (because of two minimum shortest values in one line):

S_1: P1-P7-P2-P5-P3-P6-P4 = 8,75
S_2: P1-P7-P3-P6-P4-P5-P2 = 9,00

2.9. Sequential programming algorithm

Exercise 06
In one unit of an enterprise it is made 3 products (P1, P2 and P3) on 4 machines (M1 to M4). The products processing times and liberation time for the machines are presented in table 10.
What is the order of launching in production for a minimum total time?

Table 10.

Product \ Product	M1	M2	M3	M4
P1	2	7	4	9
P2	4	8	4	11
P3	5	4	7	6
Liberation time	2	3	6	12

Solution:

Table 11.

Product \ Product	M1	M2	M3	M4
P1	2	7	4	9
P2	4	8	4	11
P3	5	4	7	6
Liberation time	2	3	6	12
Start time 1	2	4	11	15
Waiting time 1	0	1	5	3
Total waiting time 1	9			
Start time 2	2	6	14	18
Waiting time 2	0	3	8	6
Total waiting time 2	17			
Start time 3	2	7	11	18
Waiting time 3	0	3	8	6
Total waiting time 3	15			
Min Total waiting time	9	→	P1	

Table 12.

Product \ Product	M1	M2	M3	M4
P1	0	0	0	0
P2	4	8	4	11
P3	5	4	7	6
Liberation time’	4	11	15	24
Start time 2	4	11	19	24
Waiting time 2	0	0	4	0
Total waiting time 2	4			
Start time 3	4	11	15	24
Waiting time 3	0	0	0	0
Total waiting time 3	0			
Min Total waiting time	0	→	P3	

The sequence will be: **P1-P3-P2**

2.10. Priority rules used in scheduling

Proposed exercise 07

In one unit of an enterprise it is made 5 products (P1 to P5). The products processing times and due-time for the machines are presented in table 13.

What is the order of launching in production using priority rules?

Table 13.

Time / Product	Processing time	Due-time
P1	3	5
P2	4	6
P3	2	7
P4	6	9
P5	1	2

Solution:

We will calculate the following quality indicators of sequences:

T_{tot} – total time for all products in process
T_{med} – total medium time for one product
R/D – total reserve/delay
NDP – Number of Delayed Product
D_{med} – medium delay per product

5.1. FIFO (First In First Out)

Table 14.

Time / Product	Processing time	Due-time	Total time	R/D

T_{tot}	
T_{med}	
NDP	
R/D	
D_{med}	

5.2. SPT (Shortest Processing Time)

Table 15.

Time / Product	Processing time	Due-time	Total time	R/D

T_{tot}	
T_{med}	
NDP	
R/D	
D_{med}	

5.3. EDD (Earliest Due-Date)

Table 16.

Time / Product	Processing time	Due-time	Total time	R/D

T_{tot}	
T_{med}	
NDP	
R/D	
D_{med}	

5.4. LIFO (Latest In First Out)

Table 17.

Time / Product	Processing time	Due-time	Total time	R/D

T_{tot}	
T_{med}	

NDP	
R/D	
D_{med}	

5.5. LSF (Latest Start First)

Table 18.

Time / Product	**Processing time**	**Due-time**	**Latest start**	**Total time**	**R/D**

T_{tot}	
T_{med}	
NDP	
R/D	
D_{med}	

5.6. STR (Slack Time Remaining)

Table 19. **Step 1**: $TF_{i-1} = 0$

Time / Product	**Processing time**	**Due-time**	**Slack time**
P1	3	5	
P2	4	6	
P3	2	7	
P4	6	9	
P5	1	2	

First product is P___.

Table 19. **Step 2**: $TF_{i-1} = 0 + t\_\_\_ = 0 + \_\_\_ =$

Time / Product	**Processing time**	**Due-time**	**Slack time**

Second product is P___ .

Table 19. **Step 3**: TF_{i-1} = ___ + t___ =

Time / Product	Processing time	Due-time	Slack time

Third product is P___.

Table 19. **Step 4**: TF_{i-1} = ___ + t___ =

Time / Product	Processing time	Due-time	Slack time

The fourth product is P___ and the last product is P___.

Table 20.

Time / Product	Processing time	Due-time	Total time	R/D

T_{tot}	
T_{med}	
NDP	
R/D	
D_{med}	

5.7. STR/T (Slack Time Remaining/Task)

Table 21. **Step 1**: $TF_{i-1} = 0$

Time / Product	Processing time	Due-time	STR/T
P1	3	5	
P2	4	6	
P3	2	7	
P4	6	9	
P5	1	2	

First product is P___.

Table 21. **Step 2**: $TF_{i-1} = 0 + t\_\_ = 0 + \_\_\_ =$

Time / Product	Processing time	Due-time	STR/T

Second product is P___.

Table 21. **Step 3**: $TF_{i-1} = \_\_\_ + t\_\_\_ =$

Time / Product	Processing time	Due-time	STR/T

Third product is P___.

Table 21**. Step 4**: $TF_{i-1} = 4 + t_2 = 4 + 4 = 8$

Time / Product	Processing time	Due-time	STR/T

The fourth product is P___ and the last product is P___.

Table 22.

Time / Product	Processing time	Due-time	Total time	R/D

T_{tot}	
T_{med}	
NDP	
R/D	
D_{med}	

5.8. CR (Critical Ratio)

Table 23. **Step 1**: $TF_{i-1} = 0$

Time / Product	Processing time	Due-time	CR
P1	3	5	
P2	4	6	
P3	2	7	
P4	6	9	
P5	1	2	

First product is P___.

Table 23. **Step 2**: TF_{i-1} = 0 + t__ = 0 + ___ =

Time / Product	Processing time	Due-time	CR

Second product is P___.

Table 23. **Step 3**: TF_{i-1} = ___ + t___ =

Time / Product	Processing time	Due-time	CR

Third product is P___.

Table 23**. Step 4**: TF_{i-1} = ___ + t___ =

Time / Product	Processing time	Due-time	CR

The fourth product is P___ and the last product is P___.

Table 24.

Time / Product	Processing time	Due-time	Total time	R/D

T_{tot}	
T_{med}	
NDP	
R/D	
D_{med}	

5.9. RANDOM

Table 25.

Time / Product	Processing time	Due-time	Total time	R/D
P4	6	9		
P3	2	7		
P1	3	5		
P5	1	2		
P2	4	6		

T_{tot}	
T_{med}	
NDP	
R/D	
D_{med}	

Table 26. All algorithm rules

Indicators / Rules	T_{tot}	T_{med}	NDP	R/D	D_{med}
1. FIFO					
2. SPT					
3. EDD					
4. LIFO					
5. LSF					
6. STR					
7. STR/T					
8. CR					
9. RANDOM					

Conclusions ?

Questions:
1. Which are the steps of production activity control? **2.** What is scheduling in industrial systems? **3.** What is queue management? **4.** What are splitting and overlapping methods? **5.** What scheduling methods do you know? **6.** When you can use a specific priority rule?

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Module M04

Inventory Management

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Learning objectives:
⇒ to understand basic principles of inventory management ⇒ to get familiar with economic order quantity model ⇒ to understand the principles of using safety stocks ⇒ to know how to estimate the time of new order ⇒ to get familiar purchasing management ⇒ to know how to organize purchasing

1. INVENTORY MANAGEMENT

1.1. BASIC PRINCIPLES

Inventory - Stock of items held to meet future demand

- ✓ Inventory management answers two questions
  - ✓ How much to order
  - ✓ When to order

Reasons to Hold Inventory
- ✓ Meet unexpected demand;
- ✓ Smooth seasonal or cyclical demand;
- ✓ Meet variations in customer demand;
- ✓ Take advantage of price discounts;
- ✓ Hedge against price increases;
- ✓ Quantity discounts.

Inventory Costs

- ✓ Carrying Cost
  - ✓ Cost of holding an item in inventory
- ✓ Ordering Cost
  - ✓ Cost of replenishing inventory
- ✓ Shortage Cost
  - ✓ Temporary or permanent loss of sales when demand cannot be met

Example

- A company carries an average annual inventory of €200,000. If they estimate the cost of capital is 10%, storage cost of 7%, and risk costs are 6%, what does it cost per year to carry inventory.
- Total cost of carrying inventory =
- Annual cost of carrying inventory =

Inventory Control Systems

- ✓ Continuous system (fixed-order-quantity)
  - ✓ Constant amount ordered when inventory declines to predetermined level
- ✓ Periodic system (fixed-time-period)
  - ✓ Order placed for variable amount after fixed passage of time

Discussion

THE MARKS &SPENCER APPROACH

A special case of the 'how much to order?' decision in inventory control is the 'Should we order any more at all?' decision. Retailers especially need continually to review the stocked lines they keep on the shelves. One company known for its ruthless approach to the restocking decision is Marks & Spencer (M & S), which is one of the most successful large retailers in Europe in terms of the profitability of its operations. M & S has a simple philosophy: if it sells, restock it quickly and avoid stock-outs; if it doesn't sell, get it off the shelves quickly and replace it with something which will sell. The M & S approach is purely pragmatic, based on trial-and-error, and very unsentimental. This often means putting a new line on the shelves of a pilot store and watching customer reaction very closely. The store most often used for these trials is the company's Marble Arch store in London - said to have the fastest stock turnover of any store in the world. Sometimes it is possible to make a restocking decision within a few hours - not surprising when the time frame for stock rotation can be as little as a week.

For more routine stock control decisions the company uses an automatic stock-ordering system which it calls ASR (Assisted Stock Replenishment). This helps always to have the right stock of textile products in the store at the right time. The system, which is now installed in its flagship Marble Arch store, takes into account all goods bought at the till through the electronic point-of-sale (EPOS) system and automatically generates an order to replenish that item. The system anticipates orders for each item based on the previous week's sales and delivers in advance. The current day's sales are continually reviewed and any extra items required are delivered the next day. Orders arrive at the store from the local distribution centre at Neasden in North London. New orders are usually placed before 8.30 am and 85 per cent of these will arrive before close of business that day. The remainder arrives the following morning before opening time. The number of deliveries each day varies between 14 and 24 depending on the level of business.

On the sales floor the main stock control tasks are to ensure that all the clothing rails are fully stocked, that the stock tickets reflect the sales information on display and that everything is neatly and correctly arranged. During the day the area supervisor watches the stock levels and the flow of customers around the displays in case any changes to stock location need to be made. The store has a policy of not bringing stock out on to the floor during opening hours; but in the case of fast-moving items, this can at times be unavoidable.

Questions

1. Why is it particularly important for retail operations such as Marks & Spencer to make judgments quickly about how well a product is likely to sell?
2. What do you see as the major advantages of using the electronic point-of-sale (EPOS) system?
3. What kind of inventory policy seems to operate in Marks & Spencer's stores?

1.2. ECONOMIC ORDER QUANTITY (EOQ) MODEL

Economic order quantity is the level of inventory that minimizes the total inventory holding costs and ordering costs. The framework used to determine this order quantity is also known as Wilson EOQ Model. The model was developed by F. W. Harris in 1913. But still R. H. Wilson is given credit for his early in-depth analysis of the model.

Assumptions of Basic EOQ Model

- ✓ Demand is known with certainty and is constant over time
- ✓ No shortages are allowed
- ✓ Lead time for the receipt of orders is constant
- ✓ The order quantity is received all at once

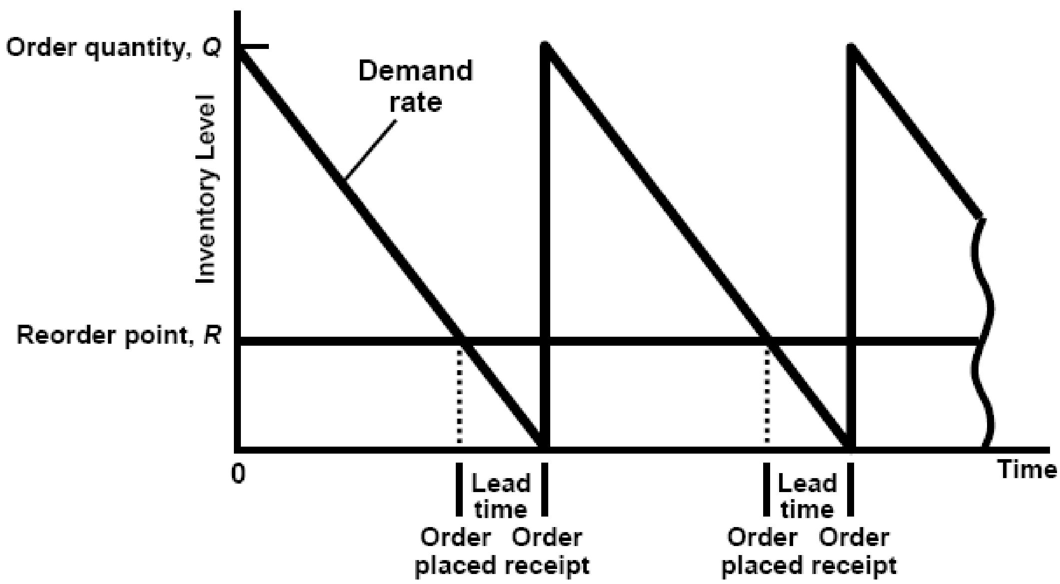

Fig. 1.1. The Inventory Order Cycle

EOQ Cost Model

Total Cost = purchase cost + ordering cost + carrying cost

- Purchase cost: This is the variable cost of goods: purchase unit price × annual demand quantity. This is P×D

- Ordering cost: This is the cost of placing orders: each order has a fixed cost C, and we need to order D/Q times per year. This is C × D/Q

- Carrying cost: the average quantity in stock (between fully replenished and empty) is Q/2, so this cost is H × Q/2

$$\text{Annual ordering cost} = \frac{C_o D}{Q}$$

$$\text{Annual carrying cost} = \frac{C_c Q}{2}$$

$$\text{Total cost} = \frac{C_o D}{Q} + \frac{C_c Q}{2}$$

Co - cost of placing order D - annual demand
Cc - annual per-unit carrying cost Q - order quantity

Deriving Q_{opt}

$$TC = \frac{C_o D}{Q} + \frac{C_c Q}{2}$$

$$\frac{\partial TC}{\partial Q} = \frac{C_o D}{Q^2} + \frac{C_c}{2}$$

$$0 = \frac{C_0 D}{Q^2} + \frac{C_c}{2}$$

$$Q_{opt} = \sqrt{\frac{2C_o D}{C_c}}$$

Proving equality of costs at optimal point

$$\frac{C_o D}{Q} = \frac{C_c Q}{2}$$

$$Q^2 = \frac{2C_o D}{C_c}$$

$$Q_{opt} = \sqrt{\frac{2C_o D}{C_c}}$$

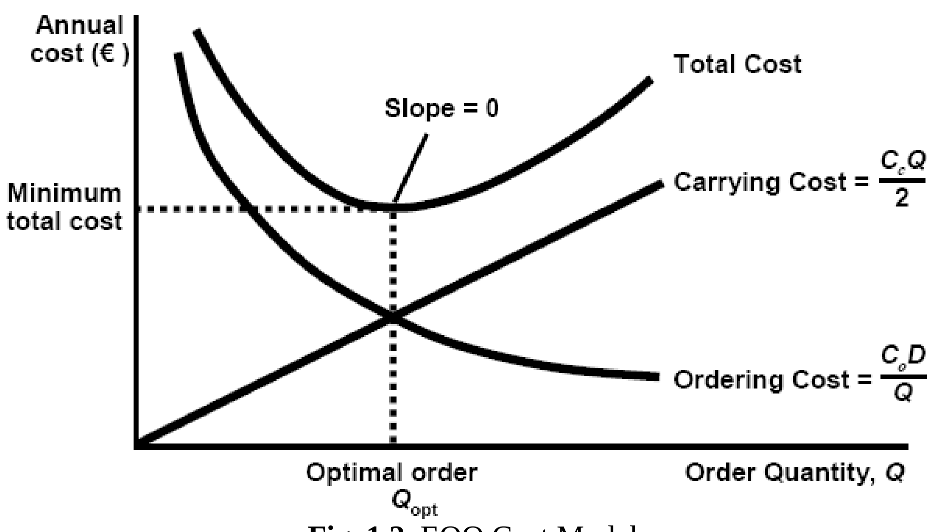

Fig. 1.2. EOQ Cost Model

Example

$$C_c = € \; 0.75 \text{ per m} \qquad C_o = € \; 150 \qquad D = 10{,}000 \text{ m}$$

$$Q_{opt} = \sqrt{\frac{2C_oD}{C_c}} \qquad TC_{min} = \frac{C_oD}{Q} + \frac{C_cQ}{2}$$

$$Q_{opt} = \sqrt{\frac{2(150)(10{,}000)}{(0.75)}} \qquad TC_{min} = \frac{(150)(10{,}000)}{2{,}000} + \frac{(0.75)(2{,}000)}{2}$$

$$Q_{opt} = 2{,}000 \text{ m} \qquad TC_{min} = € \; 750 + € \; 750 = € \; 1{,}500$$

$$\text{Orders per year} = D/Q_{opt} = 10{,}000/2{,}000 = 5 \text{ orders/year}$$

$$\text{Order cycle time} = 311 \text{ days}/(D/Q_{opt}) = 311/5 = 62.2 \text{ store days}$$

1.3. EOQ WITH NONINSTANTANEOUS RECEIPT

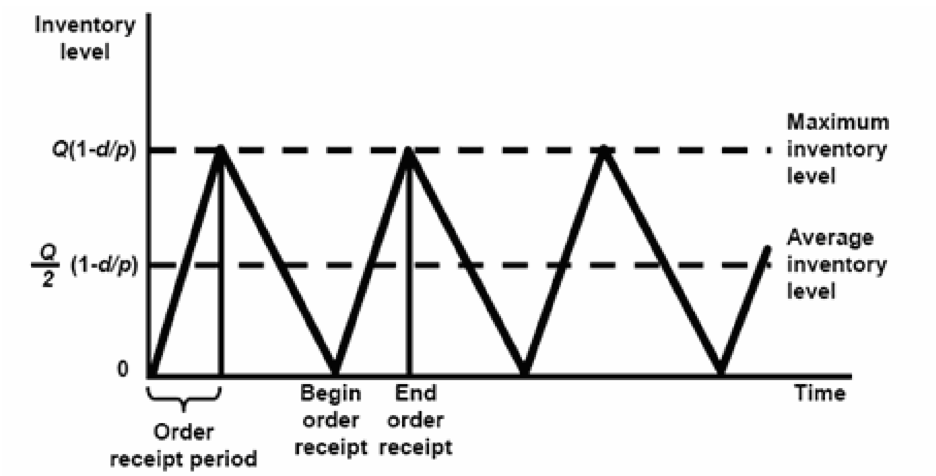

Fig.1.3. EOQ with noninstantaneous receipt

p = production rate $\quad$ d = demand rate

$$\text{Maximum inventory level} = Q - \frac{Q}{p}d = Q\left(1 - \frac{d}{p}\right)$$

$$\text{Average inventory level} = \frac{Q}{2}\left(1 - \frac{d}{p}\right)$$

$$Q_{opt} = \sqrt{\frac{2C_oD}{C_c\left(1 - \frac{d}{p}\right)}}$$

$$TC = \frac{C_oD}{Q} + \frac{C_cQ}{2}\left(1 - \frac{d}{p}\right)$$

Example

C_c = € 0.75 per m $\quad$ C_o = € 150 $\quad$ D = 10,000 m

d = 10,000/311 = 32.2 m per day $\quad$ p = 150 m per day

$$Q_{opt} = \sqrt{\frac{2C_oD}{C_c\left(1 - \frac{d}{p}\right)}} = \sqrt{\frac{2(150)(10{,}000)}{0.75\left(1 - \frac{32.2}{150}\right)}} = 2{,}256.8 \text{ m}$$

$$TC = \frac{C_oD}{Q} + \frac{C_cQ}{2}\left(1 - \frac{d}{p}\right) = €\ 1{,}329$$

$$\text{Production run} = \frac{Q}{p} = \frac{2{,}256.8}{150} = 15.05 \text{ days per order}$$

$$\text{Number of production runs} = \frac{D}{Q} = \frac{10{,}000}{2{,}256.8} = 4.43 \text{ runs/year}$$

$$\text{Maximum inventory level} = Q\left(1 - \frac{d}{p}\right) = 2{,}256.8\left(1 - \frac{32.2}{150}\right)$$
$$= 1{,}772 \text{ m}$$

1.4. QUANTITY DISCOUNTS

- ✓ **Price per unit decreases as order quantity increases**

$$TC = \frac{C_oD}{Q} + \frac{C_cQ}{2} + PD$$

P = per unit price of the item
D = annual demand

ORDER SIZE PRICE

0 – 99	€ 10
100 - 199	€ 8 (*d*1)
200+	€ 6 (*d*2)

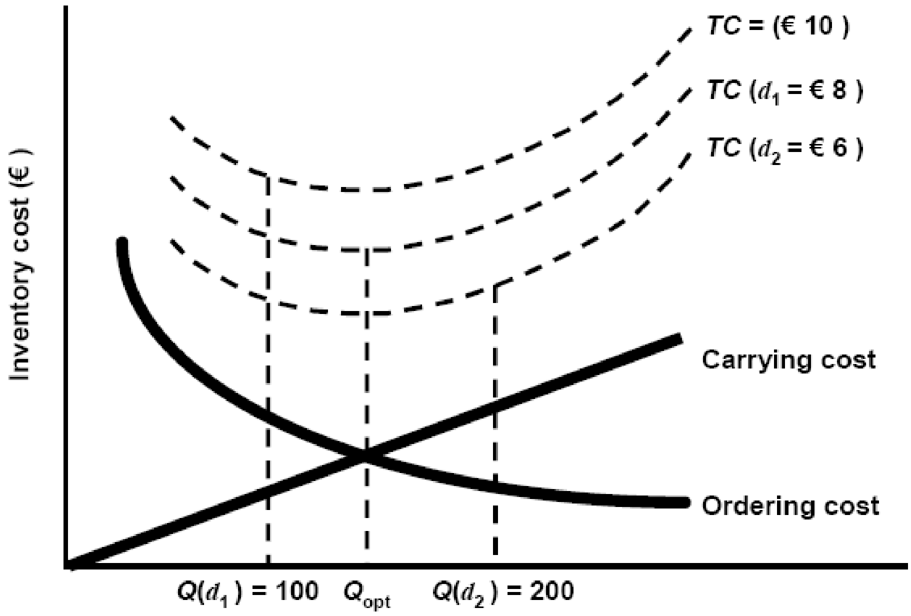

Fig. 1.4. Quantity Discount Model

QUANTITY	PRICE
1 - 49	€ 1,400
50 - 89	1,100
90+	900

C_o = € 2,500
C_c = € 190 per computer
D = 200

$$Q_{opt} = \sqrt{\frac{2C_oD}{C_c}} = \sqrt{\frac{2(2500)(200)}{190}} = 72.5 \text{ PCs}$$

For $Q = 72.5$

$$TC = \frac{C_oD}{Q_{opt}} + \frac{C_cQ_{opt}}{2} + PD = € \ 233{,}784$$

For $Q = 90$

$$TC = \frac{C_oD}{Q} + \frac{C_cQ}{2} + PD = € \ 194{,}105$$

1.5. WHEN TO ORDER

Definition: Reorder Point is the minimum level of inventory at which a new order is placed. The reorder point considers the time delay in receiving new inventory, the typical rate of inventory consumption, and the Stockout cost.

R* = *dL

where
***d* = demand rate per period**
***L* = lead time**

Example

Demand = 10,000 m/year

Store open 311 days/year

Daily demand = 10,000 / 311 = 32.154 m/day

Lead time = L = 10 days

R = dL = *(32.154)(10)* ***= 321.54 m***

Discussion

INTENTORY MANAGEMENT AT FLAME ELECTRICAL

Inventory management in some operations is more than just a part of their responsibility; it is their very reason for being in business. Flame Electrical, South Africa's largest independent supplier and distributor of lamps, is such a business. It stocks over 2900 different types of lamp which vary in value from 25 cents to over 7000 rand (€1100). The lamps, which are sourced from 14 countries including South Africa, are stored in a 5000 square meter warehouse, and distributed to customers throughout the country.

'In effect our customers are using us to manage their stocks of lighting sources for them,' says Jeff Schaffer, the Managing Director of Flame Electrical. *'They could, if they wanted to, hold their own stock but might not want to devote the time, space, money or effort to doing so. Using us they get the widest range of products to choose from, and an accurate, fast and dependable service.'*

Central to the company's ability to provide the service which its customers expect is its computerized stock management system. The system holds information on all of Flame's customers, the type of lamps they may order, the quality and brand of lamps they prefer, the price to be charged, the internal product codes which Flame uses to identify each item it stocks, and the location of each item in the warehouse. When a customer phones in to order, the computer system immediately accesses all this information, which is confirmed to the customer. This only leaves the quantity of each lamp required by the customer to be keyed in. The system then generates an instruction to the warehouse to pick and dispatch the order. This instruction includes the shelf location of each item. The system even calculates the location of each item in the warehouse which will minimize the movement of stock for warehouse staff.

Orders for the replenishment of stocks in the warehouse are triggered by a re-order point system. The reorder point is set for each stocked item depending on the likely demand for the product during the order lead time (forecast from the equivalent period's orders the previous year), the order lead time for the item (which varies from 24 hours to four months) and the variability of the lead time (from previous experience). The size of the replenishment order depends on the lamp being ordered. Flame prefers most orders to be for a whole number of container loads (the shipping costs for part-container loads being more expensive). However, lower order quantities of small or expensive lamps may be used. The order quantity for each lamp is based on its demand, its value and the cost of transportation from the suppliers. However, all this can be overridden in an emergency. If a customer, such as a hospital, urgently needs a particular lamp which is not in stock, the company will even use a fast courier to fly the item in from overseas - all for the sake of maintaining its reputation for high service levels.

'We have to get the balance right,' says Jeff Schaffer. *'Excellent service is the foundation of our success. But we could not survive if we did not control stocks tightly. After all we are carrying the cost of every lamp in our warehouse until the customer eventually pays for it. If stock levels were too high we just could not operate profitably. It is for that reason that we go as far as to pay*

incentives to the relevant staff based on how well they keep our working capital and stocks under control. ■

Questions

1. Define what you think the five performance objectives (quality, speed, dependability, flexibility and cost) mean for an operation such as Flame Electrical?
2. What are the most important of these performance objectives for Flame Electrical?
3. What seems to influence the stock replenishment policy of Flame Electrical?
4. How does this differ from conventional economic order quantity theory?

1.6. SAFETY STOCKS

Definitions. *Safety stock* is a term used to describe a level of extra stock that is maintained below the cycle stock to buffer against *stockouts*. Safety Stock (also called Buffer Stock) exists to counter uncertainties in supply and demand. Safety stock is defined as extra units of inventory carried as protection against possible *stockouts* (shortfall in raw material or packaging). By having an adequate amount of safety stock on hand, a company can meet a sales demand which exceeds the demand they forecasted without altering their production plan. It is held when an organization cannot accurately predict demand and/or lead time for the product. It serves as an insurance against stockouts.

Service level: the desired probability that a chosen level of safety stock will not lead to stock-out. Naturally, when the desired service level is increased, the required safety stock increases as well.

- ✓ *Safety stock*
  - ✓ *buffer added to on hand inventory during lead time*
- ✓ *Stockout*
  - ✓ *an inventory shortage*
- ✓ *Service level*
  - ✓ *probability that the inventory available during lead time will meet demand*

The amount of safety stock an organization chooses to keep on hand can dramatically affect their business. Too much safety stock can result in high holding costs of inventory. In addition, products which are stored for too long a time can spoil, expire, or break during the warehousing process. Too little safety stock can result in lost sales and, thus, a higher rate of customer turnover. As a result, finding the right balance between too much and too little safety stock is essential.

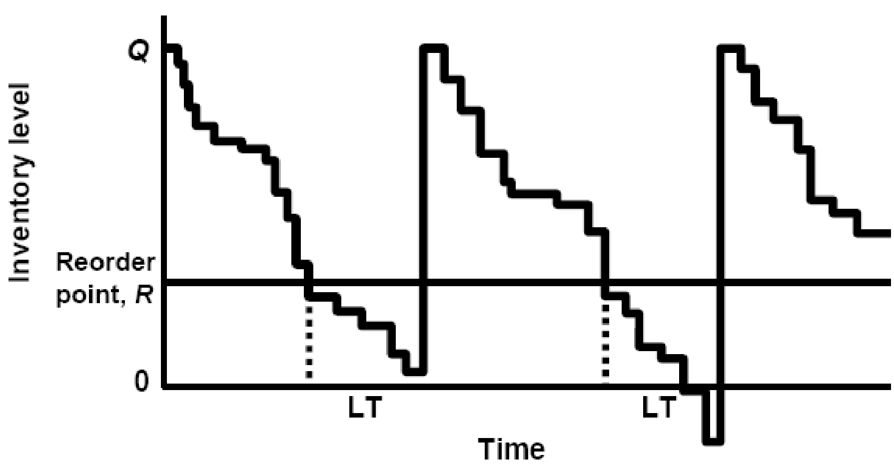

Fig. 1.5. Variable Demand with a Reorder Point

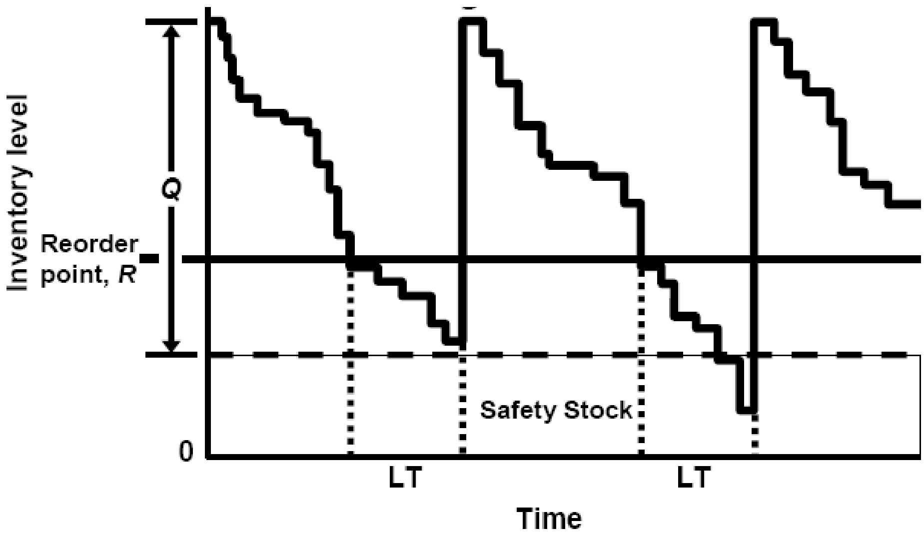

Fig. 1.6. Reorder Point with a Safety Stock

Reorder Point With Variable Demand

$$R = \bar{d}L + z\sigma_d\sqrt{L}$$

where

$\bar{d}$ = average daily demand
L = lead time
σ_d = the standard deviation of daily demand
z = number of standard deviations corresponding to the service level probability
$z\sigma_d\sqrt{L}$ = safety stock

Example

Period	Forecast demand	Actual demand	Deviation	Deviation Squared
1	1000	1200	200	40000
2	1000	1000	0	0
3	1000	800	-200	40000
4	1000	900	-100	10000
5	1000	1400	400	160000
6	1000	1100	100	10000
7	1000	1100	100	10000
8	1000	700	-300	90000
9	1000	1000	0	0
10	1000	800	-200	40000
Total	10000	10000	0	400000

Average of the squares of the deviation = 400,000 / 10 = 40,000
Sigma (σ) = Square root of 40,000 = 200 quantity of Safety stock, for 1 σ

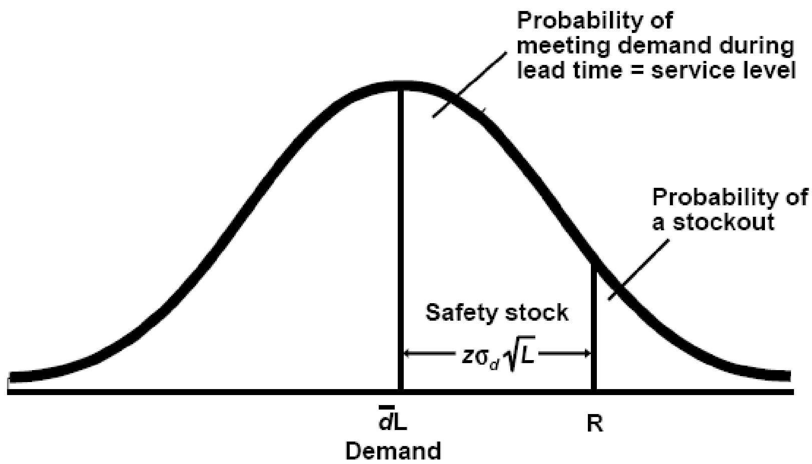

Fig. 1.7. Reorder Point for a Service Level

<u>Example</u>

Reorder Point for Variable Demand

The carpet store wants a reorder point with a 95% service level and a 5% stockout probability

$\bar{d}$ = 30 m per day
L = 10 days
σ_d = 5 m per day

For a 95% service level, z = 1.65

$$R = \bar{d}L + z\,\sigma_d\sqrt{L}$$
$$= 30(10) + (1.65)(5)(\sqrt{10})$$
$$= 326.1 \text{ m}$$

$$\text{Safety stock} = z\,\sigma_d\sqrt{L}$$
$$= (1.65)(5)(\sqrt{10})$$
$$= 26.1 \text{ m}$$

Order Quantity for a Periodic Inventory System

$$Q = \bar{d}(t_b + L) + z\sigma_d\sqrt{t_b + L} - I$$

where

d = average demand rate
t_b = the fixed time between orders
L = lead time
σ_d = standard deviation of demand
$z\sigma_d\sqrt{t_b + L}$ = safety stock
I = inventory level

Fixed-Period Model with Variable Demand

$$\bar{d} = 6 \text{ bottles per day}$$
$$\sigma_d = 1.2 \text{ bottles}$$
$$t_b = 60 \text{ days}$$
$$L = 5 \text{ days}$$
$$I = 8 \text{ bottles}$$
$$z = 1.65 \text{ (for a 95\% service level)}$$

$$Q = \bar{d}(t_b + L) + z\sigma_d \sqrt{t_b + L} - I$$
$$= (6)(60 + 5) + (1.65)(1.2)\sqrt{60 + 5} - 8$$
$$= 397.96 \text{ bottles}$$

Discussion

THE NATIONAL BLOOD SERVICE

In September 1994 a plea was transmitted on the national news in the UK for blood donors to give blood urgently. The empty racks in the blood storage bank on the television screens graphically portrayed the urgency of the request. Momentarily the National Blood Service had lost its continuing battle to balance the supply of blood with demand.

Blood and by-products need to be stored under a variety of conditions. Red blood cells, used for surgical procedures and to correct anemia, have to be stored at 4°C and have a shelf life of 35 days. Platelets, extracted from donated blood and used to treat leukemia and bone marrow transplants, have to be stored at 20-24°C and have a shelf life of only five days, during which time they have to be constantly agitated. Frozen fresh plasma is used for liver transplants and for massive transfusion operations. It has to be stored at between -30 and -40°C and has a shelf life of six months. In addition, blood can be categorized by two main systems or groups. The ABO group includes A, B, AB, and O. The rhesus group includes Rh-positive and Rh-negative. In addition there are many less common and more complex types of blood, often relating to ethnic groups. Giving a patient the wrong type of blood can be fatal. However, group O negative can be given to emergency patients before blood tests have been made. Because of this, hospitals like to stock O negative. However, O negative represents only eight per cent of the population whereas 12 per cent of blood issued is of this type.

Demand is affected significantly by accidents. One serious accident involving a cyclist used 750 units of blood, which completely exhausted the available supply (miraculously, he survived). Large-scale accidents usually generate a surge of offers from donors wishing to make immediate donations. There is also a more predictable seasonality to the donating of blood, however, with a low period during the summer vacation period.

Unless blood is controlled carefully, it can easily go past its 'use-by date' and be wasted. For some patients the control of the age of stored blood is critical. For example, new-born babies, the elderly, and patients whose immune systems have been suppressed so that they do not reject transplanted organs, are all prone to infection. Very fresh blood is therefore kept 'on hold' for these patients.

Questions

1. What are the factors which constitute inventory holding costs, order costs, and stock-out costs in a National Blood Service?
2. What makes this particular inventory planning and control example so complex?
3. How might the efficiency with which a National Blood Service controls its inventory affect its ability to collect blood?

4. What suggestions do you have which would help this kind of operation to manage its inventory?

1.7. REDUCING SAFETY STOCK

Safety stock is used as a buffer to protect organizations from stockouts caused by inaccurate planning or poor schedule adherence by suppliers. As such, its cost (in both material and management) is often seen as a drain on financial resources which results in reduction initiatives. In addition, time sensitive goods such as food, drink, and other perishable items could spoil and go to waste if held as safety stock for too long. Various methods exist to reduce safety stock, these includes better use of technology, increased collaboration with suppliers, and more accurate forecasting. In a lean supply environment, lead times are reduced which can help minimize safety stock levels thus reducing the likelihood and impact of stockouts.

Discussion

IT PAYS CUT OUT WASTE: THE CASA OF BUCK KNIVES

When Hoyt Buck started making hunting knives in the early years of the twentieth century, his competitors were other Kansas blacksmiths. One hundred years later, Buck Knives is up against companies from across the world, many of them based in countries where labour, utility and other costs are substantially below those in the US. Most companies in these circumstances send their manufacturing offshore. But Hoyt Buck's descendants were reluctant. Instead of exporting jobs to Asia, three years ago they started to import an Asian idea-the 'lean' manufacturing methods pioneered by Toyota.

The story shows, first, that the doctrines of the Toyota production system have spread far beyond the automotive sector. Fifteen years after the publication of The Machine That Changed the World, the book that popularized Toyota's management methods, the war against muda - Japanese for waste - is being fought across swaths of manufacturing industry and increasingly in services, too. Second, the experience of Buck Knives underlines that lean thinking can be a powerful weapon in the fight to keep manufacturing and other jobs in developed countries.

Lean thinking teaches managers to eradicate anything from the production process that does not add value for customers, including inventory. Instead of stockpiling goods in warehouses and praying that demand forecasts turn out to be accurate - the conventional 'push' model - lean manufacturers aim to produce only in response to firm orders. When an order is placed, raw materials are 'pulled' from the supply chain and down the production line as fast as possible. The result: high speed, no waste, low cost and a happy customer.

Irrespective of whether this ideal is achieved in practice, lean thinkers tend to be skeptical about the supposed benefits of sending jobs to low-wage economies. It is hard to run a low inventory, JIT supply chain when you are sourcing components from across the globe. What if the widgets required for tomorrow's production run are delayed by a typhoon or stuck for three days at the border? Besides, there is nothing lean about shipping steel, shoes or electronic components halfway around the world by container ship. Think of all that *muda* in time, capital and diesel fuel.

Another strand of lean thinking is the notion that frontline workers - whether on the production line or in customer service - are best placed to identify and solve problems. But they can do this only if they are very familiar with the products and can talk directly to the engineers and managers who are likely to be at the root cause of any problem. With this view, sending jobs offshore will result in fewer problems solved and unhappier customers in the long run.

Similarly, lean thinkers tend to be skeptical about the value of outsourcing jobs to contractors, even if the workers stay close by. Overheads may be reduced in the short-term, but learning opportunities are likely to be lost. At Buck Knives you can see these ideas in action. The old production line has been redesigned into a series of circular 'cells' that build knives from start to finish. The new layout minimizes the distance traveled by each product (less *muda*) and encourages communication among employees, allowing them to see the entire manufacturing process. This way of working makes it more likely that production bottlenecks or product defects will be recognized early and dealt with on the spot, says C.J. Buck, Chief Executive and great-grandson of the founder. There is less need for expensive (and sometimes oppressive) supervision.

In true Toyota style, Buck Knives last month staged a symposium for its suppliers to explore ways of improving co-operation. Running a JIT supply chain requires a higher degree of collaboration - and trust - than is usual among manufacturers used to carrying weeks or months of surplus inventory. 'Much of what we are doing today is making the company more like it was when my grandfather was running the business and everything was done on a handshake', says Mr Buck.

To be sure, lean thinking is no panacea. It is hard to learn and even harder to sustain. It has limits. Going lean was not sufficient to get Buck Knives' unit costs down to competitive levels. After more than 50 years in California, where Hoyt Buck moved in 1947, the company last year relocated to Idaho in search of lower overheads. While many of its products still carry a 'Made in the USA' stamp, its less expensive models are now made in Taiwan. And as every Chief Executive knows, a world-class cost structure and commitment to continuous improvement is only table stakes these days.

If Buck Knives wants to be around for another decade - let alone another century - it will have to come up with products that are consistently more desirable than the domestic and international competition. Innovation and inspiration must also be on the cutting edge.

Questions

1. What benefits in field of inventory management will get Buck Knives using lean manufacturing system?
2. Buck Knives sells most of its products through retail stores. What problems might this create for its lean manufacturing system?
3. Buck Knives manufactures a large number of different knives (visit http://www.buckknives.com). What challenges does this present for a lean manufacturing system?
4. What challenges would you envisage that Buck Knives has in ensuring a JIT supply of raw materials?

1.8. INVENTORY INFORMATION SYSTEMS

Most inventories of any significant size are managed by computerized systems. The many relatively routine calculations involved in stock control lend themselves to computerized support. This is especially so since data capture has been made more convenient through the use of bar-code readers and the point-of-sale recording of sales transactions. Many commercial systems of stock control are available, although they tend to share certain common functions. These include the following:

Updating stock records

Every time a transaction takes place (such as the sale of an item, or the movement of an item from a warehouse into a truck, or the delivery of an item into a warehouse) the position, status, and possibly value of the stock will have changed. This information needs recording so that operations managers can determine their current inventory status at any time.

Generating orders

The two major decisions we have described previously, namely how much to order and when to order, can both be made by a computerized stock control system. The first decision, setting the value of how much to order (Q), is likely to be taken only at relatively infrequent intervals. The system will hold all the information which goes into the economic order quantity formula but might periodically check to see if demand or order lead times, or any of the other parameters, have changed significantly and recalculate Q accordingly. The decision on when to order, on the other hand, is a far more routine affair which computer systems make according to whatever decision rules operations managers have chosen to adopt: either continuous review or periodic review. Furthermore, the systems can automatically generate whatever documentation is required, or even transmit the re-ordering information electronically through an electronic data interchange (EDI) system.

Generating inventory reports

Inventory control systems can generate regular reports of stock value for the different items stored, which can help management monitor its inventory control performance. Similarly, customer service performance, such as the number of stock-outs or the number of incomplete orders, can be regularly monitored. Some reports may be generated on an exception basis. That is, the report is only generated if some performance measure deviates from acceptable limits.

Forecasting

All inventory decisions are based on forecast future demand. The inventory control system can compare actual demand against forecast and adjust the forecast in the light of actual levels of demand.

2. PURCHASING MANAGEMENT

Purchasing is the function of management which forms the interface between supplier and manufacturer.
It is also called supply management, materials management or procurement. In a large organization there is likely to be a separate purchasing department, in a smaller organization it will form part of the manufacturing planning function.

2.1. IMPORTANCE OF PURCHASING

A purchasing department buys not only the raw materials used directly in the manufacture but also all of the indirect and consumable items.
These include lubricants, cleaning fluids, cutting tools, office stationery, computers and all other goods and services purchased by the organization.
In all of these cases an analysis is needed and choice made been alternative suppliers.
The purchasing department does not pay for the items ordered; that is the function of the finance or accounts department.

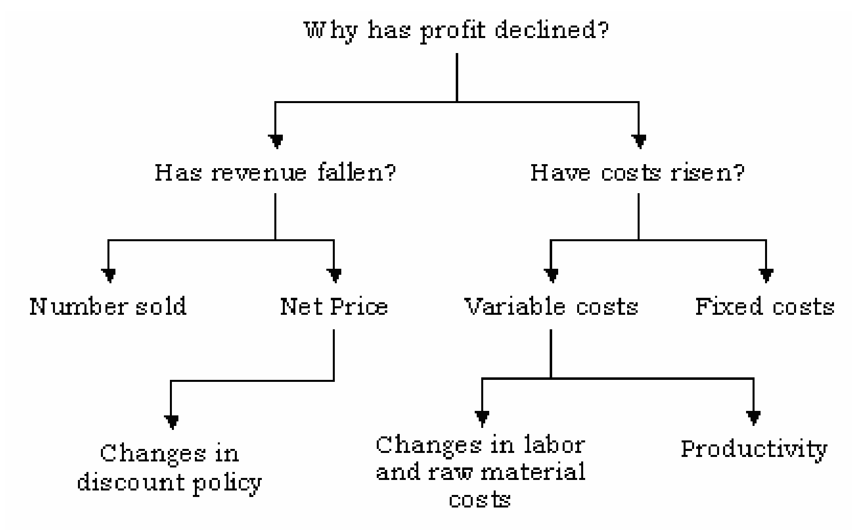

Fig. 2.1. Example for decision-making by the search process

<u>Example</u>

	Euro	**Percent of sales**
Revenue (Sales)	**€1,000,000**	**100**
Cost of Goods Sold		
Direct material	**€500,000**	**50**
Direct Labor	**€200,000**	**20**
Factory Overhead	**€200,000**	**20**
Total Cost of Goods Sold	**€900,000**	**90**
Gross Profit	**€100,000**	**10**

P/L After a 10% reduction in materials and 5% in direct labor

	Euro	Percent of sales
Revenue (Sales)	**€1,000,000**	**100**
Cost of Goods Sold		
Direct material	**€450,000**	**45**
Direct Labor	**€190,000**	**19**
Factory Overhead	**€200,000**	**20**
Total Cost of Goods Sold	**€840,000**	**84**
Gross Profit	**€160,000**	**16**

60% increase in profit

2.2 FUNCTIONS OF PURCHASING DEPARTMENT

The purchasing department does not pay for the items ordered; that is the function of the finance or accounts department.
In the case of investment in new machinery, the choice of equipment is made by manufacturing department
However the purchasing department may be involved in the search for possible suppliers and managing the tendering process.

The role of the purchasing department is to have the knowledge about sources and prices of supply of the raw materials and components that an organization buys.

The objectives of purchasing management:

- to purchase the **right quality** of material;
- delivered at the **right time;**
- in the **right quantity;**
- from the **right source;**
- at the **right price**.

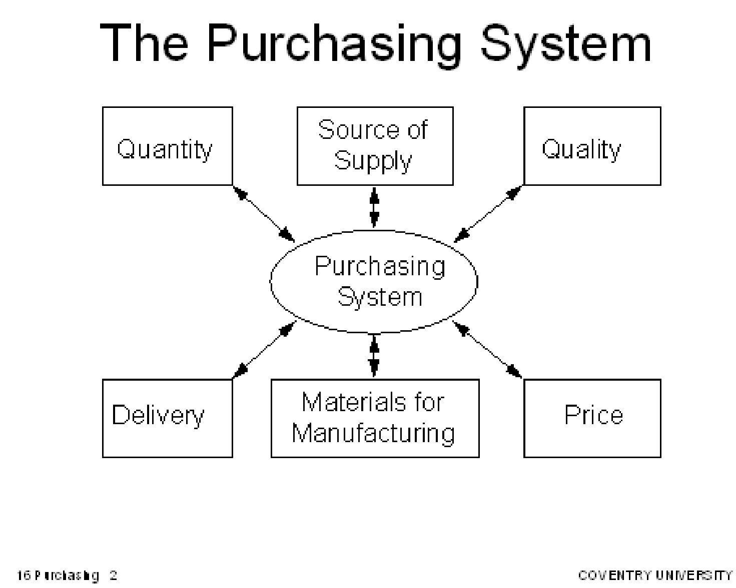

Fig. 2.2. Purchasing system

2.3. PURCHASING STRATEGY

The purchasing function must interact closely with the manufacturing planning function.
A lot of money can be made or lost by good or bad purchasing.
A small difference in the cost of materials can have a large effect on profit
It is necessary therefore for an organization to develop a purchasing strategy

Information Technology in purchasing
The basic activity of purchasing involves the placing of orders for materials and other items, the receipt of goods ordered and the payment for these goods, all at different dates.
These transactions need to be recorded, processed and progressed (checked to ensure that intended actions have occurred).
This data involves purchasing, stores, manufacturing and finance.
Databases are suitable for processing such data, although specific purchase-order processing packages are available.
Such systems are modular and can be integrated with systems in manufacturing and finance to form an integrated management information system.

2.4. ORGANIZATION OF PURCHASING MANAGEMENT

The head of the purchasing function must have the skills and authority to act effectively if the organization is to operate effectively.
This requires that the head of the purchasing function reports at a sufficiently high position in the organization structure
The purchasing department must be seen as a part of the industrial system that includes but goes beyond the boundary of the manufacturing organization.
It manages a part of the supply or demand chain.
Because of its links with the world outside the organization it must be involved right from the start of innovation projects, searching for ideas, new materials, possible suppliers and prices.
The purchasing department should be constantly monitoring prices and price trends and have a major input to the budget making process.

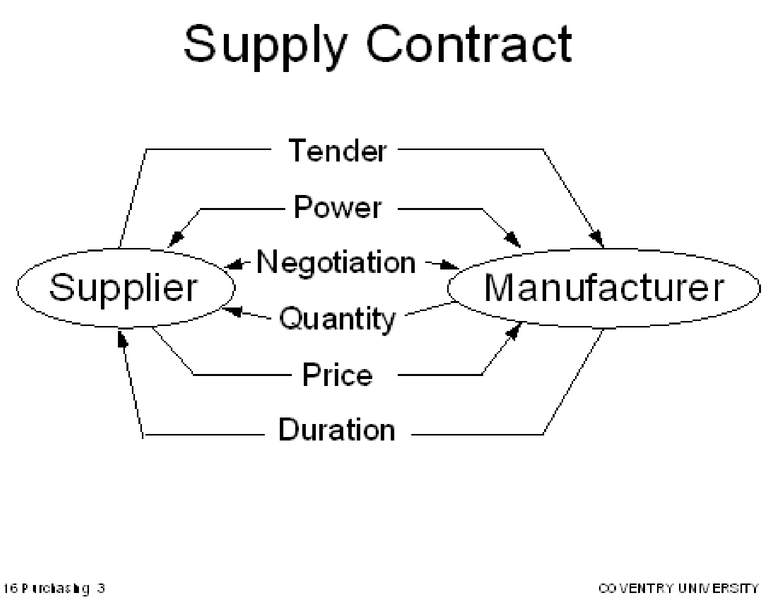

Fig. 2.3. Supply contract

2.5. PRICE

When the purchasing department wishes to buy something the buyer will usually send out a letter inviting potential suppliers to quote or tender for the business.
Although it may be tempting to accept the lowest price, the buyer must consider other factors including quality, reliability, experience etc.
The cheapest items may turn out to cost more in terms of reject work, consequential damage, guarantee or product liability claims and dissatisfied customers.
One of the most difficult things for the buyer to ensure is that 'like is being compared with like'. One example would be Hi-Fi systems.
There must be hundreds of different models available all with slightly different attributes and prices. The buyer must decide which are the important factors and compare price against specification, remembering the intended use. It is not worth paying extra for a sound frequency range that can only be heard by bats
Industrial buyers need to use the same approach.
The buyer will often be offered a discount for quantity.
The total costs and benefits must be analyzed before buying far more than needed to save 5% off the purchase price.
Another possibility is the chance to stockpile materials as an insurance against inflation and to save on possible price rises..
The money spent to buy the stock must either be borrowed or could have been invested. Either way the total effect of these costs must be considered in order to assess the benefit of buying now or later.

2.6. SOURCE OF SUPPLY

A buyer must identify or develop suitable sources of supply.
Before placing an order the financial background of the potential supplier is investigated by examining balance sheets, company reports and reports made by independent analysts.
If the contract is to be long term, it is worth finding out if the supplier is about to go bankrupt.

Help for suppliers
In order to benefit themselves, manufacturing organizations sometimes assist suppliers.
They are helping them in order to help themselves.
Companies can provide the finance to help potential suppliers to improve quality, develop new processes, install compatible systems to help with logistics etc.
Location of supplier
The geographical location of a supplier is important in reducing costs, lead times and delays and ensuring reliability of supply.
Suppliers in the same town or district can usually deliver quickly and at a lower price because of reduced transport costs.
Using overseas sources can introduce extra costs for transport and excise duties but for some items this can be cheaper than buying from a supplier in one's own country.

<u>Discussion</u>

OLIVETTI PROVIDES SINGLE-SOURCE SUPPORT

Like most retail banks, Barclays Bank has thousands of separate branch and office headquarters' sites and hundreds of thousands of individual pieces of computer equipment. These range from personal computers and work stations to computer peripherals and photocopiers. All of this equipment needs servicing and

repair support. Rather than buy in this support from several companies, Barclays decided to single-source these services from Olivetti, the computer and office equipment company. This simplified the administrative procedures and brought substantial cost savings.
Olivetti claims that single-sourcing services provides significant benefits for its clients. Contractual relationships together with invoicing procedures are rationalized and the quality of service becomes more easily measurable. Consistency-of-service procedures are also easier to achieve. These advantages of single-sourcing have also persuaded many other organizations, such as Swiss Railways and the German network of McDonald's restaurants, to conentrate on one supplier.

Questions

1. What do you think are the main operations objectives for a company such as Olivetti's computer support operation?
2. What do you see as being the major advantages and disadvantages of having a single-source agreement for computer equipment and computer equipment servicing?

2.7. POLITICS AND SUPPLY

Political changes overseas can cause unexpected price increases or a sudden withdrawal of supply. When the Suez Canal was closed in 1967 as the result of war, supplies between Europe and Asia, previously using the canal, had to go around South Africa instead. This not only cost a lot more but also took much longer resulting in a gap in supply of several months.

EU products

For a product to be sold within the European Union and be identified as being of European origin, the percentage by value of components in the product of non-European origin must not exceed a certain level.
Otherwise the product would be defined as foreign, even if it is part-made and assembled within a country in the Union.
Many overseas companies, especially the Japanese, are setting upfactories in Britain as a means of their products being described as British for sale across Europe.

Example

Cars and electrical products made in East Asia for sale in Europe are subject to quotas and import duties. Cars and other products made in Britain by East Asian companies and using designs and some components from East Asia can be sold in the European Union as 'European made' even if they contain a proportion of parts made in Europe. In this way import taxes are avoided so East Asian companies can sell in Europe and support jobs and profit in their own country.

2.8. MAKE-OR-BUY DECISIONS

When an operation decides to purchase products or services from a supplier it is implicitly making the decision not to create those products or services itself. This may not always be a straightforward decision. In some cases the operation may be able to produce parts or services in-house at a lower cost or at a higher quality than can suppliers. Yet in other cases suppliers may be able to specialize in the production of certain parts or services and produce them more cheaply or at higher quality than can the operation itself. It is part of the responsibility of the purchasing function to investigate whether the operation is better served buying in products or services, or choosing to create them itself. This is called the 'make-or-buy' decision.

Often the major criterion used to decide whether to make or buy is financial. If a company can make a part or service in-house more cheaply than it can buy it, it is likely to do so, unless there are other overriding reasons for not doing so. However, the financial analysis involved is not always straightforward. The decision often needs to be based on the marginal cost of producing something in-house. The marginal cost is the extra cost which is incurred by the operation in creating the product or service. For example, if an operation already has the equipment and staff in place to make a particular product and there is spare capacity within the part of the operation which could make that product, then the extra, or marginal, cost of making the products in-house will be the variable costs associated with their manufacture. In other cases, an operation might decide on grounds other than cost. An increasingly popular rationale for buying in services, for example, is that they are not 'core' to the operation's main activity. Many companies are increasingly 'out-sourcing' such services as transportation, cleaning, computing, catering and maintenance. Putting these services out to specialists allows an operation to concentrate on what directly wins it business in the market place (see discussion on KLM Catering Services).

Discussion

KLM CATERING SERVICES

KLM Catering Services is the largest provider of aircraft catering and supply at Schiphol Airport near Amsterdam. The company, which employs 1200 people, every day prepares around 30 000 meals and 'services' 200 flights for KLM and about 35 for other operators. It is now far more than just a food-preparation operation; most of its activities involve organizing all on-board services, equipment, food and drinks, newspapers, towels, earphones, and so on.

KLM Catering Services places considerable emphasis on working in unison with cleaning staff, baggage handlers and maintenance crews to ensure that the aircraft are prepared quickly for departure (fast set-ups). Normally, no more than 40 minutes is allowed for all these activities, so complete preparation and a well-ordered sequence of working is essential. These requirements for speed and total dependability would be difficult enough to achieve in a stable environment, but there is a wide range of uncertainties to be managed. Although KLM Catering Services is advised of the likely numbers of passengers for each flight (forecasts are given 11 days, 4 days and 24 hours in advance), the actual minimum number of passengers for each class is only fixed six hours before take-off (though numbers can still be increased after this, due to late sales). The agreed menus are normally fixed for six-month periods, but the actual requirements for each flight depend on the destination, the type of aircraft and the mix of passengers by ticket class. Finally, flight arrivals are sometimes delayed, putting pressure on everyone to reduce the turn-around time, and upsetting work schedules.

An additional problem is that, although KLM uses standardized items (such as food trolleys, cutlery, trays and disposables), other airlines have completely different requirements. The inventory of all this equipment is moved around with the planes. Some gets damaged or lost, and it can easily accumulate at a remote airport. If an aircraft arrives without a full inventory of equipment and other items, the company is obliged to fill the gaps from its local inventory which amounts to over 15 000 different items.

Questions

1. Why would an airline use KLM Catering Services rather than organize its own on-board services?
2. What are the main operations objectives which KLM Catering Services must achieve in order to satisfy its customers?
3. Why is it important for airlines to reduce turn-around time when an aircraft lands?

Questions:
1. What are reasons to hold inventory? **2.** From what consit inventory costs? **3.** What are assumptions of EOQ model? **4.** When and why safety stocks are used? **5.** What main objectives of purchasing management? **6.** How purchasing process is organized?

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<u>Module M05</u>

Logistics Approaches in Technological Preparation of Manufacturing

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Learning objectives:	
⇒	to know the basic logistic approaches in technological preparation of manufacturing
⇒	to identify the basic parts of technical preparation of manufacturing
⇒	to identify the construction preparation of manufacturing
⇒	to identify the methods of construction work
⇒	to identify the methods of technological preparation of manufacturing

Content:

1. Introduction to logistics in technical preparation of manufacturing

In company management the concept of logistics is used in wider extent and with stronger effect. Literature significantly points to growing need of system treatment and formation of logistic processes and functions in integration and strategic aspects, what can be seen in development and evolution of logistics in the sense of integrated management concept.

Idea of logistics and development and application of logistic concepts have relatively reach genealogy and tradition over the world. We talk about source of origin and formation of term „logistics”.

One source of logistics term is presented in Greek words:

- **logos** (*wisdom, mind*),
- **logistike** (*art of wisdom, calculations).*

Semantically close to this Greek word is Latin adjective
– logisticus, that means: clear, rational, capable of logical thinking.

Prefect of Roman legion was **„logistate"** – administrator responsible for securing and preparation of legion for war.

In studies and proposals of company processes (in the are of goods distribution) the term logistic was „borrowed" from army and first time used in literature in USA at the end of 50's of twentieth century. Modern sources point to the French origin of the term, where „logis" means accommodation and „logistique" related with movement art of army troops, provisions transport, territorial planning of military operations. For the first time this term was used for theoretical concept in work „Art of War Draft" from french general A. H. Jomini, published in Paris in 1837.

Historical role was taken by work of American admiral H. E. Eccles „Logistics in National Defense" published in 1959. This and other works of H. E. Eccles cause that logistics together with strategy and tactics became one of three areas of defensive doctrine of NATO. Through army administration logistics got to civil rights and currently it presents the standard of modernity and efficiency for complex security of war operation at all levels of command.

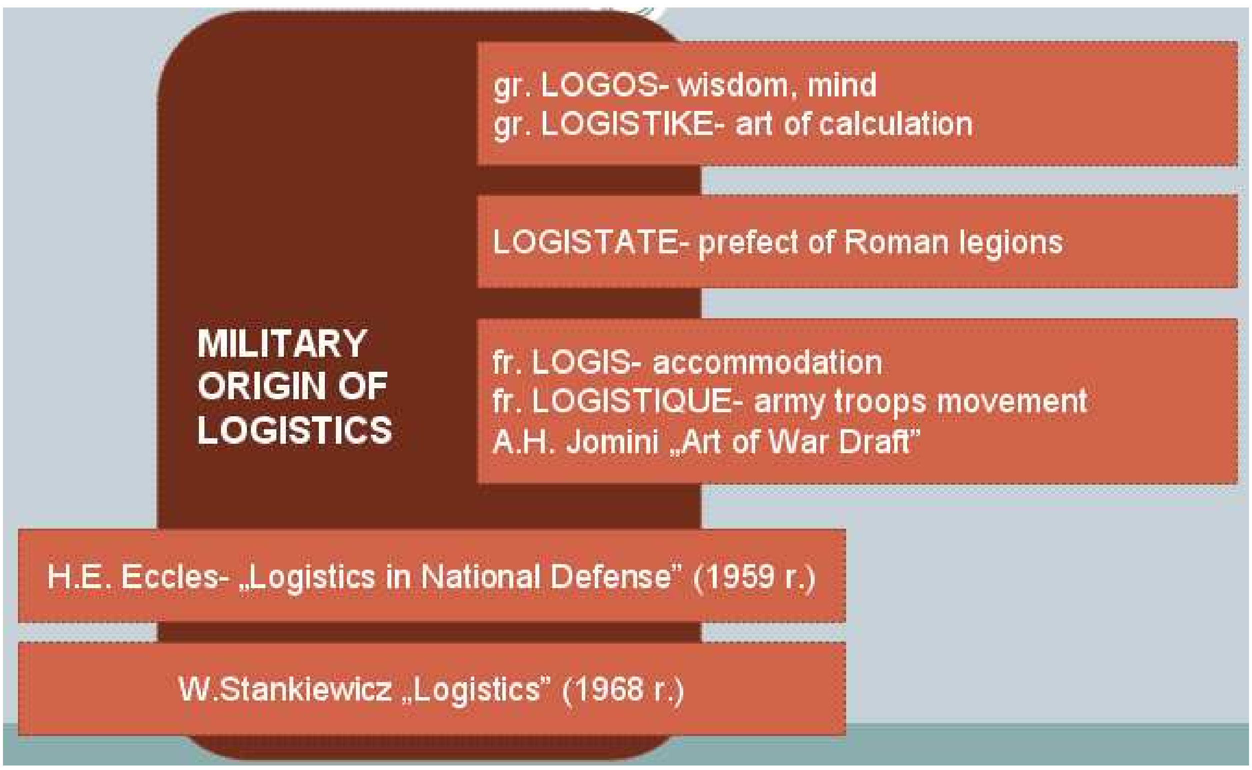

Figure 1. History of Logistics

Amount of modern logistic conceptions shows, that two basic periods have to be accepted in history of logistics:

- Antiquity period
- Modern period

Logistics of antiquity period is characteristic by high organization level of army forces of individual countries. It was followed by high – for that time – level of knowledge concerning the accumulation and distribution of provisions at battlefield.

Logistics development is connect to the economical aspects of military operations, including planning and realization of movement and accommodation of army troops, as well as securing of their needs, weapons, food, uniforms etc.

Logistics of modern period – is the logistics of changes and transformations. At first stage the logistic operations are focused mainly to the accumulation of provisions and securing of army on the battlefield. At second half of XVIII. century there are some studies that start to create the very basics of logistics itself.

Immediate reason for bringing the logistics into the economy was experience from the time of II. world war. Military logistics used during the war was one of main cause of success for alliance troops. Since that time there is no doubt about the fact that logistics presents the bridge between production and market that are distant from the viewpoint of time and location.

During II. world war it comes to dynamic development of logistics in the frame of interdisciplinary operational research, that supported the efficiency of realized military actions with use of strict discipline and scientific methods.

Understanding of logistics term was often altered with quantitative methods and proceedings used in so called Research Operations, which similarly to the logistics comes from military exploitation of mathematics to the optimal solution of complex problems in the frame of logistic securing of military operations.

Operation research provides management bodies with scientific methods for accepting of optimal decisions strictly in the sense of quantitative criteria. Theory and praxis of operation research was intensively developed in II. world war, where it was really used for strengthening of potential of army strength of allies in military operations as well as for general provisions.
Attitude based on universal mathematical system was in very effective way implemented on the base of system analysis, including close coordination of time-space complex processes of material provisions supporting the military activities. Theory of operational research has developed few very useful algorithms and techniques used for solving the practical problems of military an economics concerning mainly the optimization of complex time-space systems.

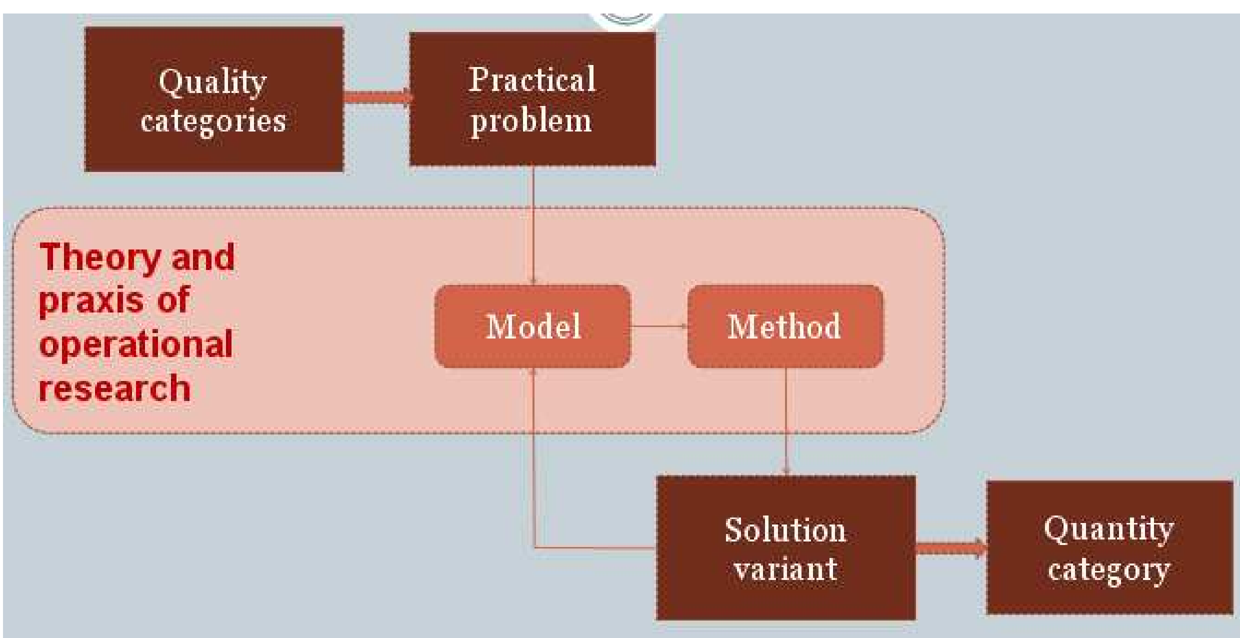

Figure 2. Scheme of using the theory and praxis of operational research

1.1. DIFFERENCES IN PRODUCTION AND NON-PRODUCTION AREA

Real interest of developed market economy of western countries in practical solutions of logistics can be observed in late 70's, where there was quick decrease of earnings at micro and macro economical level. That led to considerations about looking for reserves in non-production area that closely relates with whole market environment.

Increasing level of systematization and extent of automation of production processes became the reasons for deeper differences between time of goods creation and their sale (distribution). Real production time of goods in complex and automated production systems gets shorter and markets that are more demanding and more wide cause distribution channels to extend.

At the same time there is the fact of excess that express the domination of offer over the demand. As the result the interest of managers was moved from production area and creation to the problems of rational distribution and client services.

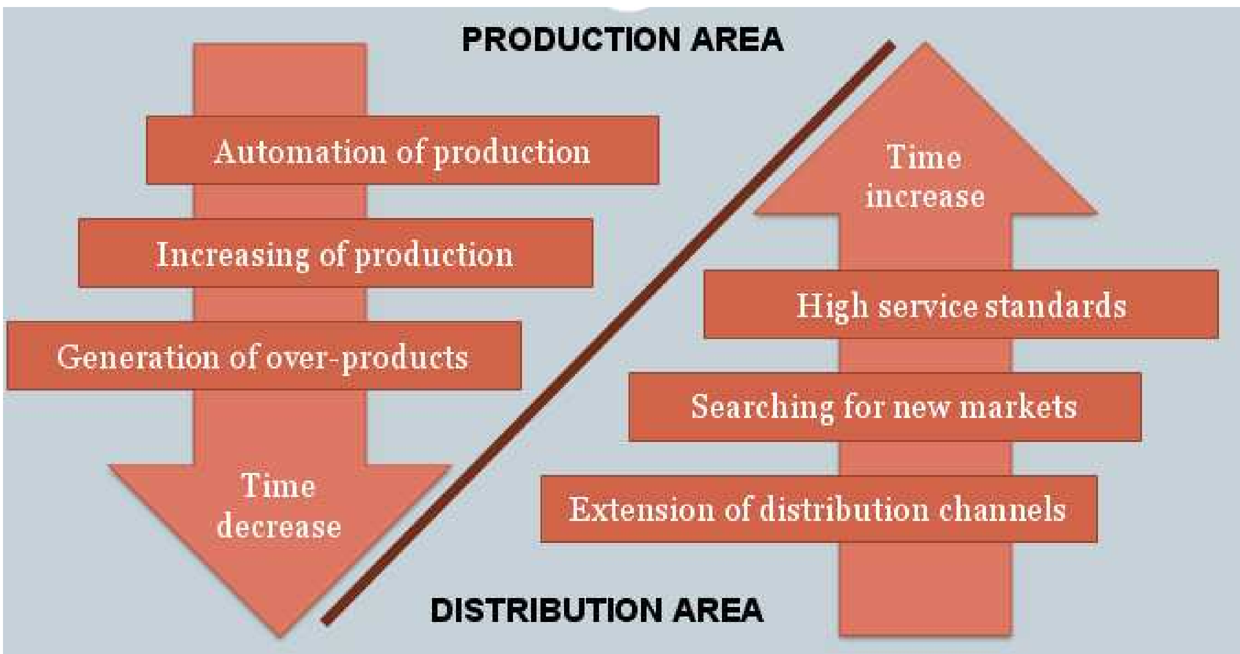

Figure 3. Time differences between production and distribution area

1.2. MARKET CONTEXT OF LOGISTICS PROCESSES

Necessary presumption for optimization of logistic chains of physical flows is their global incorporation into market economy, regarding all operators working in that market environment, with special respect to marketing principles. In this attitude the main role is played by client, his requirements and expected standards of services.

One way to reduce the sharp differences between production area and non-production sphere of distribution and sales is logistic attitude that was used primarily in army, strategy for solving the time-space problems, where primary function is performed by transport and warehouse systems, with intensive support of modern technics and tools of computer technology.

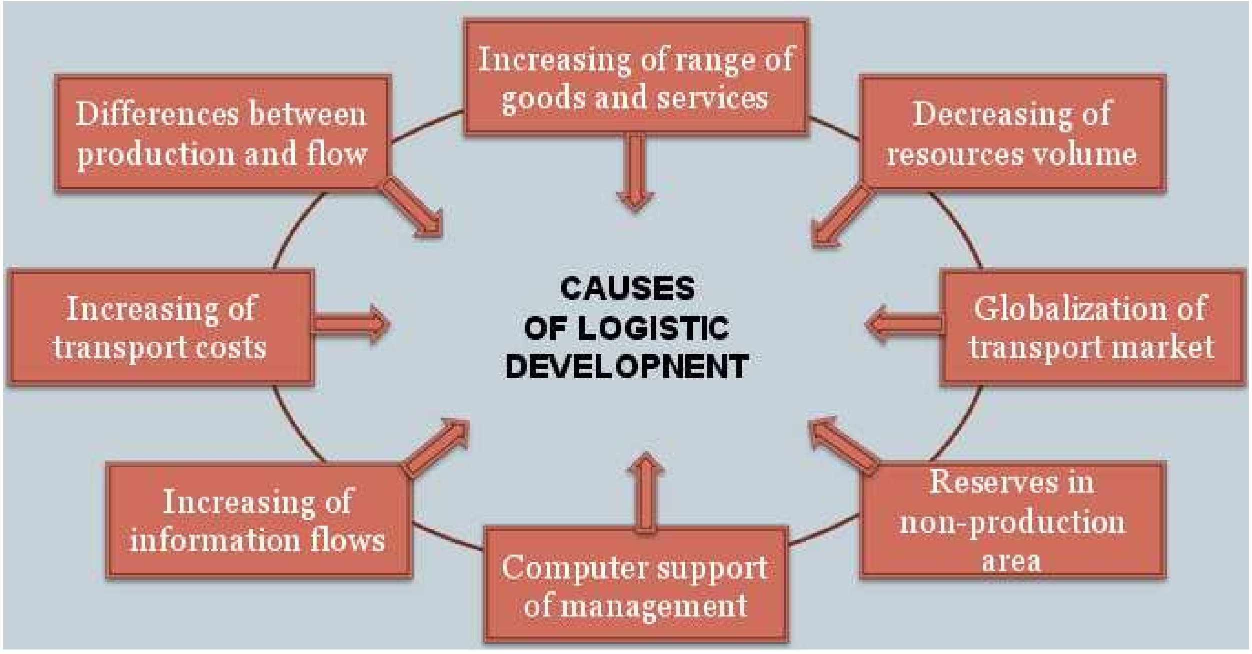

Figure 4. Causes of dynamic development of logistics

1.3. CAUSES OF LOGISTICS DEVELOPMENT

1. Persistent differences between efficiency of perfect high-performance production systems and forgotten area of flow of goods, products and services.

2. As a result of great technical progress there is fast moral aging of products, what significantly shortens their market life and makes the development-production cycle run faster in the field of products with high quality.

3. Fast increment of range of goods and services that is caused by marketing strategies focused on conquering of market and reaching of clients using different moves.

4. Lowering of kept stocks, especially directly in shops, their removing to the side of producers and wholesalers.

5. Dynamic increasing of transportation costs, especially in distribution phase, with civil transport there are challenging transport companies risen.

6. Growing globalization of market increased the portion of transport and warehouse economy in goods ratio, economy became more dynamic.

7. Change-over to market that is controlled through buyer makes the subjects of economy to do deep analysis of requirements and needs of client concerning offered goods and services in organization of supplying chain.

8. Development of new technics and computer technology results in increasing of flow and transformation of huge information streams that go with big boom of world's economy.

9. Expansion of computers causes that most of companies are considering effective tools of management and control, what points on reserves just in non-production area of flow of goods, products and services.

Renaissance discovery of civil logistics in 80's is conditioned with three basic facts:

- **first**, high productivity of concerned objects and high efficiency of economic processes,
- **second**, increasing of user-demanding market at the location of dominant producer and need for application of different marketing strategies,
- **third**, mass computation of all spheres of social-economic life and radical increment of control efficiency by economic processes.

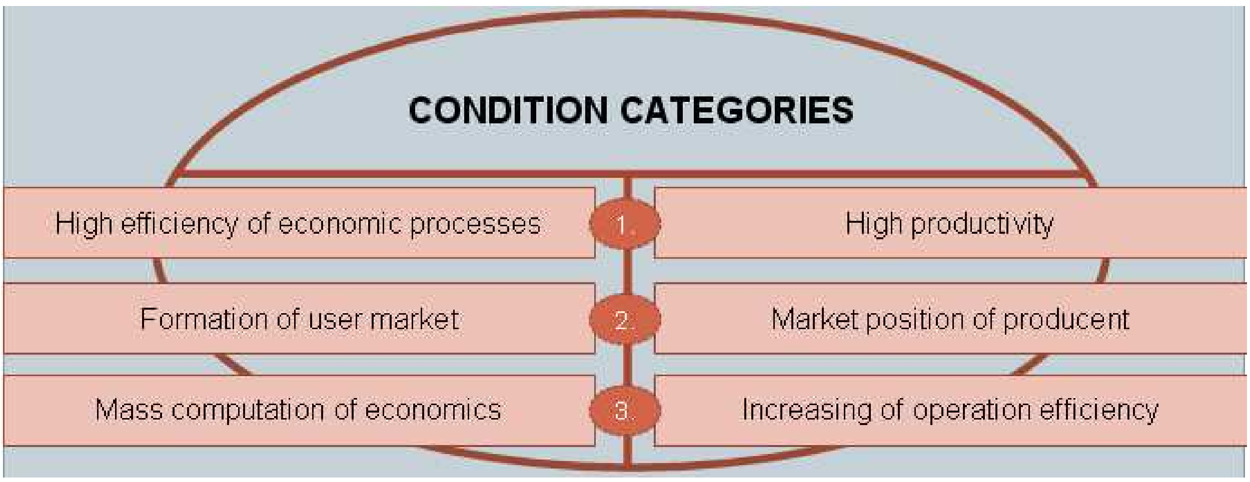

Figure 5. Main categories of conditions impacting the development of logistics

1.4. LOGISTIC IN EUROPE

These terms were brought to civil economy in 70's of last century, when in highly developed countries as a result of all automated mass-production the need has risen for new organization especially for supplying processes and provision of raw materials, materials and semi-finished products and also for new organization of distribution process for final products.

Processes of provision and distribution run in competitive market environment, where minimax criterion for minimization of logistic costs with maximal satisfaction of client needs is main requirement of effective management.

Globalization of logistic problems led on European market to the creation of so called **Eurologistics** as a standard of managing through logistic processes in countries of European Union. Eurologistics presents one entry of the logistic pyramid, where we can find micrologistics (logistics of companies), mezologistics (logistics of branches and industrial sectors), macrologistics (logistics of national economy) and eurologistics and global (worldwide) logistics.

Stable user-oriented market that has monopoly position on the location of former market of producer called the change in yet working principles of production processes – „Create the product and find the buyer for it" to strictly contrary version – „Find the buyer and then create according to his requirements."

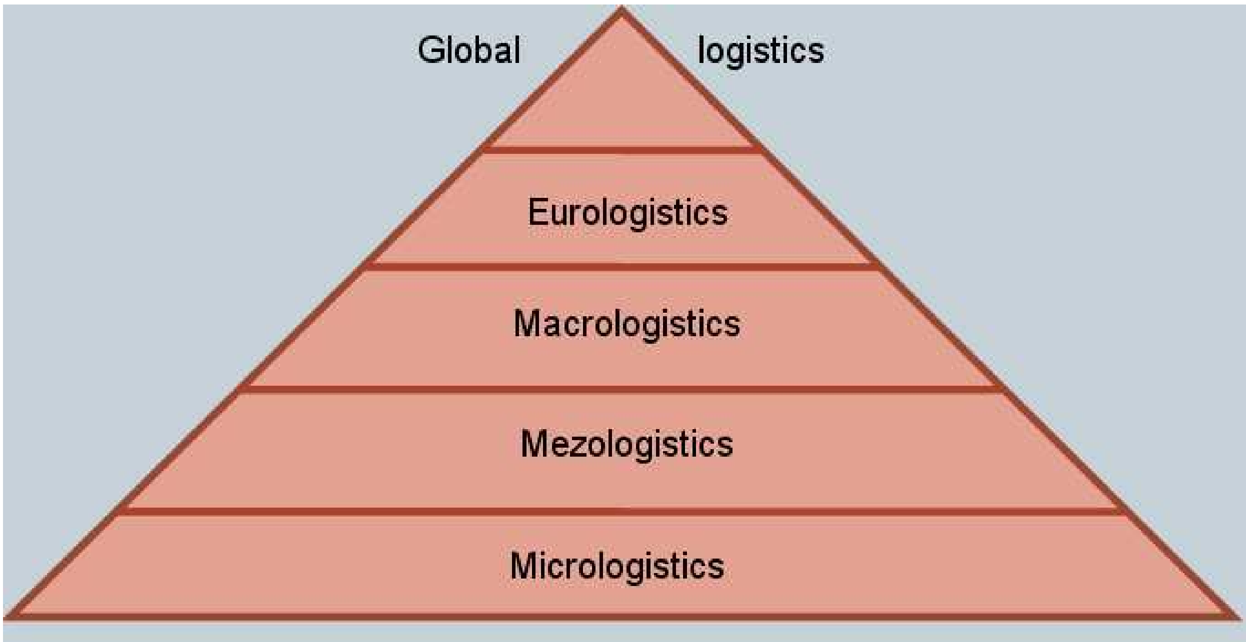

Figure 6. Pyramid of logistics

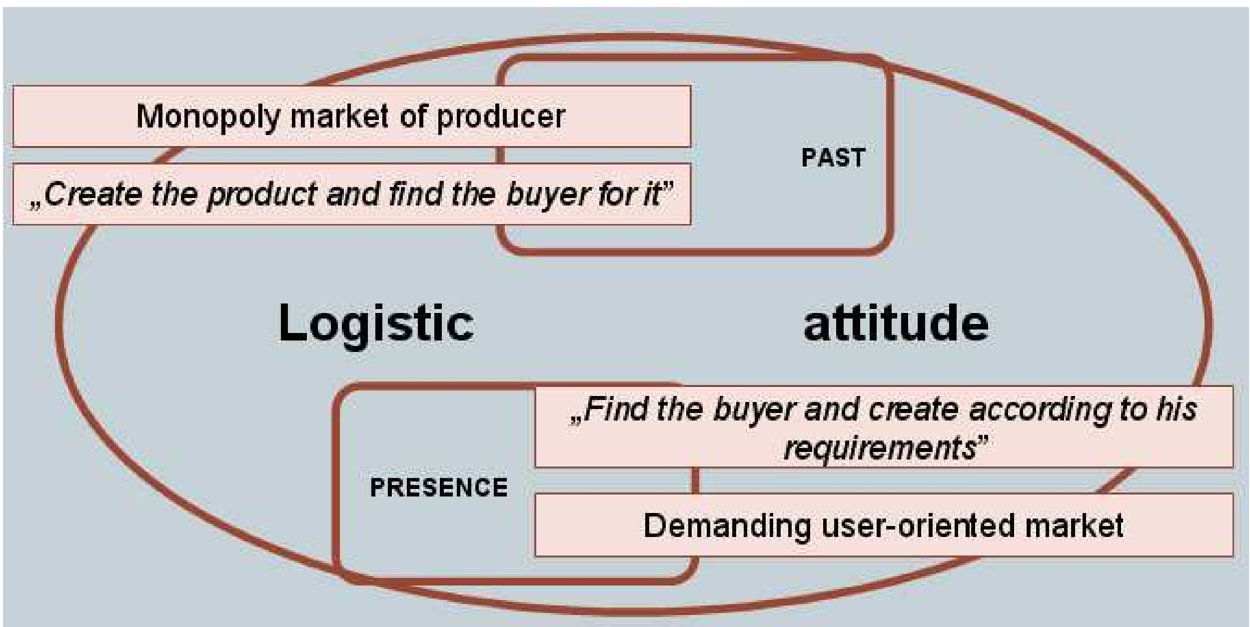

Figure 7. New logistic attitude

These changes are expressed through creation of logistic transport-distribution chains that work on principle Just in Time. From this point of view the logistics as an interdisciplinary science about management of supplying chains not only organizes but also changes actual rules of moving the materials and products and included information-decision making processes.

In widest sense we can accept the understanding of logistics as organized system of planning, realization and control of processes of physical flow of products and services together with information streams that belong to them, which is focused to maximal possible satisfaction of the client while keeping minimal possible costs of logistic processes.

Such attitude of logistics on one hand gets us to the sphere of general economy, where it can stand as **macrologistics,** on the other hand every company creates its own system in the sense of **micrologistics.** Micro and macro economical view to the logistics makes the scale for mentioned processes and flows. Both terms are in mutual dependency and they both use the same philosophy of integration of physical flows of goods and
relevant information.

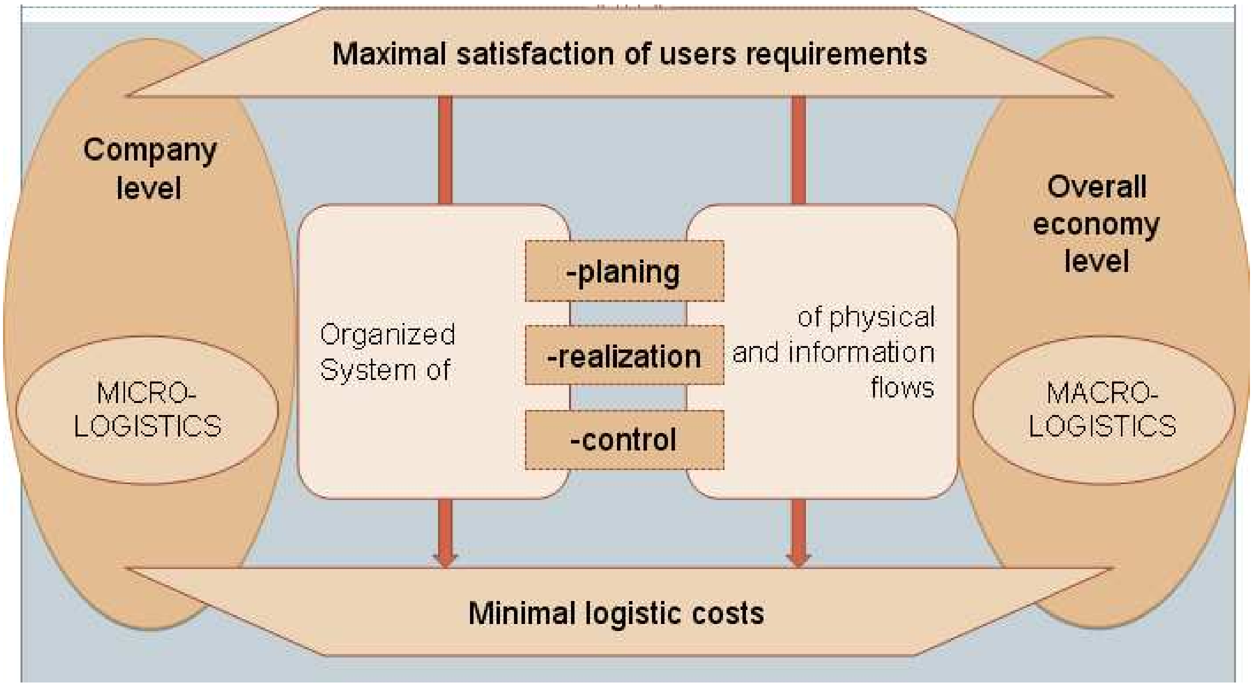

Figure 8. System relationship between micro and macro logistics

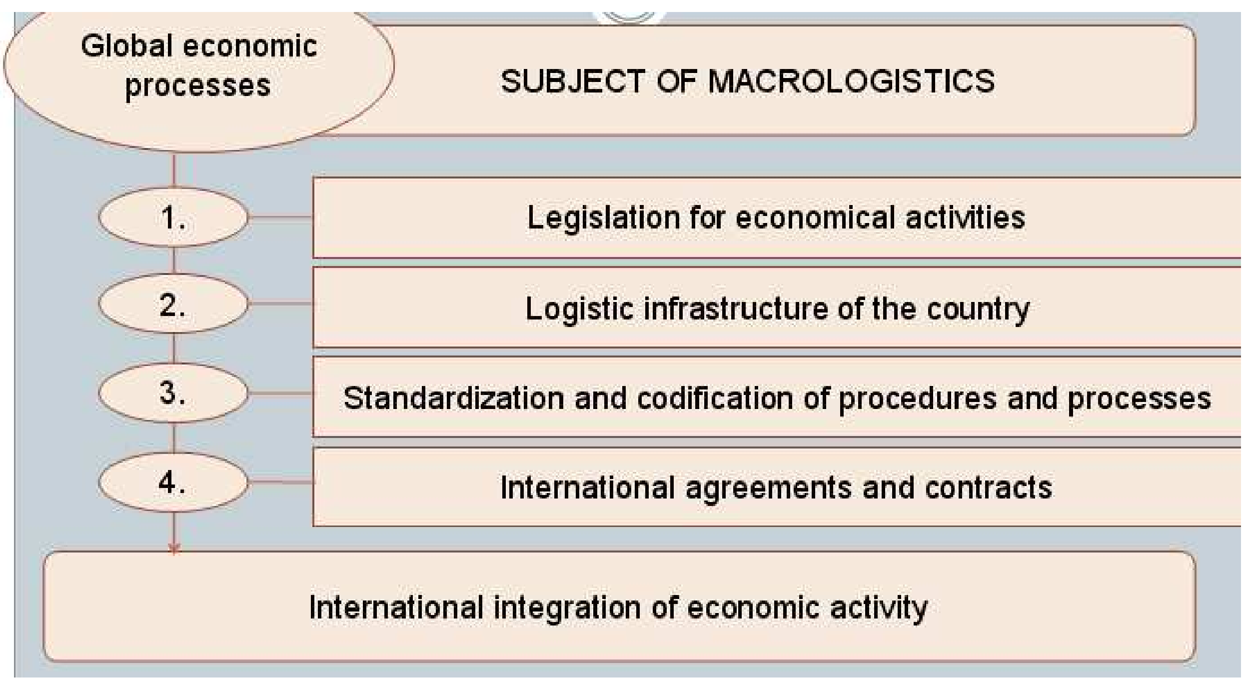

Figure 9. Area of interest of macrologistics

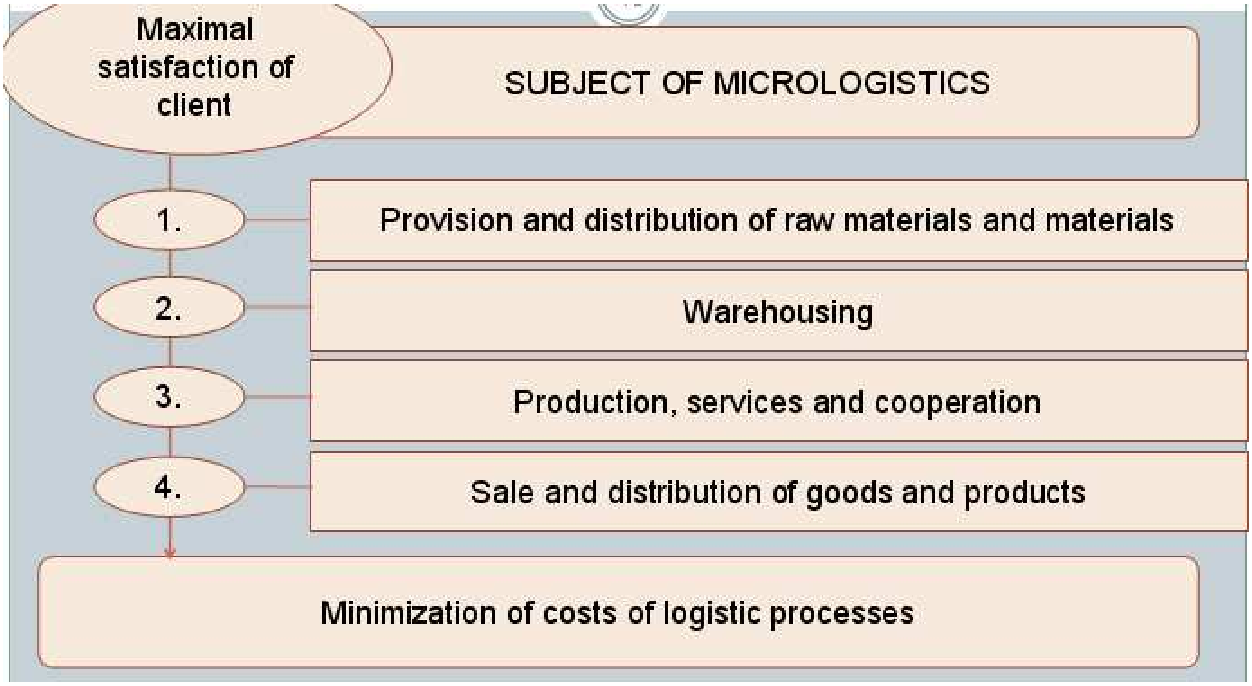

Figure 10. Area of interest of micrologistics

On the beginning o 90's there are global and also European strong tendencies for integration of national economic systems with transnational organizations, even in global extent. Perfect example is creation of European Union in 1992 and its dynamic development. In 2004 Poland joined its structures as well. Economic integration of different countries is particularly intensive in the field of logistics, in the field of physical flows of processes and information.

On the one hand it selects the development tendencies of the economy, on the other hand it obliges to the acceptance of standards and requirements of economy, with respect to the generally valid rules of given society – starting at legal standards, through qualitative standards, transportation standards all the way to the information systems, principles of coding and indexing.

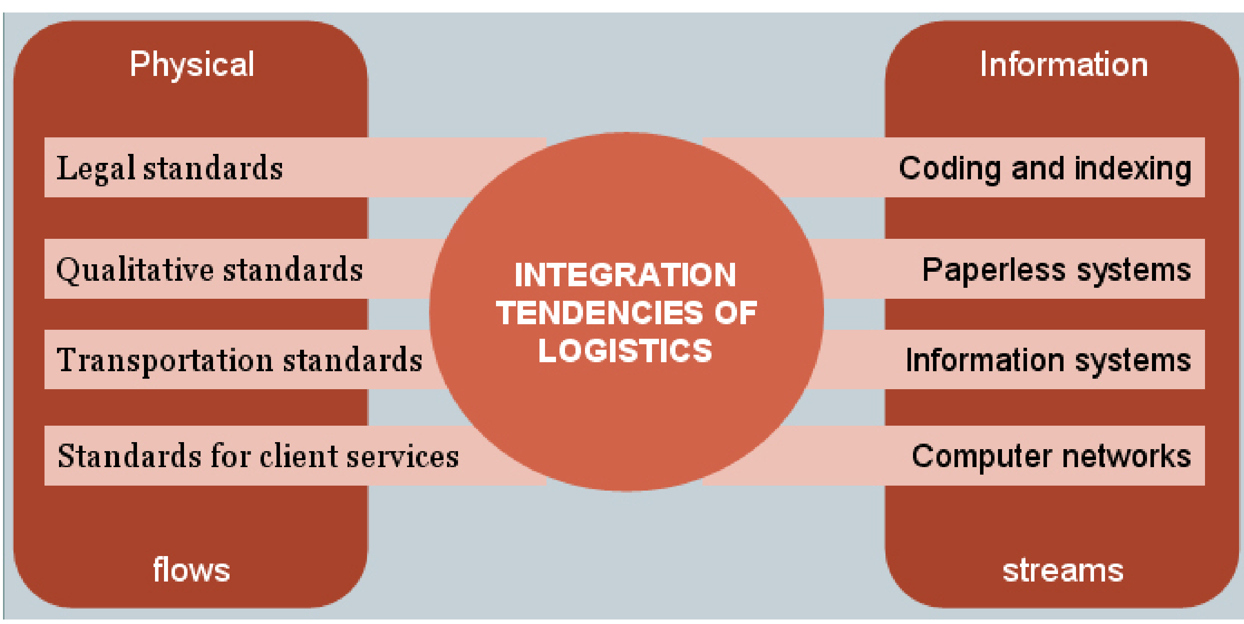

Figure 11. Integration tendencies of logistics

With respect to the open, market character of logistic processes, the integration matters concern both micro and macro logistics, thus particular leading companies, sometimes even whole branch, or whole economy of the country.

Main course and development tendencies of logistics in most developed countries concern following problems:

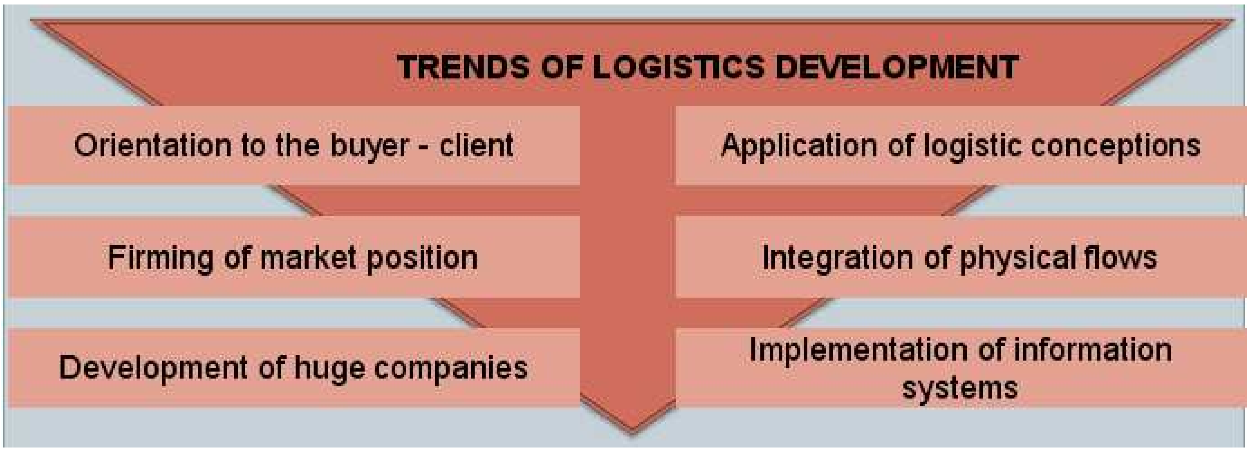

Figure 12. Main development courses of current logistics

Rising integration of economies of countries of European Union gives the reason for global increment of economy intensity, which is realized mainly in the sphere of physical flows and concerns following aspects of logistic processes:

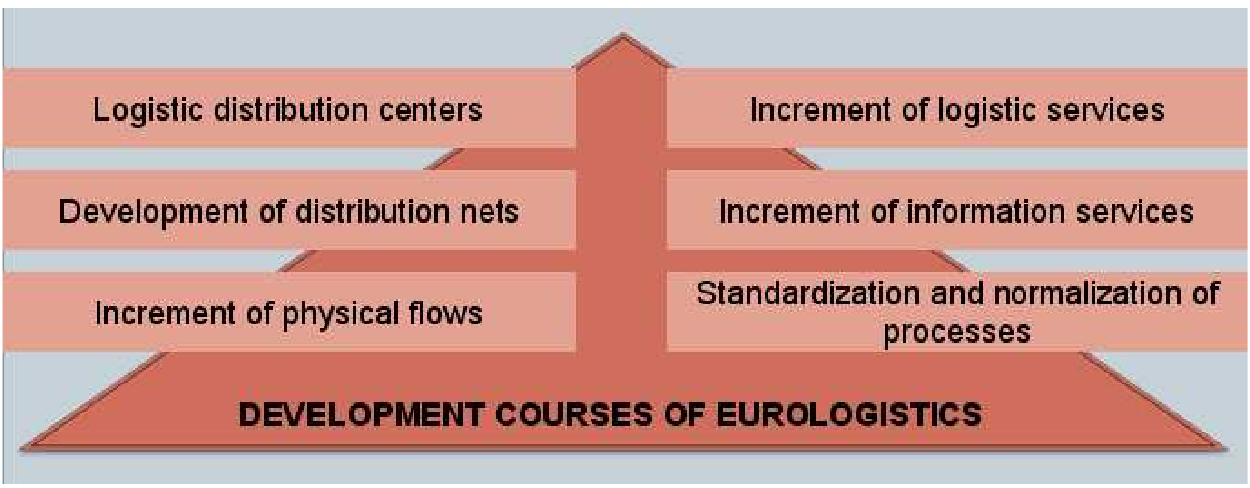

Figure 13. Basic development areas of eurologistics

Main stimulator that makes logistic processes more intensive, especially on the field of provision-transportation chains, is strongly developing computing technics, telecomunications and informatics, that made revolution in the process of information creation and also in processes of physical movement of materials.

Fully accessibility calls for creation of fast and actual logistic subjects. Scientific prognoses say that main development courses of logistics are set through development of computing technics, information logistic systems, that mostly affect following areas:

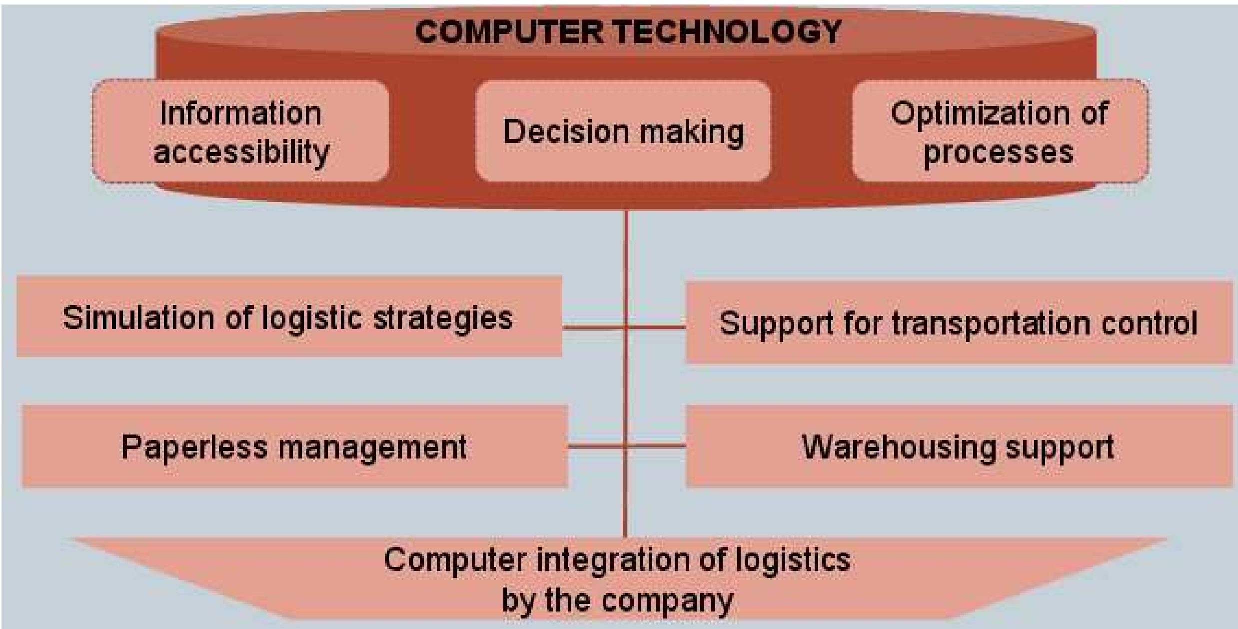

Figure 14. Courses of application of information systems in logistics

1.5. COMPUTER SIMULATION OF LOGISTIC STRATEGIES

With use of special computer applications, every decision in company level should first be verified and globally evaluated for assumption of efficiency grade. Technical tools of computer simulation are used for these purposes, what requires predefinition of simulation model of process that is to be tested on the base of mathematical categories. Most important variable of simulation model is time and subjects for simulation are particular process states.

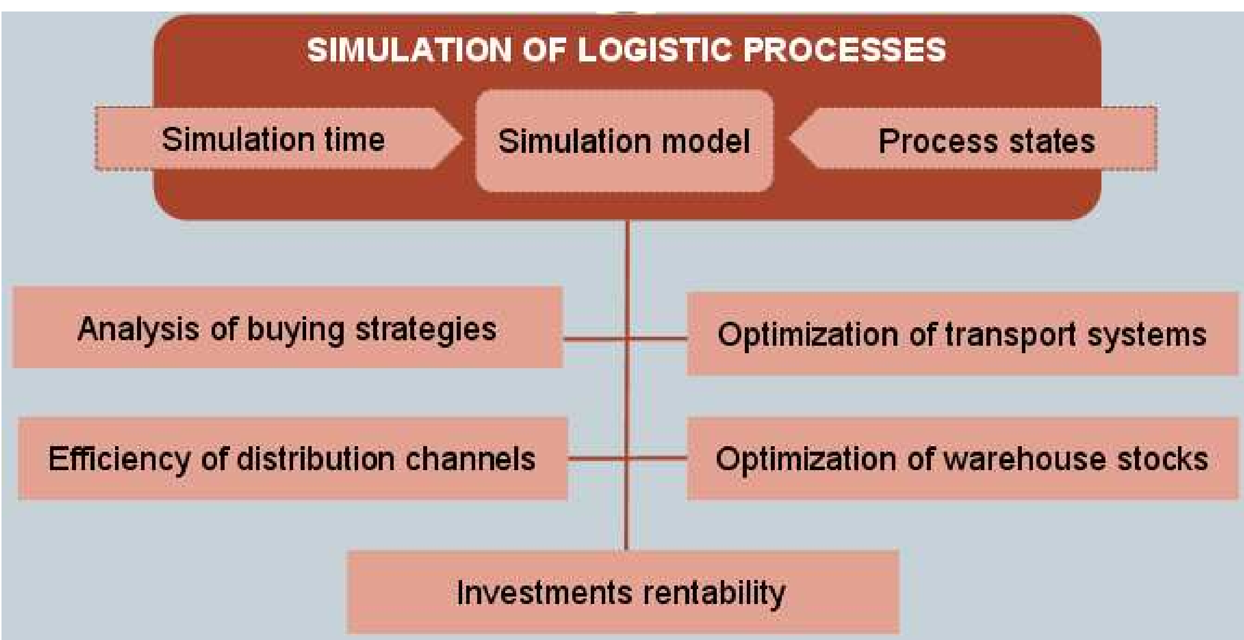

Figure 15. Computer simulation of logistic processes

Newest technology of computer network allow exchange of information from all documents using so called electronic mail, that in connection with automatic system of classification and identification of subjects and economic operations and also materials, goods and services eliminates the necessity of paper documents and other business amendments. All transactional problems can be solved using the email either in the frame of the company or in wider macrologistic structures.

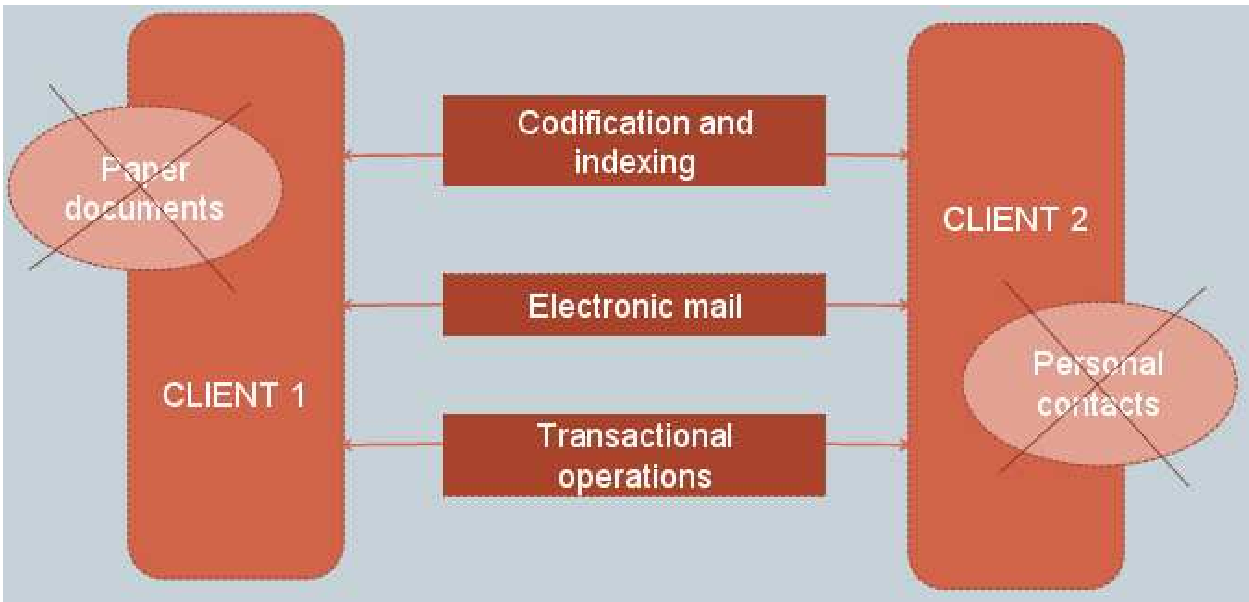

Figure 16. Concept of paperless management of logistic processes

Novelty determinant of management is sensibility to the paperless managing with exploitation of physical processes of flows using different technologies of computer networks and internet.

One of first advanced applications of logistics was utilization of some of its methods and techniques for qualitative support of transportation control, especially in the field of car transportation. These matters are included in special class of so called transportation methods with theory of linear programming.

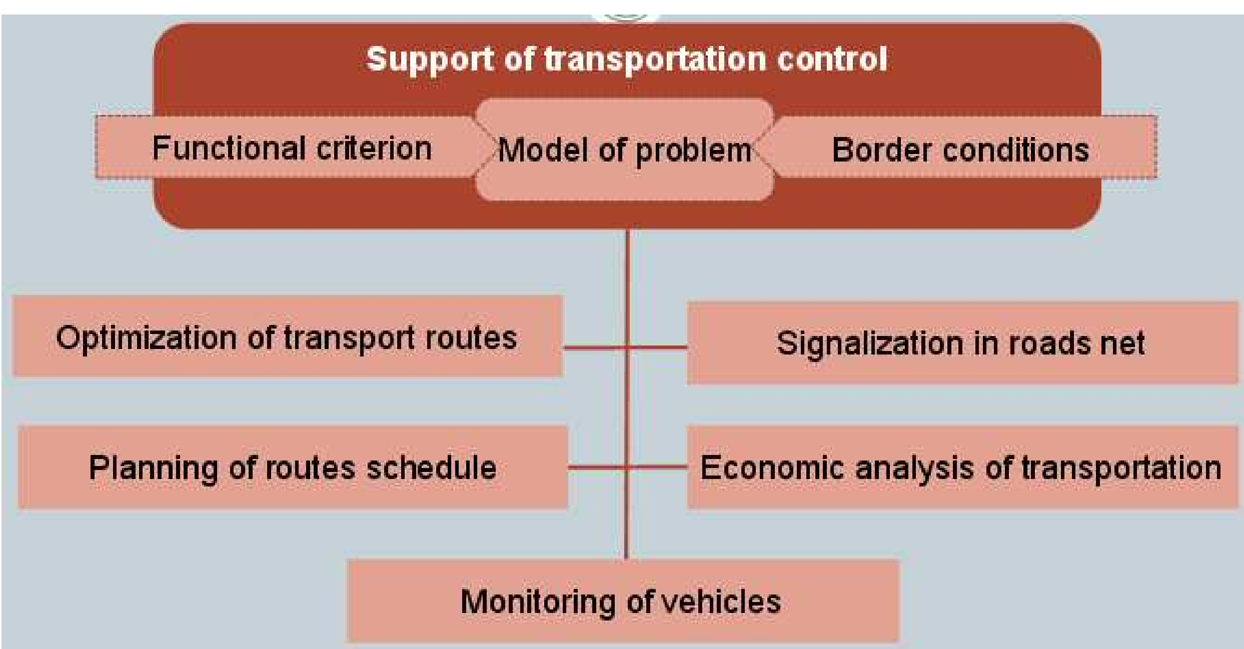

Figure 17. Areas of computer utilization in transportation control

This area uses computers for selection and optimization of car routes, detailed planning of usage schedule of vehicles, and also for control of actual motions of vehicles in route net, monitoring of usage level and transmission of actual disposition information.

Computer support of warehousing can be observed in two areas:
- Support of management processes of warehousing,
- Controlling of warehouse processes and manipulation.

Computer support of warehousing concerns such operation as: evidence about actual situation and transactional state of stocks, determination of optimal level of stock provisions, optimization of warehouse facilities use, resolving of personnel and warehouse devices, analysis of warehouse costs etc.

Current warehouse systems, especially those running in large warehouse mode, are completely driven by computer automatics with use of control-proportional systems and implementation of manipulating principles. Robotic rack manipulators allow access and searching for chosen products, generation of reports about their location and also maintenance realization, completing and packaging of packages.

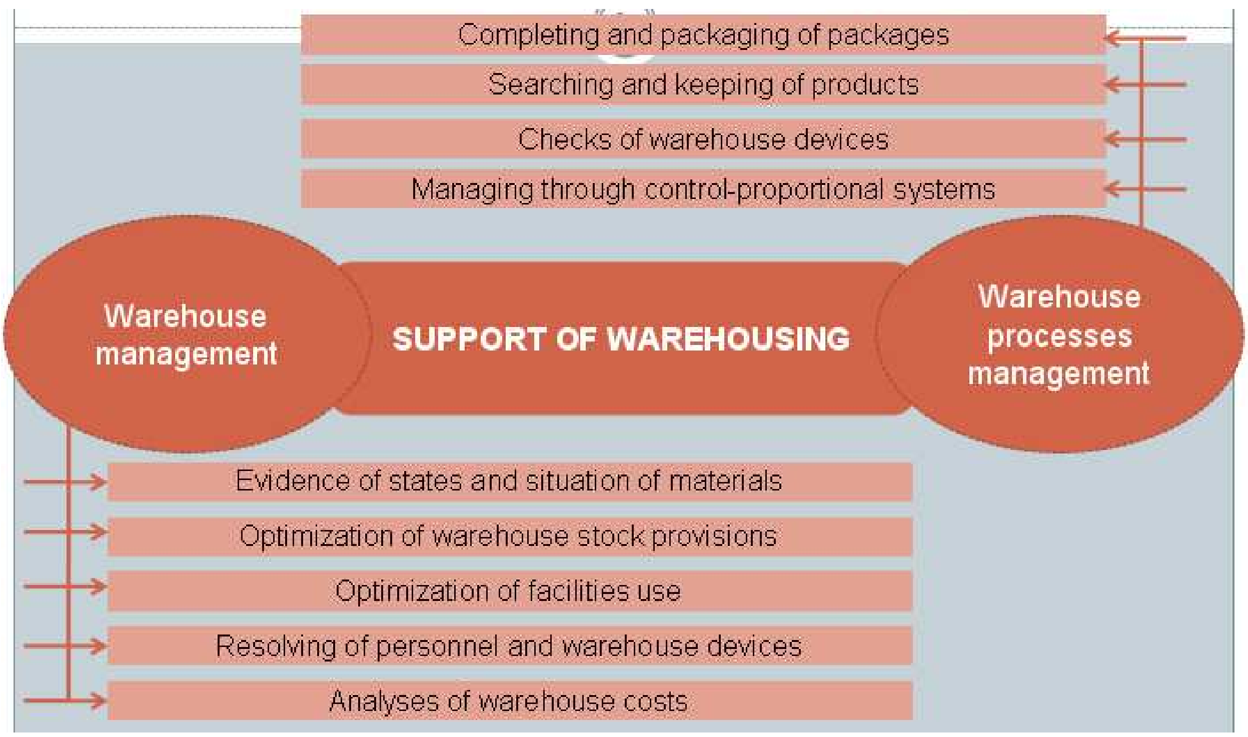

Figure 18. Areas of computer utilization in warehousing

Requirements for management efficiency force the company to maximal possible integration of information base, that determines physical integration of logistic processes. Efficiency of management also requires that that is unified database working in the company that would guarantee selective access to relevant cells for suitable and actual operations.

Only then all the concepts of integrated logistics can be realized, including (on the principle of connected containers) all kinds of logistical processes and all participating bodies in mutual interconnections in the area of information creation. Market competitiveness forces companies to look for sources of strategic advantages. For this purpose there is huge volume of information processed, concerning own company activities as well as information from the market.

From the viewpoint of evolution and development of logistic conceptions there is remarkable change in apprehension of basic components of logistic theory, reaching to the area of management concept.

Logistics is not only the opportunity, but it also presents the time demand, where processes connected to the exchange of products became more complex and where necessity to adapt to the requirements of buyers goes hand in hand with attempts to lower the operation costs, in order to assure the competitiveness of the company on the market. Solution of such problems presents main goals of logistics. They are and they will be the keys to the future success of the company on the market.

2. INTRODUCTION AND DEFINITION OF TECHNICAL PREPARATION OF MANUFACTURING

2.1. DEFINITION OF TECHNICAL PREPARATION OF MANUFACTURING

Technical Preparation of Manufacturing:

- a set of activities and technico-organisational measures that are necessary to be carried out in a company before the start of the manufacturing of a product.
- these activities are focused mainly on the preparation and processing of the technical (design, technological and project) documentation and documentation for securing the material and technical equipment of the manufacturing process.

TPM has to use such design, technological and project versions of the solution that will ensure the maximum achievable work productivity and effectiveness of manufacturing processes.

Important elements of newly proposed manufacturing processes:

- design and technological concept of the product;
- materials and input semi-finished products;
- machine parts manufacturing and assembly technology;
- manufacturing equipment, tools and jigs;
- individual types of energies;
- quality management system, organisation and management of manufacturing;
- activity of the workforce.

The quality, speed of preparation, accuracy and completeness of the design, technological and project documentation depends on the level of TPM, i.e. in particular on:

- personnel and content structure of individual units, activities and stages of TPM;
- quality and quantity of information data sets necessary for TPM;
- creation of conditions for the use of scientific and technical knowledge in TPM;
- material and technical equipment of individual TPM units;
- prevailing type of manufacturing (in pieces, serial, mass);
- complexity and size of products;
- mechanisation and automation level of the manufacturing process, etc.

Technical Preparation of Manufacturing – one of the elements of the „science – technology – manufacturing“ system

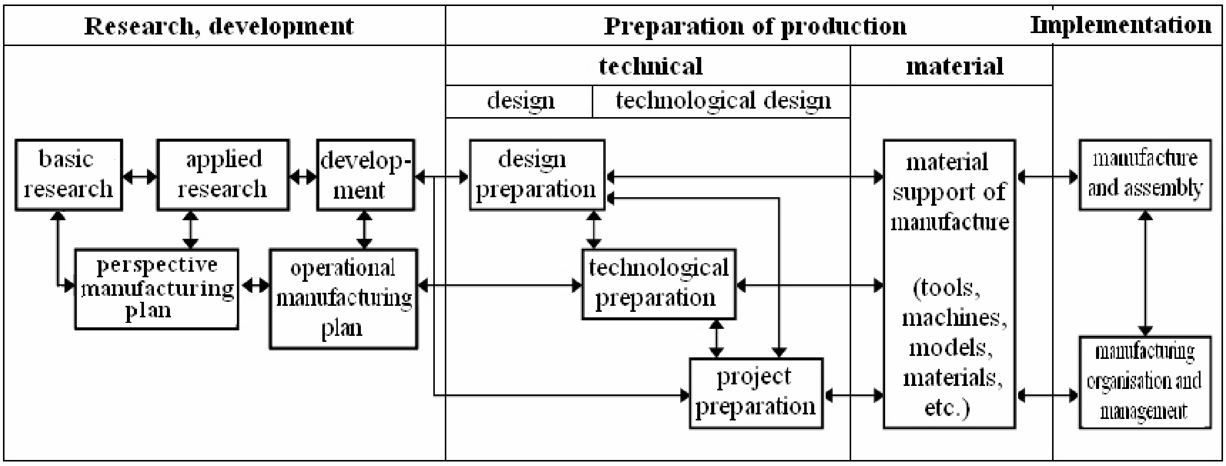

Figure 19. Technical Preparation of Manufacturing

Classification of the Technical Preparation of Manufacturing (three relatively independent stages - modules):

1. Design preparation of manufacturing,
2. Technological preparation of manufacturing,
3. Project preparation of manufacturing.

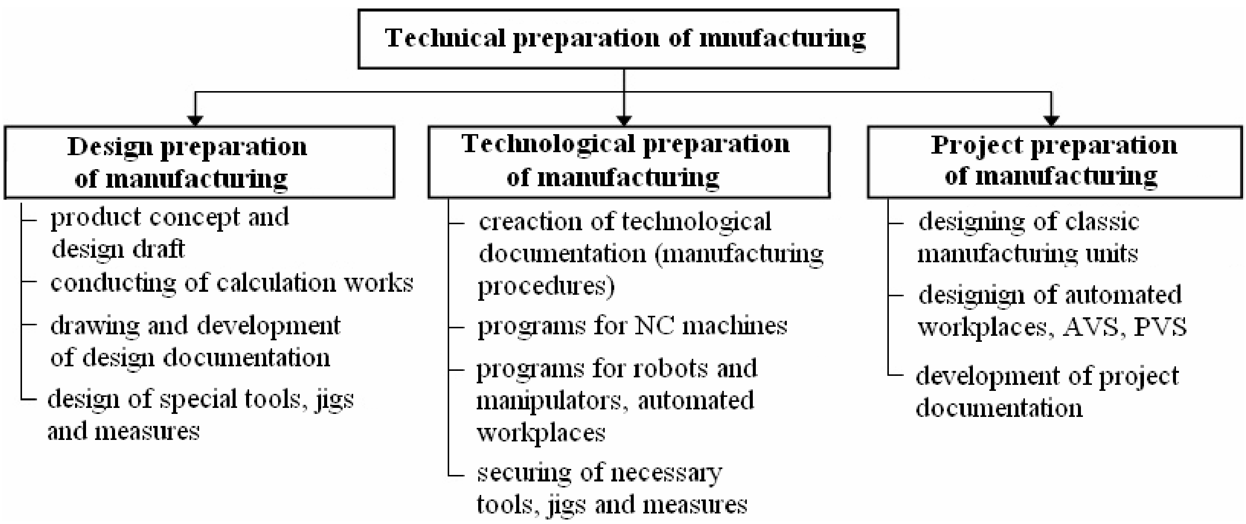

Figure 20. Contents of individual stages of the technical preparation of manufacturing

Designing of manufacturing processes:

– increasing of the degree of integration of individual activities and elements (technological, handling, control, etc.),
– close link between the TPM and the manufacturing process itself;
– larger cooperation between individual TPM units.

A model of manufacturing preparation: S1 through S3 – nodes of mutual cooperation of individual modules - KPM, TlgPM, PPM

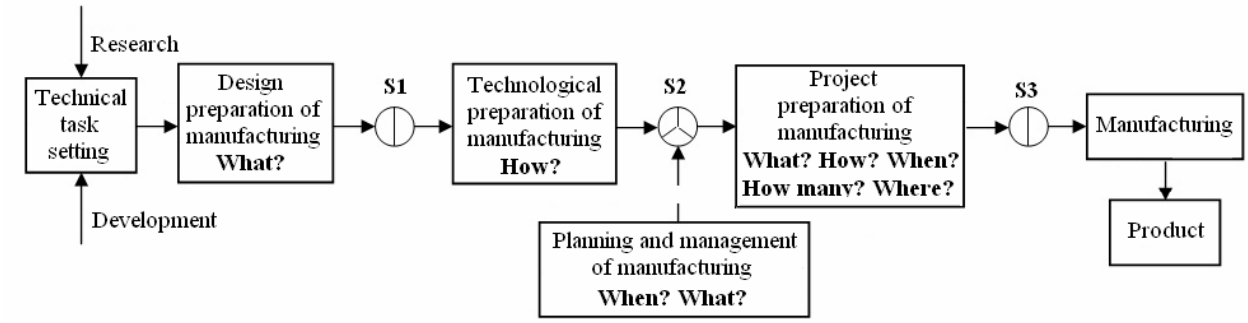

Figure 21. A model of manufacturing preparation

Technological designing – <u>the manufacturing preparation process is divided</u> into two relatively independent phases:
Phase 1 solves the relation between the „material“ and „process“ aspect of the manufacturing process, i.e.:

- What is to be manufactured?
- How will it be manufactured?

Phase 2 of the preparation of manufacturing solves the relation between the „time“ and „spatial“ structure of the manufacturing process:

- How much of what shall we manufacture?
- When shell we manufacture it?
- Where will it be manufactured?

In this phase of TPM, data of Phase 1 are analysed (design and technological) in terms of criteria, e.g.:

- maximum time and performance use of individual machines and equipment used in the manufacturing process,
- minimising of lead times,
- increasing of the degree of flexibility of the manufacturing process as a whole, etc.

<u>Task of the Design Preparation of Manufacturing</u>:

- propose a suitable function, shape, dimensions and the product’s design in terms of the needs of future users while taking into consideration safety, hygienic, fire protection and environmental regulations and current technical standards

<u>Design Preparation of Manufacturing</u> – is implemented at design departments of the company and its main role is to develop the design documentation (drawings and technical reports).

2.2. HISTORY OF DESIGNING

<u>Origins of the development of the man</u> – effort to gain control of the nature – important was the development of tools, at the beginning made for own needs and later also for exchange. They were made by handy craftsmen on the basis of their *experience and own ideas*.

<u>Medieval Times</u> – the idea of a product was transferred to *sketches*.
The best known: genius artist and technician Leonardo da Vinci (1452 - 1519)
His main inventions include: a centrifugal pump, an excavator for deepening canals, a gun loaded from behind, firearms with spiral grooved barrel, a roller bearing, etc.

<u>And also:</u>

- ideas and experience captured on sketches gradually became *drawings containing the main dimensions*.
- Requirements to achieve ever higher precision of products and replaceability of parts forced the setting of more precise conditions and requirements for the manufacturing, in particular of housings. Thus the *basics of tolerances, measuring gauges, etc.* were created.

Knowledge of *basic strength calculations* – a new quality in designing (little consideration was given to e.g. cyclical stresses and strains due to temperature, etc.).
Frequent faults of parts and engines forced manufacturers to *test designed equipment* and to remove occurring defects.

Three main rules **for ensuring <u>successful designing</u>:**

1. theoretical calculations, derived from natural laws;
2. respecting of previous experience, in particular technological;
3. verification and modifications after tests or operation.

At the end of the 19th and start of the 20th centuries, however, there was still too little theoretical knowledge that could be applied in designing. Therefore the designing methods were based mostly on *the designer's experience and feeling*. Parts, however, were made too strong and products too heavy.

After World War I, theoretical and practical knowledge quickly accumulated. The designing becomes ever more complex, which led to <u>*narrow specialisation*</u> and to the spreading of work sharing in designs and research. The growing theoretical knowledge in individual scientific fields e.g. strength and flexibility, was reflected in a higher certainty in dimensioning, especially of critical parts of machines. But it did not influence the style of designing work, so the designing still remained exclusively a matter of *intuition*.

After World War II there was a boom in <u>*designing methods*</u>. A summary of methods – *designing methodology* - will acquire the character of *scientific designing.*

Historical period	**Designing methods**	**Characteristics of creation (designing method)**	**Progress in designing**
Ancient Times	trial	manual manufacturing without a model	manufacturing experience
Medieval Times	feeling and trial	pictures drawn by hand	improvement of visuality
18th - 19th centuries	feeling and intuition	orthogonal projection, begin--nings of strength calculations	improvement of the strength solution
1890 - 1920	intuition	dimensions, tolerances, good strength calculations	improvement of reliability, increasing the precision of manufacturing data
1920 - 1960	intuition and verification	classic designing with basic scientific knowledge	good strength solution, improvement of look
1960 - 1990	designing methodology	current designing with the use of methodology and computing	automation of a part of the solution, calculations by computer
After 1990	scientific designing	scientific designing with computers and progressive methods	increasing of the share of creative work, complexity

Figure 22. Historical development and prognosis of designing

In the previous historical development, until about 1960, the human designed alone. A need to automate the designing process appeared. The arrival of equipment for processing information allowed to *partially or completely automate designing.*

2.3. MAIN RULES OF DESIGNING

Designer's main task:
- create the most competitive design, which will bring the highest economic effect, has the highest technico-economic and operational parameters, satisfies the needs of world producers and achieves high application on the market.

Main indicators:
high productivity, strength and reliability, low weight, low material consumption, small dimensions, low energy consumption, low extent and cost of repairs, low workforce costs, long interval between repairs, high durability and high degree of automation, simplicity and safety of operation, comfortable control, easy disassembly and assembly / installation and removal.

Importance of factors – *they depend on the purpose and use* of the designed machine:
1. For machines generating and transforming energy the most important is the efficiency, which determines the perfection of the transformation of consumed energy into useful one.
2. For working machines – productivity, machining precision, range of carried out operations.
3. Manufacturing of instruments – sensitivity, precision, stability of readings.
4. Transport equipment (mainly aviation and rocket) – low weight of the design, high efficiency of the engine (important due to low on-board fuel reserve).

When designing equipment it is essential:
- to observe the requirements of *technical aesthetics* (focus on the design),
- think about the *economy* (when designing, focus on increasing the useful output of the machine and increasing its durability and also on decreasing own costs and shortening times required for its manufacturing).

***Significance of the designer's work*:**
a) The designer influences:
- the costs of materials at 80 %
- unit (piece) wages at 60 %
- overhead costs at more than 20 %
- overall own costs at 55 %
- quality at more than 60 %

b) The designer, together with the researcher and technologist, ensures the turnaround of products, in which the decisive thing is the ability to compete.

The designer is a person who is involved in designing, i.e. scientific creative activity, whose objective is to achieve the required final effect (function) through the optimal combination of technical elements of various degrees of complexity, while observing other required or necessary conditions and properties, and to express the idea of the solution in the form of technical documentation according to which it is possible to manufacture and use technical objects.

Designer's activities:
1. repeatable – it is possible to algorithmise them,
2. non-repeatable – related with methods of creative work.

Methodology of designing – a set of work methods and developed special methods for optimal proceeding and work managed methodologically.

Strengths of work managed methodologically :
- Allows purposeful discovering of new technical solutions
- Allows to assess all suitable solutions for the materialisation of a certain function
- Rationalises the process of solving a problem on the basis of a specified procedure (saves time)
- Makes the selection of an optimal solution easier
- Creates a possibility for algorithmising tasks and for the use of computing equipment.

A good designer – should be able to *design actively*.
That means:
1. Should not copy existing models, but design thoughtfully and choose the most purposeful solution out of a multitude of current design solutions for given conditions;
2. Know how to combine various solutions and find new, more perfect ones, i.e. design with creative initiative and the discoverer's imagination.
3. Constantly improve the parameters of machines and manage development in the given field of the mechanical engineering industry in line with the technical progress.
4. Keep in mind the dynamism of the development of the industry and create lasting and flexible structures, which correspond with the growing needs of customers and safeguard machines against becoming obsolete.

Technique of Design According to Prof. Wőgerbauer

Prof. Wőgerbauer of Munich University of Technology, in his works dated to 1943, made a distinction between the technique of design, i.e. the art of designing, and designing as a separate activity, i.e. creating and designing of products.

Prof. Wőgerbauer:
1. Defined the relation between the time necessary for designing and the worker's designing capabilities, expressed in percentage.
2. He also expressed the functional dependence between the quality of the product, consumption of materials and manufacturing costs, and the percentage of designing skills.

Significance and Content of Activities of a Design Department

Early 20th century:
- replacement of old products with new ones was slow,
- a product could be manufactured, with small modifications, for 20 to 30 years,
- the designer could get experience from operation and prepare a new product.

Nowadays:
- a major mechanical engineering product is obsolete and impossible to sell in 6 to 8 years.
- in the case of consumer goods it is even much earlier, i.e. in 2 to 3 years.

Conclusion:
- the requirement to shorten product replacement cycles and to increase user value and complexity of products also forces changes in the way of designing;
- an individual is not able to solve large tasks alone in a short time;
- there is an apparent transition to a higher share of work;
- tasks are mostly solved by a group of designers;
- an ever increasing number of progressive methods and special equipment are used.

2.4. ORGANISATION SCHEME OF A DESIGN DEPARTMENT

Design units in companies (if they exist in a company), in terms of organisation, are mostly included into the structure of the technical unit of the company.

The location of the design unit within a company's technical unit:

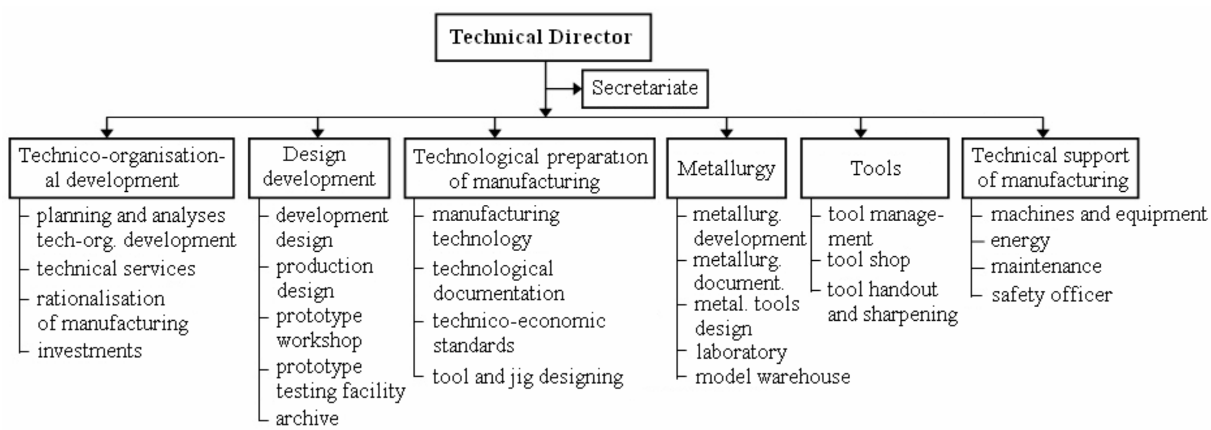

Figure 23. Location of the design unit within a company's technical unit

Technical development – continual process, in which the results of research are used for the development and mastering of the manufacturing of new technical means.

***Solution of technical development tasks* – two phases:**
1. Product development – the core of the work is in the designing activities,
2. Mastering of the manufacturing of the product – the core is in the technological activities.

The biggest part of the work on the new product is secured in the development design in cooperation with other departments.

Department of development design – included in the design development unit.

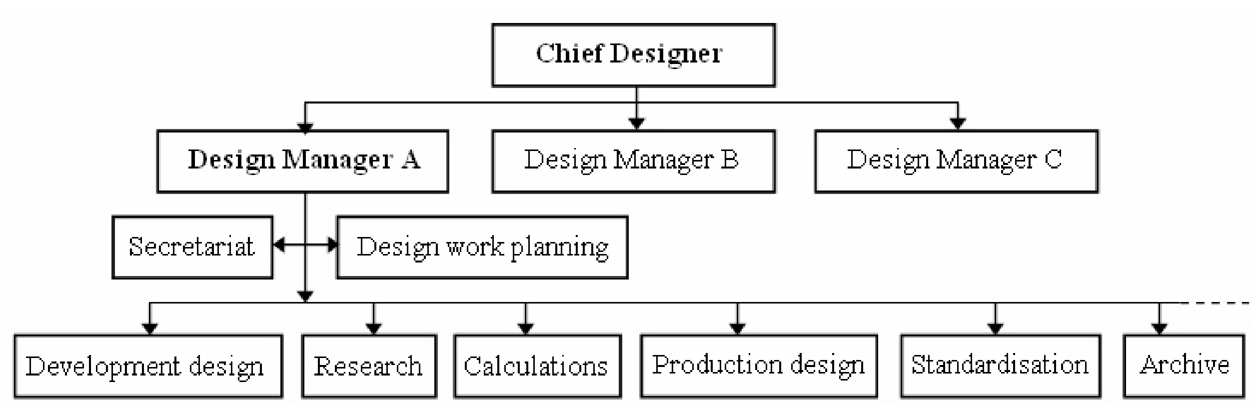

Figure 24. Basic organisational scheme of a design department

The role of the technical development ends by the manufacturing and successful tests of the zero (verification) series. Then the normal production can start. The technical section of the company is responsible for that. The manufacturing of the product is provided by the production section of the company.

Specialisation at Design Departments

Occupation of positions at design departments:
- large design departments: it is also possible to occupy special posts
- small design departments: a single worker covers more functions simultaneously

Main professions at a design department of a large company:

- Chief Designer – for the coordination of more different fields, e.g. machine tool, gearbox and tool fields.
- Design Manager – e.g. in the machine tools field.
- Deputy Design Manager – performs the function in the absence of the Manager.
- Correspondent – deals with sending, reception and recording of correspondence.
- Design Planner – plans all types of work in design units.
- Archivist – makes records, ordering and lending of drawings.
- Change Request Officer – ensures the implementation of design changes.
- Improvement Proposals and Inventions Officer
- Standardiser – cares for the observation of standards and deals with new standards.
- Officer for Scientific-Technico-Economic Information – searches for and processes information.
- Value Analysis Technician – manages value analysis tasks for decreasing costs.
- Materials Technician – ensures economical use of materials.
- Welding Technician – secures economical designing of welded parts.
- Packaging Technician – secures the attachment of a machine and its packaging for transport.
- Climato-Technologist – approves design drawings for equipment supplied to areas with more difficult climatic conditions.
- Designer – solves the main tasks of the design in terms of aesthetics and ergonomics.
- Spare Parts Designer (Officer)
- Documentation Technician – secures the processing and delivery especially of manufacturing and accompanying documentation.
- Designer for Quotations and Queries – secures their preparation, processing and supply.
- Development Designer – solves new difficult tasks that are part of the technology development plan.
- Researcher – conducts applied research on models or real products in order to get necessary information for ensuring higher reliability of the product and verification of new design principles.
- Calculation Specialist – makes demanding calculations, usually with the use of a computer and a suitable software.
- Designer – makes routine calculations and proposals and develops design documentation.
- Drafter – re-drafts drawings on tracing paper or special canvases or plastic films.

Besides the above, other specialists may also work at design departments of large companies.
In the design departments of small companies, one worker covers simultaneously several functions, in very small companies s/he also may cover the tasks of TPM.

2.4. CLASSIFICATION OF DESIGN TASKS

Design tasks are classified:
1. *By specification*:
a) tasks whose specification is compiled by the customer,
b) tasks whose specification is compiled by the designer himself,
c) tasks specified inside a design

2. ***By purpose*****:**

a) Development tasks – they are solved on the basis of outlooks into the future;
b) Manufacturing tasks – for a specific customer, mostly repeated tasks or tasks with small changes;
c) Standardisation tasks – e.g. unification of repeated similar components;
d) Tasks without material deliveries – the customer is delivered only drawings;
e) Offers – development of a simple draft design for the customer before entering into an economic contract;
f) Overhead tasks – e.g. for own workshop;

3. ***By the use of earlier drawn design documentation*****:**

a) Repeated;
b) Modified;
c) New.

Designing – one of creative technical activities (includes inventing – solution of technical issues, projection, designing – creation of designs, rationalisation – improving the use of technology).

Designing stages:
<u>Stage 1</u>: formation of ideas into drawings and documentation;
<u>Stage 2</u>: making a design, e.g. manufacture of parts, assemblies, assembly and testing.

By demand on designers' capabilities:

1. Plain designing – includes designing of simple details or a simple assembly from specified details.
2. Reproductive designing – drawing of details of a given assembly, with copying of drawings, with making drawings according to templates (principle of design is known).
3. Productive designing – designing of new details, new assemblies and machines on the basis of known equipment (uses known principles of equipment in new conditions, looks for analogies – it is not copying of already made things).
4. Creative designing – it is closely connected with inventing. At this level, new principles are looked for, new designs and inventions are made, creative work methods are most often used.

The engineer should apply his skills in particular at the fourth designing level (creative one).

Thinking operations in designing

By a thorough analysis of creative designing work, whether it is a solution of the whole design or just of a part, or a complex task, or a simple one, we can find out that the whole thinking procedure in designing consists of just a small number of thinking operations.
In designing, in particular the following thinking operations come to the fore:

1. Understand the requirements of the specification.
2. Set the conditions and criteria for decision-making.
3. Look for possible solutions.
4. Unify solutions by criteria.
5. Make a decision over a suitable solution or set new requirements.
6. Verify selected solutions.

These operations are sometimes called analysis and synthesis. The above basic thinking operations are done by the designer many times a day. Sometimes they relate to the whole task (then the second operation was made by the person specifying the design task), sometimes to its part, a component, or the smallest element of a component (e.g. thread on a bolt). Once the designer draws any line, by that he has completed, either consciously or subconsciously, all five operations in relation to that line, or has skipped them due to his ignorance of basic thinking operations and therefore has done them less well than he could.

Basic thinking operations

The basic thinking operation is understood to be an operation that is created by dividing individual partial thinking processes that are very diverse into ever smaller parts, until, at a certain division depth, the number of various types decreases to a minimum, an that is the *basic thinking operation.*
A specific course of designing is a complex individual thinking process. All designing processes, however, consist of a small number of basic thinking operations. The basic thinking operations of designing are:

1. Specification of the task.
2. Looking for a solution.
3. Making a decision.

These basic thinking operations run at various levels, e.g. at the machine level or a machinery complex level, an assembly or a component, but, despite that, they are formally identical by the type of their input and output information.
The basic thinking operations, however, are not the smallest elements of the thinking process of designing. They include smaller processes, such as: sorting of information, calculations, verification, intuitive considerations, etc. The significance of basic operations is in the fact that there is a minimal number of them and, because they are identical by their input and output operations, it is possible to set generally applicable rules for them.

Elementary chain of basic thinking operations
All basic thinking operations in the order: task setting, looking for a solution, decision making, create the basic chain of the thinking procedure of designing (see the picture).

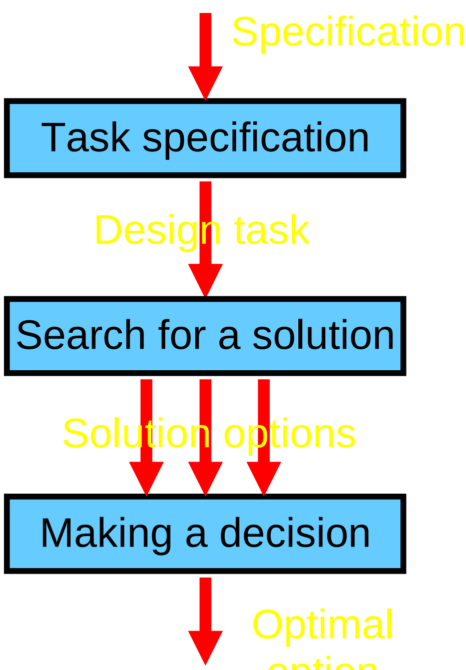

Figure 25. Elementary chain of basic thinking operations

The elementary chain is a building unit of individual designing procedures. The picture implies that the input information of the task specification operation is the specification of the design task. The output information of that operation is the design task, which is also the input information of the basic thinking operation of the searching for a solution. Likewise, the output information of that basic operation is the solution options, which are also the input information of the basic operation of making a decision.
The output information of that basic operation then should be the optimal solution (option).

2.5. METHODOLOGICAL PROCEDURE IN SOLUTION OF DESIGN TASK

Intuition and methodological procedure

Intuition:
– a sequence of thinking in which the designer relies on the right solution to come to his mind.
– designing based on intuition has been widely used in practice until now, because the use of methodological principles had not been known earlier.
– it has its own justification especially where we still do not know the methods, sometimes it is also the only possible method of designing.
– ideas obtained by intuition may sometimes be very successful, but sometimes they may disappoint, since an immediate idea may not be successful.

Methodology of designing – the total of all thinking, logical and organisational rules that usually allow to obtain a faster, more optimal solution of a design issue.

Relation between the intuition and methodology of designing: We use both for getting and evaluation of ideas when solving a design issue. One method always complements the other, it is therefore not possible to turn down the first or the second method.

With the gradual development of the designing methodology, more partial methods, which are gradually interconnected into ever larger systems, including suitable methods for computing equipment, are being added. That allows to change a part of creative tasks into routine ones, by which more room is created for the solution of new creative tasks.

Methodology of designing work

The decisive factor for the ever more successful designing is the use and continual improvement of the designing methodology, in which the proper rules and methods are brought together and generalised.

The methodology of the designing work itself includes three basic components:

1. Methodology of task specification.
2. Methodology of solving designing tasks.
3. Methodology of the selection of options and their evaluation.

All these three components are not, however, individual time phases of the designing work, which would follow one another in a time sequence, because they overlap. In terms of the methodology it is very difficult specify a precise boundary between the basic elements. On the other hand, each design task has to go through all these components.

2.6. METHODOLOGY OF DESIGN TASK SPECIFICATION

Design task:
– specification that contains requirements, data and comments necessary for the solution.
– it should be given by a certain number of elements of the specification, so that it is specified sufficiently, but not overspecified.
– it specifies the requirements for a new product or its improvement.

Phases of design task specification:
1. Task specified for the designer.

2. Analysis and review of the task (including economic aspects).
3. Study (of literature, own existing products, others' products, research reports, inventions, standards).
4. Final report on the study.
5. More detailed specification of the task.
6. Approval of the task.

The task specification can be defined as a basic thinking operation, by which the external or internal specification changes into a task, which means a set of clearly formulated requirements and conditions essential and also sufficient for its resolution.
The input information of the basic thinking operation of task specification is the specification.

Formulation of a technical specification

Specification:
– starts from the perception of the subject of designing as a material technical object,
– represents a total of properties the technical object should have.

A design task is mostly preceded by the requirement to create a technical object. It is caused by the need to create a technical object either because the required product does not exist, or it exists in a non-satisfactory quality.

Designer – has to check the specification in terms of accuracy, completeness and consistency.

The significance of the correct specification is characterised by a bit exaggerating statement:
"The correct and complete specification is a half-resolved task"

Depending on who compiles the specification for the designer, we know three types of specifications:
- specification compiled by the customer;
- specification compiled by the designer;
- specification of tasks within a design.

Specification compiled by the customer

Customer:
– compiles the specification of a design task for his conditions,
– concentrates in particular on the main parameters, price and deadline,
– does not have detailed knowledge of the proposed equipment as a designer.

The designer is morally obliged to review the specification in particular from the following aspects:
1. The designer will secure the required effect when he solves functions, the specification should not contain a requirement for a function, the designer would be limited in solving.
2. Completeness of the specification (e.g. is it desirable to exceed the parameters?), inconsistency of the specification (e.g. is a normal version required or an abnormally low noisiness?)
3. Completeness of the conditions of the specification, e.g.: climatic conditions specified as between +50°C and -50°C, but the relative air humidity is not specified, etc.
4. Conditions with technical parameters will be the criteria for the fulfilment of the task after it is resolved..
5. Possibility to use standardised or earlier resolved issues.
6. Requirements for spare parts, guarantees or warranties, etc.

The designer acts here as the opponent of the specification.
By disregarding these rules the designer runs a risk of different interpretations of the specification and negative impacts, e.g. additional modification or designing of the equipment exactly in line with the specification, but the equipment would not be satisfactory in practice because the specifying party compiled the specification incorrectly, which is the worst possible case.

Specification compiled by the designer

In this case the whole technical and economic specification is compiled by the designer in cooperation with workers from other departments.
The designer cannot act here as a critic. Therefore for new development tasks, the specification is assessed at an opponent session by a group of experts.
The designer usually compiles the specification for the whole power or dimension range of products or for a kit version.
In tems of the thoroughness of the compilation of a specification, the same rules as those for the compilation of the specification by the customer apply.

Specification of tasks within a design department

The above rules apply likewise also for the specification of partial tasks within the design, e.g. for assemblies or components, but the specifying party here is always the designer and the task is received by other designer.
Most such tasks are currently specified orally. In the case of large tasks it is no longer possible, like, for example, in the case of nuclear power plants, and tasks have to be specified in writing.
In the case of not complete specifications, the designer should always complete the data in order to avoid the possibility of not respecting some requirements.

Setting of conditions and specification of criteria for a design task

Setting of conditions and specification of criteria **–** one of the thinking operations of designing, not just for the design task as a whole, but also for each part, assembly and component of a designed object and the smallest element of a single component.
The following rule applies to the designer: Like the user of the object is the opponent of its properties, the designer should be the opponent of the conditions of the design task in terms of their error-free state.

The designer should never accept a task unless its conditions are OK.

Main rules:
1. Insufficiently specified work and operational conditions of the object of the design, e.g. the equipment works in a sheltered machine room, but it is not specified whether it works in a dusty environment with coal dust, which requires a non-explosive modification.
2. Conditions that contradict each other, e.g. the equipment has to meet the STN standards and the standards of other state (if the standards contradict each other, it is necessary to specify them in more detail, e.g. the equipment has to meet in particular the STN standards).
3. Inaccurately specified conditions, which are not possible to interpret unambiguously, e.g. the diameters of two input necks are 100 mm and the distance between them is 300 mm, it is necessary to specify in more detail to: the dimensions of the to input necks 100 ± 1 mm and the distance between them 300 ± 0,5 mm.

Similar deficiencies in the conditions of the task lead to a failure of the design.

Though other deficiencies of the conditions may not lead to the failure of design works, they unnecessarily limit the freedom of the solution and prevent the designer from achieving the best result.
Typical example: confusion of the required effect with a function, operation, or intrinsic properties of the object. They usually are, e.g. the way of implementation, dimensions or material, which, however, should be left for the designer to be decided upon.

Incorrect	Correct	Methodological lesson
The part has to be made of stainless steel	The part has to be resistant to corrosion in the environment with dripping process water	Prevent the confusion of the effect with the function
The skin has to be 2 mm thick	The skin has to withstand an impact of a round weight with the effect of 100 Nm	Prevent the confusion of the effect with the function
The cutting edge has to have hardness of HRC = 58	The cutting edge has to last at the full power output of 10^4cuts	Prevent the confusion of the effect with the function
The drum of the belt conveyor has to turn at 30 RPM	The belt conveyor has to provide an output of at least 0.5 $m^3$of sand per minute	Prevent the confusion of the effect with the function
Secure the distribution piping with stop cocks	Secure independent manual closing of both branches of the distribution piping	Prevent the confusion of the effect with the function

Figure 26. Examples of incorrectly and correctly set conditions

Requirements for the machine should be specified by a set of utility properties. Dimensions, speeds, etc. should only be specified by the conditions, if they are connecting dimensions to other equipment. This method of specification is more demanding for the specifying party.

The specifying party should always set the conditions for:

1. Effect – type and quality of utility value;
2. Performance – quantity of utility value;
3. Operational and working conditions;
4. Quantities and deadlines;
5. Economic effectiveness;

A special attention is deserved by the so-called inverted (oppositely-specified) conditions, which state what the product does not have to meet. Their respecting may make the manufacturing or operation of the designed product much more economical.

Condition	Possibility of savings
The machine does not have to have reverse run.	The design solution just for one turning direction. A device for changing the turning direction is eliminated.
The component does not have to be demounted.	Use grooved pins instead of bolts.
The pull-push rod transfers only pull	Use a cable a tape instead of a rod.

Figure 27. Examples of oppositely specified conditions (inverted conditions)

The whole set of conditions also includes all types of regulations (safety, construction, health, quality, standards, patents, etc.), furthermore they also include limiting influences (condition of the manufacturing base, availability and price of materials, transport possibilities). These conditions are not specified by the party specifying the task or the design task solution provider, but the designer is always obliged to respect them.

The main criterion for the fulfilment of a design task is the meeting of its conditions.

The criterion by means of which the final solution is chosen, however, in most cases also includes the possibility to improve such conditions of the specification, especially where it means the achievement of better results against the requirements.

The above overview of methodological rules about the conditions of the design task also similarly applies to the conditions of each part of the machine. The difference is that these conditions are set by the designer himself. A part of the machine is then in the same relation to the higher-level unit as the machine is to the specifying party. To keep the highest freedom of design, also here it is necessary to set the requirements for the effect of the part, not for its function, design or modification (general expression of the specifying party's requirements is necessary, i.e. without a proposal of the design solution, the designer secures the effect by solving a specific function).

When designing, the requirements should be chosen to fit as best as possible in terms of the effect of the part. The conditions and criteria of a part are usually more simple. The criterion is often very simple. In most cases it is the achieving of the effect at the lowest production costs or at the lowest weight.

2.7. METHODOLOGY OF SOLVING DESIGN TASK

The most important activity of the designer is the solution of technical tasks and issues.

That implies the designer's contribution to the design team and development of the company.

Main rules for solving design tasks:
1. Although the designing work is distinctive by its use of exact sciences, its core (drafting, inventing, creation of technical means) largely keeps its character of an intuitive activity.
2. Designing work may be rationalised by complementing intuitive thinking procedures with procedures based on conscious exact thinking.
3. The use of exact methods in designing is directed towards the use of computers for not just numerical calculations (e.g. strength ones), but also for logical operations in the field of synthesising technical solutions and their selection.
4. Even during the replacement of the intuitive activity with methodological one, its significance in designing work will not decrease. The creative work will be freed of activities in which it is replaceable, towards activities in which it is irreplaceable.
5. The knowledge and the use of exact methods of thinking work may, besides its own application, act positively on the increasing of the level of intuitive thinking.
6. It is necessary to strive to make sure the work of excellent designers does not leave just perfect designs, but also everything that is possible to say about the methods they were made with.

Individual solutions of design tasks may be achieved in multiple ways (methods). This stage of the designer's work is often called the searching for alternatives.

When looking for alternatives, the designer should be governed by the following rules:

1. For a given specification it is usually possible to find more alternative solutions and therefore the very first idea should not be drawn into details immediately, it just should be noted.
2. When looking for other alternatives use suitable special methods.
3. Try to generalise the issue and first find the basic principles, and only then, after the selection, solve partial issues.
4. Do not copy models blindly, but try to find a better solution alone and justify it.
5. When proposing alternative solutions, own proposing intertwines with the calculation and decision making according suitable criteria.

   It is not important what way new ideas are obtained, whether there is reliance on the capabilities of the brain, or whether also some special methods, focused on the support in obtaining proposals, are also used. There are several methods to assist in searching for alternative solutions.

Methodology of design tasks

The most important activity of the designer - solution of technical tasks and issues.

That implies the designer's contribution to the design team and development of the company.

Designer's main tasks:

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2. Designing work may be rationalised by complementing intuitive thinking procedures with procedures based on conscious exact thinking.
3. The use of exact methods in designing will be directed towards the use of computers to the ever larger extent for not just numerical calculations, but also for logical operations in the field of synthesising technical solutions and their selection.
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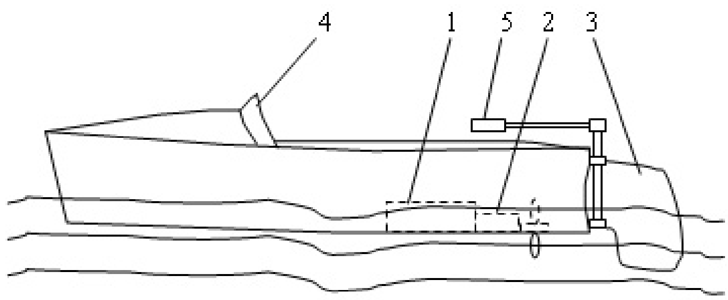
Method of setting relations

The setting of relations follows the setting of conditions and often intertwines with the search for possible solutions. It is advantageous to depict mutual relations graphically.
Relations between components or a group of components of an existing product can be shown graphically relatively easily. This allows to use a similar diagram also for a new product. Instead of specific components or groups of components, relations of a generally specified internal mechanics are marked out graphically.
<u>Example</u>: Marking out of relations between assemblies of a designed product – sporting vessel – is shown in fig. 28. The generalised diagram of external relations of the sporting vessel is in fig. 29.



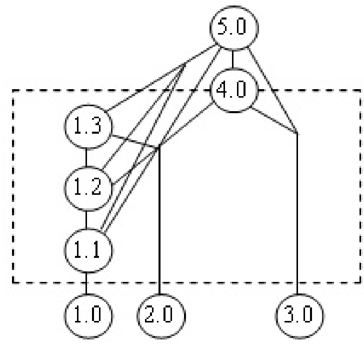


Figure 28. Main design assemblies of the vessel
(1.0 drive, 1.1. engine, 1.2. clutch, 1.3. transmissions,
2.0. transmission of movement, 3.0. change of direction,
4.0. frame, 5.0. control)

Fig. 29. Diagram of vessel's external relations

The advantage of the depiction of external relations in a diagram is in the fact that it is more successful in detaching from the existing solution. In the diagram we can look for many alternatives.

Systematic methods

Systematic methods in the field of creative thinking start from the current state of scientific knowledge of phenomena and logic of the laws of development. Their common methodological basis is the scientific methods of knowledge, such as analysis, synthesis, abstraction and generalisation, specification, induction, deduction, etc.
In methods of systematic thinking it is always the matter of a logical, scientifically orientated and often complex thinking process of gradual creation of hypotheses and prediction of effects. Based on these principles is further procedure of systematic thinking and solving of issues.
The percentage of probability of finding a suitable solution with such methods is definitely higher than in the case of methods based on the intuitive technique of creative thinking.

Methods based on adopting models from the nature

On the basis of these methods of the so-called bionic principle we examine how a required effect is materialised in the living nature.
Bionics – science about original technical systems and technological procedures the man has developed on the basis of ideas taken from the living nature. Along the diversity and perfection of natural designs, the nature knows just one development method, i.e. gradual small, almost continuous changes. In a certain period of time however, by our measures immensely long, quantitative changes will grow into a qualitative change. Thus, by a long development, created were, e.g. fins out of body wrinkles, legs from fins and wings from fins. Abstract thinking allows to speed up this long-term development and thus obtain a qualitatively new solution.

Methods of evoked (provoked) intuition

The basis of generated ideas is the process of psychological thinking irritation and the provoking of sensual and thinking processes. The information source of the stimulated intuition, based mostly on association processes, is:

- information on the historical and present states of science and technology;
- knowledge learned from the solution of various phenomena in the nature;
- general knowledge of physical and chemical laws and phenomena;
- life experiences from various fields of life, etc.

There are several proved methods of evoking an atmosphere full of original ideas:
brainstorming, brainwriting, metaplan, synectic method,126 method, prompt word analysis, window-viewing (look through a window).
It is possible to used them at every workplace and in the solution of any issues.

1. Brainstorming

I literally means “storming (attacking) the brain".
Essence of the method: - 5 to 12 people get together for about 1/2 to 3/4 of an hour to think up the maximum number of possible solutions to a specific issue:

- it is suitable for the solution of not too specialised issues;
- each participant should mention about 6 to 8 ideas;
- between 50 and 100 ideas should be generated by the brainstorming;
- participants in the group should not know each other; they should not be workers who’s job is to develop the task or who know it;
- the solution providers will get proposals in the end, they will assess their viability and develop them; the ideas are considered to be the product of the group;
- everybody may think freely, say anything; let ideas flow freely; they do not have to be thought over or justified in advance;
- the brain gets into a tempo, barriers in thinking are overcome;
- rules have to be followed: senseless ideas are welcome, only then the original ideas are delivered; criticism is forbidden, nobody should be afraid of what they say;
- quantity is more than quality, it is better more ideas are accumulated rather than a few perfectly thought ones;
- all ideas have to be assessed additionally;

2. Brainwriting

It is actually a written form of brainstorming, which has one advantage: Also those who otherwise do not speak very much get their “turn to speak". Time in which each person writes down on a card his/her own idea about how to solve a specific issue and passes it on clockwise has to be specified in advance. Each new idea is written on a new card and passed on around, so that everybody comments on it. At the end, all cards are collected, ideas are written on a large board and assessed.

3. Metaplan

The procedure is similar to that of the brainwriting. Each participant, however, remains anonymous, so no teaser or critic may disrupt the creative process of the team. Nobody speaks, everybody spontaneously writes on cards ideas how to solve a specific issue.

4. Synectic method

Synectics (Greek) means the connection of various, apparently not related elements.

It is more systematic when compared with brainstorming. The spontaneousness is replaced by conscious evoking of associations and an effort to mimic a creative process artificially.
The group has between 2 and 6 persons who should be well acquainted with the use of the method. The method requires a suitable subject of discussion and the team leader's talent.
Rules for the use:
1. An unknown task becomes known by a detailed analysis, a precise definition, or by new formulation of issues;
2. Participants are deliberately presented the issue in a way to gradually get away from the usual view of it as they learn about it.
3. The issue is assessed from new perspectives, new possibilities for solutions appear, which are assessed by not engaged specialists.

5. 126 method

A solution providing team (6 members) is presented an issue. Each of them writes 3 proposals for the solution. After about five minutes he/she passes his/her sheet to the neighbour. When the sheet makes a turn, after each member adds his/her own proposals, the initial member adds 3 proposals to it.
On each sheet there are 7 x 3 = 21 proposals for solutions.
On 6 sheets there are 6 x 21 = 126 proposals for solutions.

6. Prompting word analysis

It often happens that the solution of a burning issue appears in a completely different field. Example: A proposal for a new stall at a trade fair. A 'prompting' word from the lexicon is chosen.
It must not have anything in common with the issue being solved. Write everything that is related with the word, whatever comes to anybody's mind (cat – claws, whiskers, paws, back, etc.). Then a relation between those words and the original question is sought (claws may lead to an idea to equip the stall with bright colour information, sensitive whiskers to protect expensive displayed machines by sensors).

7. Window-viewing (look through a window)

This modern method for increasing creativity requires in particular an agreement with the manager or the colleagues:
The worker gets a permission to disengage from his everyday work. Thus he has an opportunity to dream, being freed from stresses. In this way a lot of constructive ideas are born.
In Japan: The best paid collaborators of advertising agencies are called window-viewers. They do not have any deadlines or document files, they are not disturbed by a telephone. They, alone, dreaming, in peace, look 'into nowhere', dream and create.

Elementary methods for obtaining new solutions

For normal practice, and in particular for solving small assemblies and parts of machines, suitable are so-called elementary methods, which allow to get quickly many optional solutions. They include:

a) Analogy method

New topics for the solutions of issues can be obtained from the analogy of similar situations for other issues in the nature or in the technology. For example, the knowledge of the working of the nervous system is used in the technological field of information processing (artificial neuron networks). Example: A maple seed falls from the tree and is spinned up by the air drag, the rotation of the rotor of a helicopter is an analogy.

b) Method of the application of a manufacturing factor

It is the transfer of solutions into a different field or industry. The designer, who knows the solution to an issue in one field, uses his knowledge in the designing of new equipment.
Example: A car designer has moved on to design machine tools and when designing a lathe, he used a gearbox and a clutch from a car. The design of the lathe was very successul and the lathe was made for a long time under the SUR brand.

c) Function comparison method

The essence of the method is the search for objects that would fulfil the same or a similar function more economically than the given object.
Example: Instead of using a combustion engine drive it is possible to use an electric motor drive or a pneumatic drive.

d) Similarity comparison method

It is based on searching for products or activities that are similar by shape, arrangement, dimensions, weight, operations or movements with the compared product (not a similarity of the utility substance of the object).

e) Aggregation method

The essence of the principle is the connection of at least two known, so far individually used elements.
Example: In the Škoda 100 car, the differential and the gearbox are merged into a single box.

f) Inversion method

The principle of the kinematic inversion method is the swapping of elements of a solution.
Example: A gear pump delivers pressure oil and if it is fed with pressure oil, it works as a motor.

g) Adaptation methods – transformation of a solution for new conditions.

2.8. METHODOLOGY OF SELECTION OF OPTIMAL OPTION

The selection of the optimal option (deciding) follows after finding solutions to a design task. The result must be a decision on the best solution – optimal option, or the rejection of the evaluated optional solutions and a recommendation to continue with searching for a more advantageous solution.

Designer's deciding – a specified measure (criterion) is applied to individual alternatives, out of which the resulting alternative (optimal option) is the one for which the criterion has showed the highest value (e.g. efficiency), the lowest value (e.g. the friction coefficient for a bearing), or a satisfactory value of a measured property.

Criteria for deciding

The main criterion for the fulfilment of a design task is basically the meeting of its conditions and the proving of the product at the customer.

The method of searching for the highest or lowest value of a measured property of a criterion is used by the designer, if he has an exact criterion and measurable properties of alternatives (e.g. precision, loading capacity, own costs, etc.).

He proceeds in the same way, if he uses his sense and assesses in his imagination e.g. the level of reliability, safety or controllability.

In most cases it is the matter of expressing a ratio between the required effect and the incurred costs.

A criterion should include the main required effect of the object and the resources that are used for ensuring the effect. For most simple objects and parts it is possible to assume that their utility value or effect is the same and that, as the criterion, there only remains the measure of the incurred costs, e.g. the price, own costs, weight or labour intensity of the part.

A criterion may not only be met but also exceed. Sometimes the value of a criterion should be as high as possible (e.g. loading capacity, output), sometimes we require a criterion to be as low as possible (e.g. consumption of fuel per 1 km).

A complex situation occurs in particular when it is necessary to compare alternatives whose utility values cannot be described by a single parameter.

Methods for comparing complex alternatives

If it is he matter of a simple design, the deciding is simple. According to the evaluation of advantages and disadvantages of individual alternative solutions, it is possible to select the optimal solution properly. If more complex alternative solutions are evaluated, where the number of used parts reaches hundreds or even thousands, the situation is more complex. The designer must compare and decide on individual alternatives whose utility values cannot be described by a single parameter. In that it is usually not possible to convert one parameter into another, or to transform both into savings or other common parameter. In such cases the designer must use one of the special methods for the comparison of more complex alternatives.

a) <u>Point method</u>

The essence is in the evaluation of individual alternatives on the basis of selected criteria. The optimal solution is declared to be the one that obtains the best evaluation. The following operations are repeated in the evaluation:

- proposal and selection of criteria;
- selection of measures of criteria;
- specification of partial values of criteria;
- processing of partial values into the overall value;
- deciding on the optimal option.

The selection of criteria is difficult, the evaluation uses a simple or complex indicators. The problem may also be the possibility to determine the values of specified criteria.

The evaluation of the criteria may not always be objective and unambiguous. It is not useful to choose as criteria such properties whose values are not possible to determine in the given stage. From the physics, mechanics and other technical subjects we know units by which some properties can be measured. The evaluation of a criterion should characterise its suitability for the given requirements and should move between ‘meets very well’ and ‘does not meet at all’.

In the designing practice it is possible to allocate point evaluation of quality, e.g. by grades:

- meets very well .... 4 points,
- meets well .... 3 points,

- meets satisfactorily.. 2 points,
- sufficient .... 1 point,
- does not meet... 0 points.

It is possible to use a multipoint evaluation scale, but without a guarantee of objectiveness. If it is necessary to make the evaluation finer, it can be achieved by the expression of the weights of individual criteria. The evaluation is then a multiple of the evaluation points and the weight points. To allow some objects to be evaluated objectively in terms of quality, it is necessary to mutually allocate the selected quality points to the achieved values of properties.
The determination of values of criteria in the designing stage is difficult, as many indirectly shown properties are only possible to determine on the basis of thinking models and the corresponding methods of experiments. Here the designer's experience and honesty are the most important factors.
The last operation of the evaluation is the processing of point evaluations of individual selected criteria into the overall value. There are several known ways, from simple summing up of the points up to extremely complex processing methods. A simple and easy-to-read overall processing in a tabular way is in the form of an evaluation table:

Criteria / Alternative	1.	2.	3.	. . .	n	Σ
A						
B						
C						
. . .						
N						

Where: N - maximum number of evaluated alternatives
n - maximum number of criteria

Figure 30. Evaluation table

After the summing up of point values of individual alternatives, the alternative with the maximum number of points is specified as the optimal alternative, suitable for further development.

b) Final effect method

Initial consideration: Each proposed alternative solution consists of a certain number of elements, performs certain functions, or meets certain requirements. By the performance of the required function by the proposed equipment, or by the performance of the function by its subassembly – mechanism, a transformation process occurs, which results in certain effects. Each element or function may have:

1. positive effect – marked by value +1, +2, +3, ..., +m
2. no effect – marked by value 0
3. negative effect – marked by value -1, -2, -3, ..., -n

where: m, n – size of the evaluation of the effect.

This value is usually chosen from the range between 3 and 10. It depends on the required precision of evaluation. The higher is the effort to evaluate the effect more precisely, the bigger is the size of the evaluation of the effect. The equation m = n is usually applied. The evaluation of elements and functions of an alternative solution is followed by the evaluation stage. The final positive effect, negative effect and overall negative effect are determined for each solution.
Final positive effect:

$$FPE = \sum_{i=1}^{k} m_i$$

where: m_i - individual values of positive effects,
k - maximum number of positive effects.

Final negative effect:

$$FNE = \sum_{i=1}^{j} n_i$$

where: n_i - individual values of negative effects,
j - maximum number of negative effects.

Overall final effect:

$$OFE = PFE + NFE$$

All proposed alternatives are evaluated in this way. By the comparison of the calculated values of the overall final effects of individual alternative solutions we will find out the optimal solution. As the optimal solution we select the option with the calculated maximum positive overall final effect.

Optimal option:

$$OO = max\ (+\ OFE)$$

If the calculation produces an optimal option with a negative value of the overall final effect, the proposed alternative solutions do not meet the specified criteria and it is necessary to continue with searching for other more suitable solutions.

A disadvantage of this method is that after the selection of the optimal option, where also negative effects are taken into consideration, we cannot determine with certainty whether the positive effects are substantially suppressed by negative effects or not. The advantage is the possibility to algorithmise the evaluation with the use of a PC and shorten the time necessary for making a decision.

c) Final effect method

It is a graphic method, based on a simple consideration whether the final effect will be positive or negative. Besides the new product, also the raw material, materials, technology and other factors participate on the final effect. Each such effect may be solved in different ways, so it may influence the final effect:

- positive (+),
- does not bring effect (=),
- negative (-).

Effects of solutions of individual factors are depicted graphically in a decision-making triangle (decision-making tree).

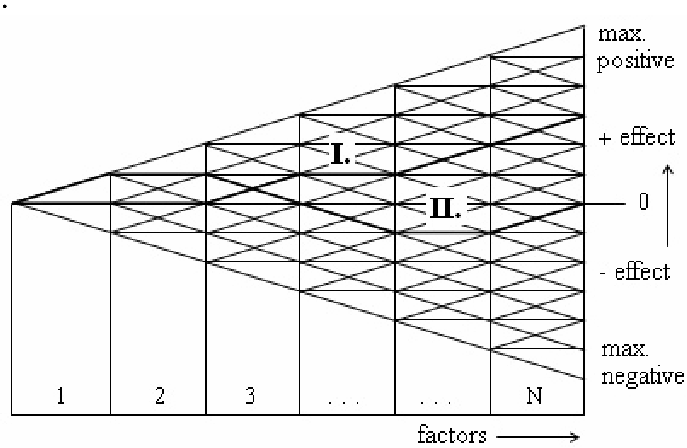


Figure 31. Decision-making triangle (decision-making tree).

A disadvantage of the method is that the effects of individual factors, 1, 2, 3 …N, are not sufficiently evaluated by three values (+, =, -). E.g. it is possible to state about option I that it definitely brings a positive effect. In the case of option II we do not know whether the positive effects of some factors are suppressed by negative effects of other factors.

d) Histogram method

It belongs to graphic methods for the assessment of multiple alternative solutions.
In the overall evaluation stage, a histogram – column diagram – expressing the number of units in individual groups into which the units were classified, is suitably used here. The philosophy of the method is similar to that of the point method – criteria are specified gradually, suitable measures are chosen for them and the sizes of individual criteria are specified.
The difference is in the processing of individual values into the required overall value and in the specification of the optimal option. The evaluation is done graphically in the form of a histogram. In it, on the horizontal axis there are individual assessed alternatives and on the vertical axis there is the number of evaluation points.
From the histogram it is clear that the most advantageous alternative is the one with the maximum height of the column. That is then developed further in the form of a complete technical documentation, which will be the source for the practical materialisation of the technological system.

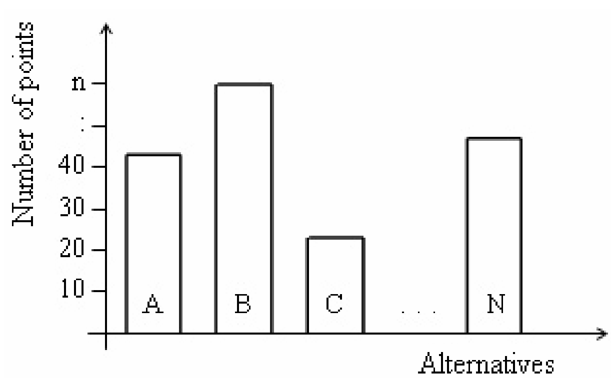


Figure 32. Evaluation histogram

2.9. STAGES OF THE SOLUTION OF A DESIGN TASK

When solving a design task, the designer goes through several stages:

Stage 1 – Study of the task
For the study of the task, the designer usually needs technical and economic information with the focus on the conceptual solution. The main type of information is literature and patent searches.

Stage 2 - Draft or project
A wide range of information from researches is evaluated. It is found out whether others' industrial and/or patent rights are infringed or not.

Stage 3 - Design (making drawings)
During the development of the design manufacturing documentation, information for the solution of assemblies and complex parts is required most frequently. Then a new solution is checked whether it infringes the protected field of industrial rights or not. At the same time, patent applications for key new solutions are prepared. In this stage, a so-called intermediate opposing procedure takes place.

Stage 4 – Manufacturing of a prototype
During the manufacturing of a prototype, the designer usually compiles draft regulations for the operation of the designed equipment, etc.

Stage 5 – Tests of a prototype
For the preparation of the tests and for the tests themselves, information is necessary in particular for tests carried out by a testing institution or by an authorised testing centre.
The designer compiles a list of patent applications.

Stage 6 – Modification of documentation
The designer requires information necessary for the compilation of the final design documentation, manufacturing, original, etc. Also compiled is the information for the preparation of the final opposing session. The modifications of the design documentation are followed by the approval of the product for serial production.

If the period from the start of the designing up to the introduction of the machine into the production is to be described in more detail, that period consists of the following stages:

1. designing;
2. manufacturing of a prototype;
3. factory modification and completion of the tested prototype;
4. industrial tests of the prototype;
5. re-working of the prototype on the basis of the results found by tests;
6. state tests and acceptance of the prototype;
7. development of the technical documentation of the zero series;
8. manufacturing of the zero series and its industrial tests;
9. development of the documentation for the serial production;
10. preparation of the operation for the serial production;
11. start of the serial production.

During those stages the designer is forced to cooperate with other units of the company. He cooperates with the technical department units, which are responsible for the materialisation of the task, and with the manufacturing department units, which secure the manufacturing of the product.

A diagram of units that materialise the company technical development process:

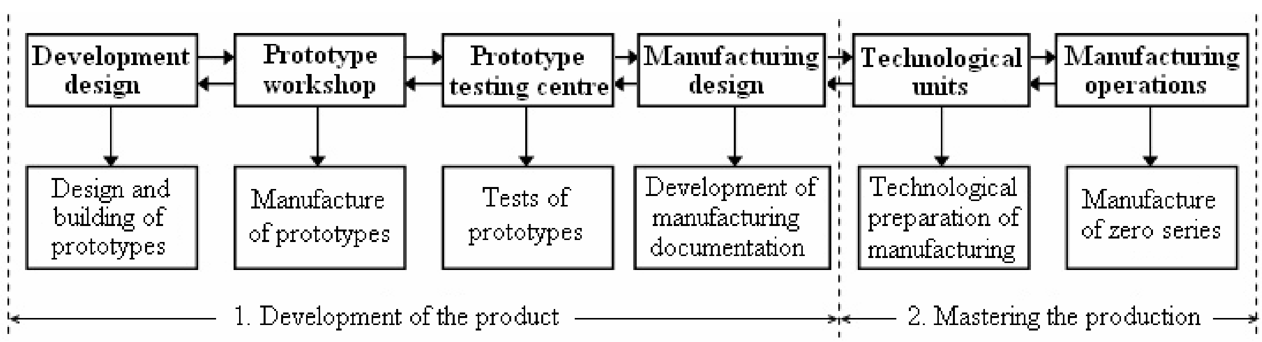


Figure 33. Units implementing the technical development in the company

Questions:
1. What is the history of the logistics?
2. What are diferences between macrologistics and micrologistics?
3. What are three basic modules of technical preparation of manufacturing?
4. What are main specialisations at design departments?
5. What are formulations of technical specifications?
6. What are methods of selection of optimal option?

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Module M06

Actual Logistics and Maintenance Challenges

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Modern Approach to Machines Operation Maintenance

Abstract: New trends in machines operation maintenance have been presented in the paper. Three methods and three periods of machines operation maintenance have been characterized. Among the concepts which have appeared, the most important ones are RCM (Reliability Centred Maintenance) – reliability oriented operation maintenance and TPM (Total Productive Maintenance) - general productivity oriented operation maintenance or operation maintenance integrated with production. Other contemporary concepts of operation maintenance as the 5S method and operator's own technical inspection have been presented too. At the end of the paper interrelationship of the quality of technological machines operation maintenance and the quality of products has been shown.

Keywords: machines operation, maintenance, RCM, TPM

1. CONCEPT DEVELOPMENT, THE IDEA OF SYSTEMATIC AND SYSTEMIC APPROACH TO OPERATION MAINTENANCE

The increasing contribution of direct operation maintenance costs to the variable costs of an enterprise, as well as competition, necessitate intensive search for the possibility to reduce those costs. Many indices show that not only the importance of machine operation maintenance increases, but so do the absolute and relative costs of that maintenance (it has been known for many years). The ratio of the operation maintenance costs to the turnover, depending on the branch, is 4 – 13 % (Werner G.W., 1998).

An analysis of the approaches to operation maintenance in time perspective allows for the distinction of three periods (Jasiulewicz - Kaczmarek M., 2005; Moubray J., 1996; Piersiala S., Trzcieliński S., 2005) which evolve one into another (Fig. 1):

I – the period of reactive maintenance – repairs when a failure appears,

II – the period of preventive maintenance – planned and preventive repairs,

III - the period of predictive-proactive maintenance – preventive inspections, technical condition monitoring, participation of the machine operators in the operation maintenance, RCM, TPM, 5S, operator's own inspections.

The first period, from the beginning of the use of machines and devices to approximately the beginning of the Second World War, was characterized by immediate reactions to failures, i.e. reactive operation maintenance dominated. At that time, due to relatively low level of mechanization, failures had not significant influence on production continuity. Therefore, with some simplification, it can be stated that preventive actions were not necessary except cleaning and lubrication. Machines and devices were simple in their design and the service of them did not require high qualifications. Major service actions, such as machine overhaul, units' repairs or regeneration of parts were performed as a reaction to failures. Enterprises were oriented for the product and manufacturing, considering operation maintenance as an auxiliary activity, which cannot be planned, and the cost of which is hardly predictable. That opinion was a consequence of the conviction that the intensity of failures of technical objects depends on their age and is related to their growing physically old.

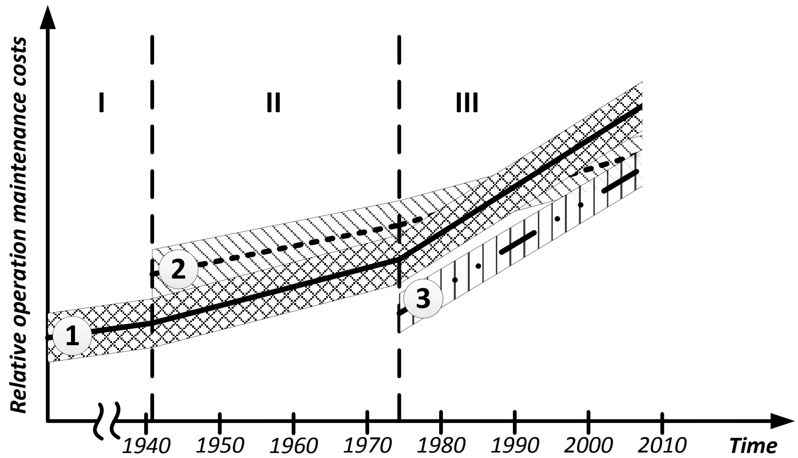

Fig.1. Three periods of development (I, II, III) and three methods (1, 2, 3) of machines operation maintenance

During the Second World War the availability of labour decreased while the demand for industrial products, particularly those for the military forces, grew. This necessitated a higher level of mechanization of the stock of machines. Since the fifties many technological machine types were already numerically controlled and their design was increasingly complicated. The influence of a failing device on the production continuity has also grown. The question whether a failure can be prevented and how this should be effected have become important. The concept of a system of planned preventive repairs has appeared. Its essence is servicing machines and devices at predetermined time intervals or after a predetermined work is performed (strategy acc. to operational potential).

At that time, the change in thinking about operation maintenance has resulted in:

• the concept of failure prevention (preventive operation maintenance), because the manufacturing processes have become more dependent on the condition of machines and devices and the opinion on the failure intensity has changed,

• increase of the importance of the systems of planning and control of operation maintenance due to the increase of operation maintenance costs as compared to other operation costs,

• interest of enterprise management in the extension of technical object life due to the increase of the capital engaged in the machines and devices.

The application of the strategy acc. to operational potential (the system of planned and preventive repairs) is a start of new thinking in terms of a system as regards operation maintenance. From that moment one can speak about systems of operation maintenance of machines and devices.

The strategy of preventive operation maintenance is not successful when a significant number of failures occur at an early stage of utilization. This fact and the further development of industrial production (increasing number of utilized machines and devices of growing value have changed the attitude to the methods of operation maintenance. According to Moubray (Moubray J., 1996) in the middle of the nineteen seventies the new approach to the operation maintenance has begun (beginning of the III period of the development of operation maintenance methods – compare Fig. 1), the most important element of which was the assurance of trouble free operation of machines and devices in the whole period of their exploitation. At that time, the characteristic features of industrial production, influencing the way of thinking of operation maintenance were (Jasiulewicz - Kaczmarek M., 2005):

• significant changes in industry – increase of the number, variety and complexity of technical objects as well as automation and robot utilization in manufacturing processes;

• new possibilities of performing operation maintenance works resulting from the development of technical diagnostic tools;
• new concepts of enterprise organisation and management, particularly the world-wide tendency to manage the inventories according to the Just-In-Time principle (JIT) and improvement of product quality by the method of Total Quality Management (TQM);
• increase of the operation maintenance costs; in some branches of industry it is the highest or the second highest element of operation costs and, as a result, in 30 years operation maintenance costs have become a priority in the cost control;
• constant raising of the standards of industrial safety and the questions of environment protection: the number of legal requirements to be observed with proofs of the observance;
• new understanding of the relationship between the physical age of machines and devices and the intensity of failures.
A consequence of the above changes was new concepts of operation maintenance of machines and devices. In the classical approaches, the importance of inspections was emphasized, in the new ones the attention has also been drawn to:
• auxiliary tools for decision making, such as: risk assessment, models of failure intensity and analysis of failure results, expert systems,
• new techniques of operation maintenance, e.g. condition monitoring,
• modified understanding of organisation leading to participation and team work.
Among the concepts which have appeared then, the most important ones are RCM (Reliability Centered Maintenance – reliability oriented operation maintenance (strategy according to reliability) and TPM (Total Productive Maintenance) - general productivity oriented operation maintenance or operation maintenance integrated with production).

2. RELIABILITY ORIENTED OPERATION MAINTENANCE

Publishing of the RCM concept at the turn of the nineteen seventies and eighties was, in many aspects, a milestone in the way of improving the operation maintenance methods. According to Moubray (Moubray J., 1996) RCM is a procedure of determining the actions necessary to maintain machine's or device's efficiency considering the conditions of utilization. Their importance for the production process and for the product quality is taken into consideration. Furthermore, consideration is also given to the working conditions, technical condition and the history of the machine utilization. Reliability oriented operation maintenance is particularly recommended in the cases of public health and safety hazard.
The essence of the RCM approach is illustrated by the seven basic questions formulated by the International Society of Automotive Engineers (acc. to Jasiulewicz - Kaczmarek M., 2005):
1. What functions does the technical object fulfil and what performance standards correspond to it (e.g. productivity, product quality class, service cost, safety) as related to the current production assignments?
2. In what way can the object fail to fulfil its functions (in what way do failures arise)?
3. What can be the reason of each functional failure?
4. What can be the results of each of those failures (what happens when a failure occurs)?
5. What is the significance of each of the failure results?
6. What can be done in order to predict or prevent each of the failures?
7. What should be done if an adequate "proactive – preventive" action cannot be found?

The key notion in the concept under discussion is failure. Two kinds of failures can be distinguished: a so-called **functional failure** is inability of the whole machine or its unit to perform its function, i.e. to meet the predetermined conditions or standards of operation; a **potential failure** is understood as physically identifiable symptoms indicating that a functional failure is about to take place.

In the RCM procedure, monitoring is largely used for the prediction of potential failure points. Due to that each part can realize its whole service period. The measurements of failure resistance decrease and illustration of the tendency in their results allow for the prediction of the point of failure.
The RCM procedure is used for the creation of the system of operation maintenance. The working schedule is significantly shorter than in the traditional methods. Less routine work means that the other tasks can be performed better. Combined with the elimination of unproductive tasks, this leads to more effective operation maintenance. A general layout of the RCM method can be seen in Fig. 2.

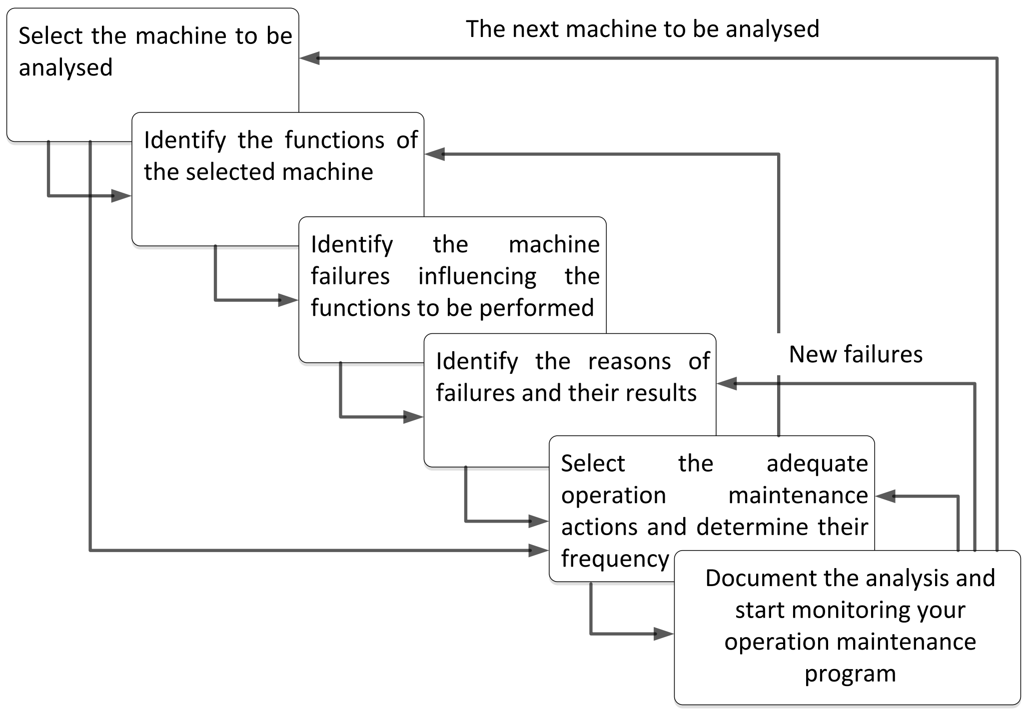

Fig. 2. General layout of the procedure in the RCM method
(acc. to Jasiulewicz - Kaczmarek M., 2005)

Correct understanding of the RCM implementation steps contributes to the improvement of operation maintenance effectivity. Success, however, is reached only if much attention is devoted to planning, to the determination of how and who performs the analyses, to audits and team work.
In the implementation of the RCM, special importance is attributed to team work. This is because, in practice, the operation maintenance specialists cannot answer the seven RCM questions on their own, particularly when the questions concerning the functions, their fulfilment, effects and results of failures. That is why the requirements concerning operation maintenance should be checked by small teams, the members of which are operators of the machines and devices. Team work allows one to learn the knowledge and opinions of each member, but also to acquire vast knowledge concerning the functioning of machines and devices.

3. PRODUCTIVITY ORIENTED OPERATION MAINTENANCE (OPERATION MAINTENANCE INTEGRATED WITH PRODUCTION)

The TPM concept is characteristic of the third period of operation maintenance development. According to Nakajima (Nakajima S., 1988) operation maintenance of machines and devices is keeping them in proper “health condition”. He defines TPM as an action performed by each

employee, being a member of a small team, in order to ensure increase of the productivity of machines and devices.
The TPM concept includes operation maintenance in the whole enterprise and its implementation involves, among others:

- identification and elimination of the basic losses occurring on the work stand: loss of availability (machine failures, adjustment and tool exchange), losses of performance (idling, decreased operation speed) and quality loss (rejects and modifications, losses due to test batches),
- preparation of a program ensuring autonomous realisation of the operation maintenance works,
- planning of the activity for the organization unit responsible for the operation maintenance works,
- improvement of the skills of the staff responsible for operation maintenance,
- preparation of a program oriented for optimization of the work of new machines and devices.

An important feature of the TPM is the introduction of autonomous keeping of machines and devices by their operators, i.e. integration of many basic service actions with the production process. The incorporation of the operators in the works for operation maintenance and the transfer of responsibility to them allows for a better utilization of the knowledge they possess, reinforces their sense of their own value and makes them aware of their participation in the achievement of the enterprise's objectives.
In the Japanese model of the TPM, four phases and seven steps of the system are assumed (Fig. 3).

Phase 1	**Phase 2**	**Phase 3**	**Phase 4**
Reduction of the exploitation period range scattering ⇓ Step 1: Ordering Step 2: Determination of the trouble reasons Step 3: Elaboration of cleaning and lubrication plans	Extension of the exploitation period ⇓ Step 4: General inspection (gradual incorporation of machine element groups)	Execution of actions conditioned by the occurring disturbances ⇓ Step5: Conservation and inspection performed by the device user	Determination of the future exploitation period ⇓ Step 6: Awareness of quality and attempting at cleanness Step 7: Maintenance of operation efficiency by the device user

Fig. 3. TPM steps and phases (Werner G.W., 1998)

When the seventh – final - step is executed, the machine or device operator takes over:

- conservation;
- inspection activities meaning initially "having a look" without tools and "listening" – the user should be adequately trained to enable him to apply measurement tools;
- simple repairs, such as exchange of worn parts, the operator also co-operates with the operation maintenance staff during the machine shutdown.

The TPM concept is not a universal solution for all enterprises. Nakajima (Nakajima S., 1988) says: “The mode and details of the TPM system utilization for maximum increase of the effectivity of machines should be adapted in practice to the individual possibilities of each enterprise. Each company must elaborate its own plan of activity considering the specific requirements characteristic of the plant, branch, production methods and the condition of the machines and devices in its possession”.

When combined TPM and RCM concepts are applied, synergetic effect arises in operation maintenance (Jasiulewicz - Kaczmarek M., 2005). The effect is possible due to the fact that the work of operation maintenance engineers (RCM) and that of machine and device operators (TPM) is combined. An example of successful implementation of both those concepts has been recorded in an automotive enterprise. Due to skilful combination of TPM and RCM, the enterprise has found the areas, in which the operators could avoid failures, prevent them or detect them sufficiently early. This has resulted in reduction of repairs and made it possible to engage the operation maintenance staff in problems requiring expert knowledge. As a result of the undertaken actions the availability of the technical objects has risen by as much as 50%.

4. OTHER CONTEMPORARY CONCEPTS OF OPERATION MAINTENANCE

In the TPM system, some elements of other, previously formulated concepts of work stand organization and observation of machines when performing their normal work have been used. One of them is the **5S method** known also as the 5S practices, assuming good discipline, order and careful management. The name of 5S comes from Japanese words:

- seiri – selection (get rid of unnecessary things),
- seiso – tidying (tidy your working place),
- seiton – systematics (a place for everything and everything in its place),
- seiketsu – nattiness (establish standards),
- shitseke – self-discipline (keep the standards).

The 5S practice is an organized program engaging all the employees in keeping clean, tidy and safe working stands. This is one of the ways leading to full engagement of the employees in the quality and reliability of machines. Although the practice is often defined as “thriftiness”, the true meaning of 5S is much broader than what is generally understood under thriftiness. It is a method of systematic teaching discipline, standardization and attempting at perfection.

The 5S method allows for creation of an environment that is of significant importance during implementation of other so called best practices:

- it is the first step towards the sense of property and pride of the place of work,
- it is an important step towards better care for the devices and their maintenance by preventive actions and early detection of defects,
- it allows for shortening of machine preparation due to reduction of time necessary to find adequate parts and tools,
- it facilitates problem solution by showing incorrectness,
- it boosts quality control by eliminating contaminated products and operator mistakes.

Operator’s own technical inspections (OTI) are procedure based on the same assumptions as TPM (Materiały, 2001). Initially, all the observations of machine and device functioning are performed by the operators during their normal works as, for example, watching the instrumentation, or day-to-day checking of predetermined elements with the use of physical effects such as smell, sounds, vibration, temperature, sight observation, changes of appearance, necessity to apply force etc. Then, after training, the operators perform inspections on their own, take full responsibility for the inspections, maintenance, cleaning, adjustments and small repairs; they also permanently attempt at improvements.

The difference between the 5S principles and the operator's own inspections are often described in the following way (tab. 1): 5S concern the place of work, but operator's own inspections – machines and devices.

Tab. 1. A comparison of operator's own technical inspections and the 5S (Materiały, 2001)

Operator's own technical inspections	**5S**
Stage 1. Initial cleaning	•sorting – action related to removal of unnecessary objects •cleaning – initial cleaning
Stage 2. Elimination of contamination sources and inaccessible areas	•cleaning – facilitation of cleaning
Stage 3. Establishment of cleaning, lubrication and checking standards	•cleaning •standardization
Stage 4. General inspection of the device	•"cleaning and thinking"
Stage 5. Operator's own inspection	•"cleaning and thinking" •standardization
Stage 6. Working stand control and management	•organization with the use of visual aids •standardization
Stage 7. Fully autonomous inspections	•keeping discipline

Operator's own inspections are the so called **best practice** used by operators who take the responsibility for the equipment and the basic maintenance by their correct service, keeping clean, lubrication and regular checks. If a problem is detected as a result of inspection, the operator performs small repairs himself and notifies the servicing staff about serious failures. Advantages of operator's own inspections are as follows:

- lower machine failure frequency,
- higher machine efficiency,
- longer machine utilization period,
- better sense of property and responsibility,
- the operation maintenance staff have more time for more advanced operation maintenance, and analysis of failure reasons,
- better utilization of the operator's potential skills,
- less time for operation maintenance.

5. COMPARISON AND ASSESSMENT OF THE VARIOUS MACHINES AND DEVICES OPERATION MAINTENANCE CONCEPTS

The method of operation maintenance of specific machines and devices depends on their design characteristics and the role they play in the production process.
Complicated, expensive devices working in automated technological lines should be maintained very carefully as their failure causes shutdown of the whole line. Therefore, the exploitation strategy should be adapted to the specific machines and devices and to the working conditions. Consequently, in workshop practice, one can find each of the approaches shown in Fig.1.
When analysing the contemporary concepts of operation maintenance (those of period III – Fig. 1) one can observe different identification and solution of problems and different perception of the role of operation maintenance in an enterprise as compared to periods I and II (Jasiulewicz - Kaczmarek M., 2005). The new approach to operation maintenance is characterized by (Jasiulewicz - Kaczmarek M., 2005); Moubray J.,1996):

- avoidance, reduction or elimination of failures, not only preventing them;
- incorporation of people's safety and natural environment protection, product quality and the level of customer service, and not only costs, into the operation maintenance;
- abandoning of the opinion relating the age of the machines with the intensity of their failures;
- determination of the frequency of operation maintenance actions basing on failure symptoms, not on the failure frequency indices;
- elaboration of common operation maintenance methods only for identical machines whose exploitation principles, functions and expected execution standards are identical
- elaboration of operation maintenance programs by the enterprise itself with reasonable consideration of the manufacturer's, not treating him as the only one authorized to elaborate recommendations;
- elaboration of programs of operation maintenance by the operation maintenance staff and the operators, not only by the operation maintenance staff;
- recognition of the engagement of the employees of all management levels, not only the technical actions of the operation maintenance staff as the key factor of success;
- recognition of operation maintenance as a strategic area of the enterprise, not only as an auxiliary service.

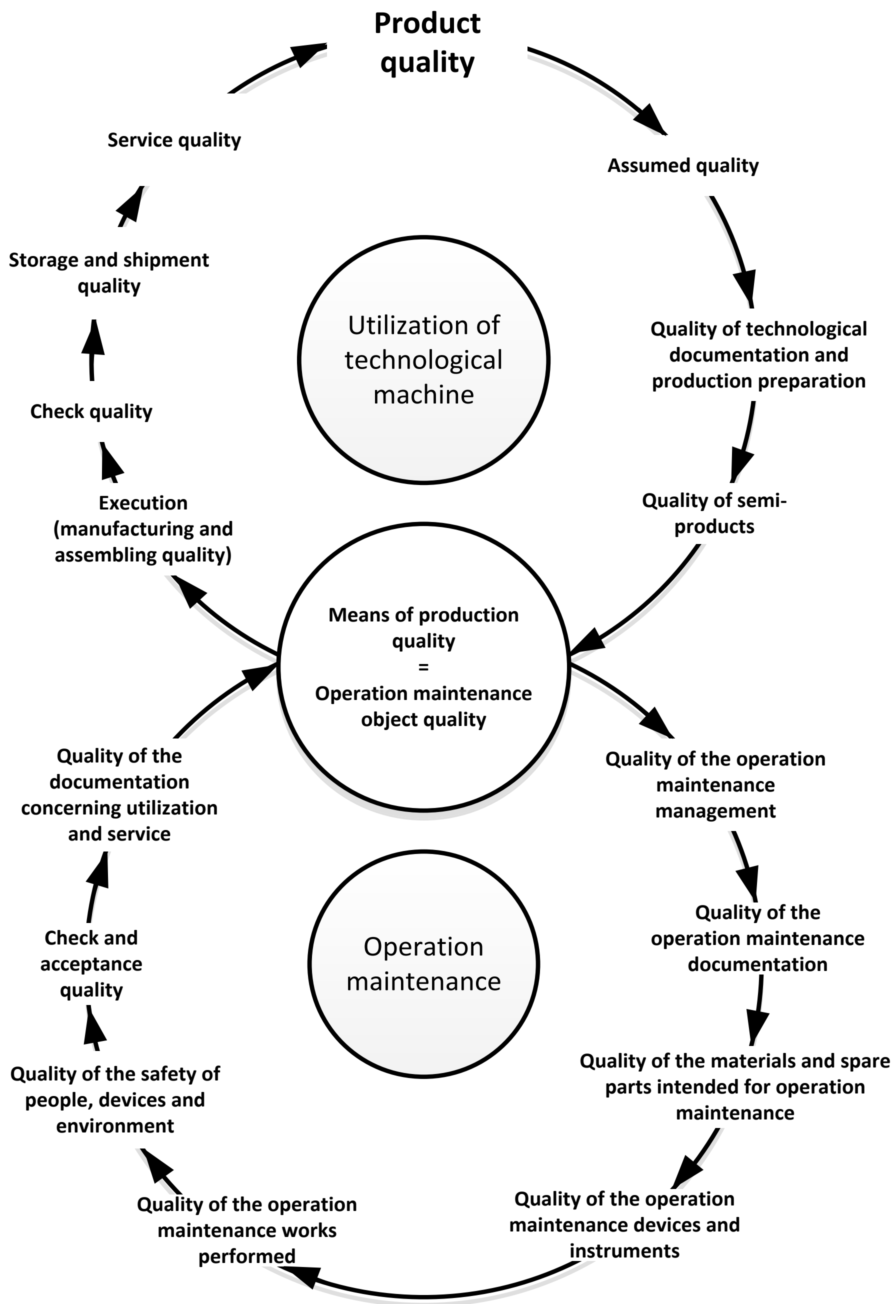

Fig. 4. The dependence of the product quality circle on the operation maintenance circle (based on Werner G.W., 1998)

6. INTERRELATIONSHIP OF THE QUALITY OF TECHNOLOGICAL MACHINES OPERATION MAINTENANCE AND THE QUALITY OF PRODUCTS

Operation maintenance is involved in the production enterprise's attempts at manufacturing high quality product. It is so because the quality of the means of production (i.e. machines and devices), to a large extent determining product quality, depends on the quality of operation maintenance (Fig. 4).

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Module M06

Actual Logistics and Maintenance Challenges

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MANAGEMENT OF THE SPECIAL CUTTING TOOLS HAVING STRATEGIC MEANING – A CASE STUDY

Abstract: *The paper deals with the subject of the functioning of logistics in a modern enterprise with a large production potential. Logistics of characteristic cutting tools has been analyzed. A value analysis has been performed and maps of logistic processes have been made for the tools under consideration by describing the present state and the proposed one. An assessment of the expected modification results has been attempted. In the summary, conclusions concerning the management of logistics in the enterprise structure have been stated.*
Key words: *logistics, strategic – special tools*

1. INTRODUCTION

Enterprises which want to acquire and maintain the status of modern organizations face continuous challenges. In order to meet the requirements of broadly understood customer, the organization, as an open social and technical system [4], should maintain management standards. Those are quality standards, of constant improvement, in the spheres of technology, production, logistics and controlling – to list only the basic categories.

Flow management in an enterprise includes, among others, two important streams: the one of production and the one of necessary tooling supply to the working stands [1, 3]. The tasks of the Tooling Department are: planning, realization, monitoring and withdrawal of adequate tools to and from the proper places while providing for the supply of them [2]. We are describing an enterprise in which strictly defined cutting tools have a special position, very important for the maintenance of continuous production and, consequently, for fulfilling the customers' requirements. The use of those tools is required by the technological processes approved by the customers and they usually have no substitutes. Their importance is determined by the difficult design process, very high specific cost and long term of supply, application of detailed procedures involved in the reception to the store, working tests or wedge wear monitoring and discarding. In the long years of experience, the enterprise has selected a group of so-called strategic tools which meet the above mentioned criteria. Due to the specific character of the firm, those are special tools, designed by the experts of the Tool Design department. The group includes: gear-shaper cutters of the thimble type and mandrel type, module hobbing cutters of the mandrel type, involute broaches and groove broaches (flat ones).

The logistics of the strategic tools in the enterprise under consideration shows some discontinuities and inadequate couplings. Due to the enterprise's change to the new computer system, too, the process requires redesign and adaptation to higher requirements. The quickly modified organization diagram of the enterprise also necessitates changes. In the scope of the insufficient system of ordering in the technical production preparation (TPP), long period of offering and reoffering of purchases, long time of waiting for supplies and imprecise criteria of supply acceptance, unclear internal transfers, those factors result in that we tend to assume a system approach to solve the said problems.

In the logistic chain of supplies, shortening the delivery times is now understood as a source of competitive superiority [1]. It allows for a stock reduction, storage costs and increases the added value of the whole chain. The complex added of the chain is made of economical utilities: possession, form, place and time. Two of them belong to logistics. In this case one can speak about the utility of place and time. The utility of place is the logistic reaction to geographically variable demand. Satisfying of that demand creates the added value. An equally strategic scope is that of the utility of time an expression of which is the delivery of a product or service in the strictly defined time. Such action also creates the added value and makes the customer satisfied. Creation of the added value is much dependent on the management of logistics including the logistics of supplies.

2. MAP OF THE PRESENT-DAY STATE OF STRATEGIC TOOLS LOGISTICS

Mapping of the material and information transfer serves for presentation of the present and the future state of processes in selected functional areas. The analysis of the strategic tool logistic processes in the whole enterprise made it necessary to create a map of the flow of value streams in order to make the material for assessment and improvement.

The map consists of:

- the basic plane horizontally divided into cells participating in the process,
- circles describing actions,
- line connections to the arrow heads defining the flow direction,
- rectangles symbolizing the records in the enterprise computer system,
- symbols of sheets type document and check,
- small rectangles containing digits and numbers, symbolizing the problem.

In Figure 1 one can see a map of the present state of strategic tools logistics with detailed consideration of the subsequent stages of the circulation of tools in the enterprise, as well as information and documentation related to the circulation. The indicated relations have pointed out critical points creating problems. Such a map is an effect of the work of an interdisciplinary team of experts.

The critical points indicated in the map can be characterized as follows:

1. Problems related to strategic tools, located in the Technical Department:
   - description of the tools in the computer system for proper selection,
   - insufficient competence related to the knowledge of the design,
   - problems with the assessment of tools delivery time, particularly for the realization of new implementations.
2. Problems concerning the Design Section:
   - difficulties in the acquisition of quantitative data of the existing tools from the computer data base,
   - lack of precisely specified tool offer path.
3. Problems concerning the Tool Room Planning Section:
   - lack of information on the quantity of available tools due to the utilization by many users and no records of the quantity in the computer system of the enterprise,
   - lack of information feedback from the Purchase Department on the offer of tools,

- lack of computer software for planning of demands and maintaining the standard states.

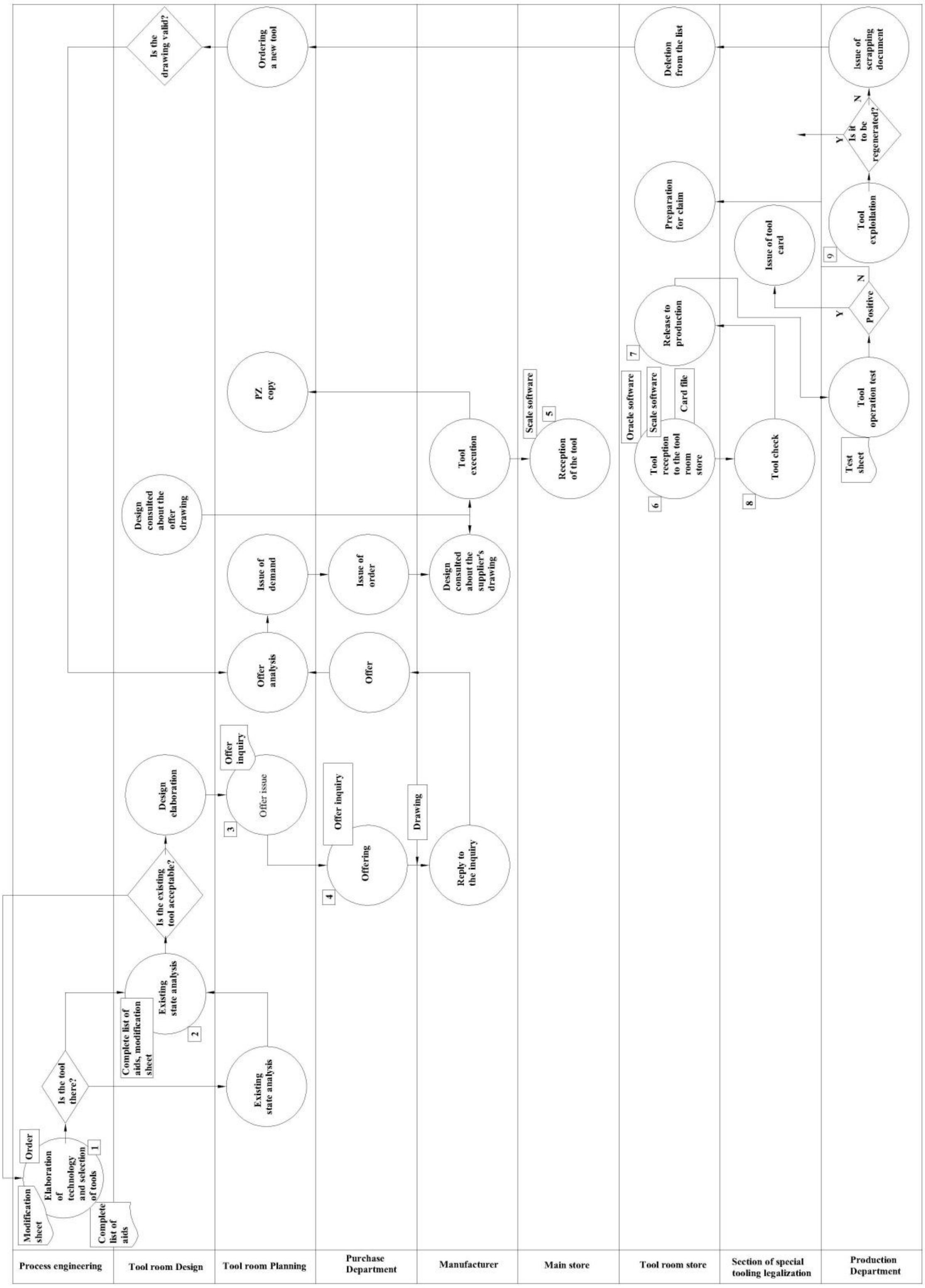

Fig. 1. *Map of the present-day state of strategic tools logistics*

4. Problems concerning the Purchase Department:
   - too long process of demand approval,
   - incomplete information on the tools being offered,
   - due to the above, too long offer cycle and too late signal to start the purchase
5. Problems concerning the Main Store:
   - tools given with the omission of the tool room store,
   - tools delivered without invoices.
6. Problems concerning the Tool Room Store:
   - incomplete store documents with the tools delivered,
   - lack of tools returns despite their wear,
   - no documentation taken for trials or, if taken, not returned in due time,
   - so small number of tools taken for trials.
7. Problems concerning the Tool Room Control:
   - no input check of new strategic tools, ones after trials and ones after sharpening.
8. Problems concerning Production Department:
   - lack of records and systematics in the assessment of strategic tools wear on the operators' side.

Basing on the problem identification performed, the following summary can be formulated:

- at almost any stage of the process, the problem is lack of information on the condition of the tools being used,
- making a demand for a new tool when it can be no longer used is too late,
- late signal of demand for a new tool results in quick decision making without detailed analysis,
- short time for the realization of an order results in limitation of the number of suppliers and the suppliers take advantage of the enterprise's situation,
- delay in tool delivery influences the extension of the production cycle,
- tool operation trials are not obligatory, new tools are not returned after trials or are kept in the store without being tried.

While the logistic system of workshop technological tooling functions well, that of strategic tools requires improvement. A proposal of systemic modifications is the map of future state of logistics presented in the next section.

3. ASSUMPTIONS FOR THE DESIGN OF THE MAP OF THE FUTURE STATE

Complex analysis of the process of strategic tools logistics leads to the conclusion that the computer system of the enterprise, comprising all logistic actions, is not fully integrated**.** It does not force the users to perform the necessary actions and does not possess adequate data bases serving for broadly understood management, from the design of a tool to its physical wear and utilization. The enterprise is at the stage of implementation of a modern computer system SAP, which supports managing of the enterprise. It is assumed that the previous computer system will be given up completely. The possibilities of the new computer system will allow for better circulation of the strategic tools in the enterprise. Nevertheless, all the above mentioned shortcomings must be eliminated because the system will not function properly without purposeful activity of the employees of various services, operators, supervision and control.

4. MAP OF THE FUTURE STATE OF STRATEGIC TOOLS LOGISTICS

Improvement of a process is not always its shortening. Some areas can be reduced while others should be brought to the state of full usability. The criterion adopted when designing the map was purposefulness of action for the achievement of the final effect - integrated transfers of all the components in a way free from the possibility of collision (Fig. 2).

The following modifications have been introduced:

- the process of the selection of tools and the relevant analysis has been relocated from the scope of the Technical Department's activity to that of the Design Section,
- the process of elaborating offers has been simplified by postulating, after the tool design is made and the demand is approved, placing an order at well proven, qualified suppliers; feedback in the case of not conforming offer drawing of the supplier,
- the task of design wear limit determination for all the strategic tools has been imposed on the designer,
- input check of the strategic tools has been introduced,
- an obligatory system of tool operation test execution with adequate couplings has been introduced; operation tests are the subject of the new issue of the adequate instruction,
- the task of recording the design determined tool wedge wear has in the computer system has been imposed on the operators,
- new principles of sharpening the strategic tools combined with the wedge wear analysis and quantitative tool wear analysis have been introduced,
- absolute obligation of records, adequate to the activity of the individual organizational units, to be done in the SAP computer system of the enterprise has been introduced; this is to improve the discipline of documentation circulation and ensure its completeness.

The present day knowledge concerning the SAP system allows us to state that the value map designed in this way can be transposed to the system modules. This requires the participation of all the services involved in logistics of the strategic tools, including the experts of the Computer Science Department.

5. EVALUATION OF THE PROPOSED SOLUTION RESULTS

The results of the presented solution will be evaluated basing on the changes seen from the map of the future state:

- The simplified actions in the Technical Department, consisting in ordering the necessary tool in the Design Section without additional analysis is expected to shorten the time of works involved in the technology elaboration. Additionally, the effect of clear distribution of tasks eliminates their double execution and precisely defines competences.
- Introduction of design wedge wear measures, combined with tool monitoring in the production departments, will result in better discipline of orders and deliveries on time.
- The enterprise has qualified suppliers, subjected to point assessment every year. Directing the orders directly to the selected supplier will significantly shorten offer elaboration and manufacturing of tools.

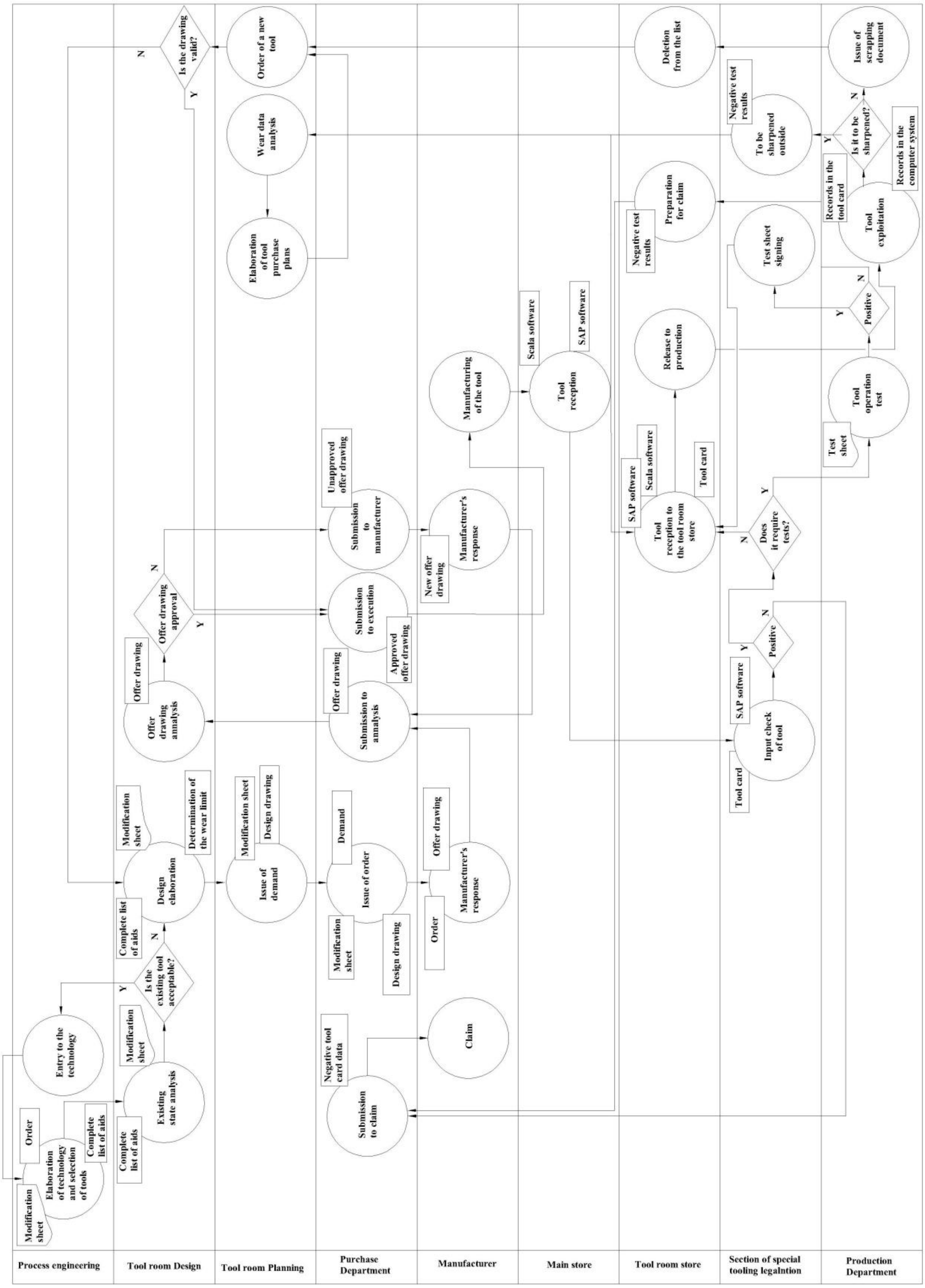

Fig. 2. *Map of the future state of strategic tools logistics*

• The created loop of the supplier's drawing approval by the designer will minimize the number of executions based on inadequate drawings. Data exchange is affected by the electronic way and the whole process is affected within not more than 8 hours. The time is incomparable to the time necessary for repeated execution of a tool.

• Introduction of the input tool check brings two kinds of effects. On the one hand, it forces the introduction of an expensive organizational unit into the structure of the enterprise; on the other hand, it makes sure that a not conforming tool, with high specific cost, will not be accepted. If a tool is accepted and entered on the list without check, no claim of it will be accepted. The cost of creation and functioning of the input check will be balanced by the quality of the tools delivered; the quality requirements in relation to a supplier can be extended by ascribing some check activities to him.

• Tool operation tests are a continuation of the input check and the same principles are to be observed in them. They generate additional costs of sample execution and performing the tests in production departments. That is why one circumscribes these strategic tools (broaches, gear-shaper cutters of the mandrel type and some of the thimble type ones, as well as mandrel type hobbing cutters) which absolutely require tests. Assigning the execution of the tests to the supplier is generally useless.

• Completely new approach to strategic tools sharpening also creates new quality. The principle of tool sharpening by the manufacturer as the one who possesses adequate means for the purpose, has been introduced. The costs of issuing orders for the service, transport, time of the process are born. What is obtained is a qualitatively well prepared tool, ensuring repeatability of application. The costs of sharpening by the manufacturer can be balanced by the value of product made by such a tool.

Some of the above mentioned estimated assessments are based on shortening of the time of specific activities. This, of course, can be recalculated into financial values, but expression of any assessments in hours is standard in many technical actions (offer elaboration, load planning).

6. CONCLUSIONS RELEVANT TO THE PROBLEM UNDER DISCUSSION

Logistic activities in the enterprise are scattered with the possibility of double execution by the individual organizational units. Therefore, it is necessary to meet the requirements as regards logistics by clear statement of its functioning. The analysis of the state of logistics in the enterprise makes us propose a systemic solution of the process. In other words, a position of Logistics Coordinator, adequately fixed in the structure of the enterprise subjected directly to the Operational Director or to the General Director, is necessary. The Coordinator should manage the network of units, practically established, in each vertical section of the organizational scheme. The introduction of the Logistics Coordinator as proposed above should bring order the activities in the scope of:

- review and assessment of the enterprise’s internal processes in respect of logistics,
- review of external processes in which the enterprise participates,
- creation of a record of the Coordinator’s activity in the Book of Processes in the category of the Main Process,
- mapping of the value stream of the logistic activities in the whole enterprise and in the outer environment,
- creation (formalization) of the subjected structure on elastic principles reacting to the changes in managing,
- concentration on the creation of internal value for the enterprise itself and external one for the customers.

Creation of the added value is one of the important postulates helping to acquire competitive prevalence. It is also important to establish criteria for the measurement of logistic activities, to check its effectiveness. All the activities should be well represented in the enterprise's SAP computer system.

The basic activities of the Logistics coordinator have been listed. In the areas located lower, a review of the processes like the one performed in the present work is postulated. The method renders excellent results in problem identification, thus creating premises for their solutions.

In each case, an interdisciplinary team of employees should be established to solve the specific problem, which would make it possible to see the problem in many aspects simultaneously.

The most important conclusion is based on the utilization of the possibilities of the SAP computer system. The stage of the system implementation is about to close and the integration of the enterprise's activity in any field should be based on that system.

7. CONCLUSIONS CONCERNING FURTHER WORKS

The activity of any enterprise should be improved. Below, one can find a number of proposals, variously detailed concerning strategic tools; in the authors' opinion the proposals should be considered in respect of the enterprise under discussion:

- As regards purchases, it is suggested that the activities involved in quality acceptance of the deliveries should be done by the supplier.
- Signing long term agreements with qualified suppliers is suggested as well as simplification of the procedure of supplies down to those to the working stand; this is a form of delivery management by the supplier.
- There is a statement saying that enterprises know better what they buy than what they use; inventory control of strategic tools should be performed, the percentage being beyond control should be assessed, as well as how much the enterprise loses due to shortage of tools.
- Electronic identification (coding) of strategic tools is postulated to be effected by the application of adequate memory carriers to locate in them all the significant data, such as the current wear state, place of utilization (identifiability), ordinal number of the tool etc.
- Advantage should be taken of the "scale profits" in the purchase of a large amount at a time, which enables lower specific price to be obtained.
- Due attention should be devoted to the packing of strategic tools to facilitate transport, handling, storage and utilization of them.

Fulfilment of the whole set of proposals listed here will bring measurable advantages. Nevertheless, any rationalization will contribute to the improvement of the functioning of the strategic tool logistics.

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Module M07

Planning and Scheduling of Maintenance

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Learning objectives:
⇒ to understand the concepts of reliability and maintenance ⇒ to understand the indicators of reliability ⇒ to understand the importance of design of reliability from the maintenance point view ⇒ to get familiar with planning and scheduling of maintenance ⇒ to know and use the different scheduling methods

1. Introduction

As far back as most old times the human tried to lighten the existence through the invention, the realization and the utilization of tools and products. Likely with the problems with the invention, the realization and the utilization of tools and products appeared the problems with these qualities.

With the increase of technical level and default the level of complexity of products we can observe the increase of influences on our life: the material welfare, the health, the safety, etc. More, the social and economic implications of some features of products succeed about the peoples who made it. We talk about reliability, maintainability, availability, assurance of environment, efficiency, cost-price and many others.

More, in the last time to be in a good position in business the companies must, beside the main targets (high-volume manufacturer of commercial products or a low-volume, high-value-added producer), to develop the ***RELIABILITY*** targets. The justification it's simple: the demands of commercial market for better products and product with constant qualities in all functioning life period.

We can easily justify the importance of reliability as science. The specialty literature [12] evaluate that a single defect can easily cost 100 units in diagnosis and repair if it is detected early in production whereas the same defect in the active life may well cost tens times more to rectify. If the failure is a design error then the cost of the re-design, documentations, re-test and eventually the cost of replace the damages products can increase at hundreds or thousands times. Compared with such losses the cost of reliability and maintainability activities is easily justified.

Another example [1]: in 1948 the radiolocation equipment of USA was in non-operating condition 84% from total time, the hydro-acoustic equipment was in the same condition 48% and for the radio-telecommunications equipment the failure percent was 14%.In a riskful period the situation was unallowable and after 10 years of research for increase of reliability and maintainability, including the activities for implementation the results, the time for non-operating condition was 2,9% for radiolocation equipment, 6,7% for hydro-acoustic equipment and 7,7% for radio-telecommunications equipment.

Likewise can be presented the situation of person involved in maintenance activities[1][2][10]:

- 20% from the total number of re-enlist personal and 15% from total number of US Army works in these activities;
- before the ravel of Soviet Union more than one million persons works for remove the failures and for keep in function the machines and equipments.

The domains in which the reliability was involved with good results are multitudinous (with permanent increasing) and the most important are in figure 1.

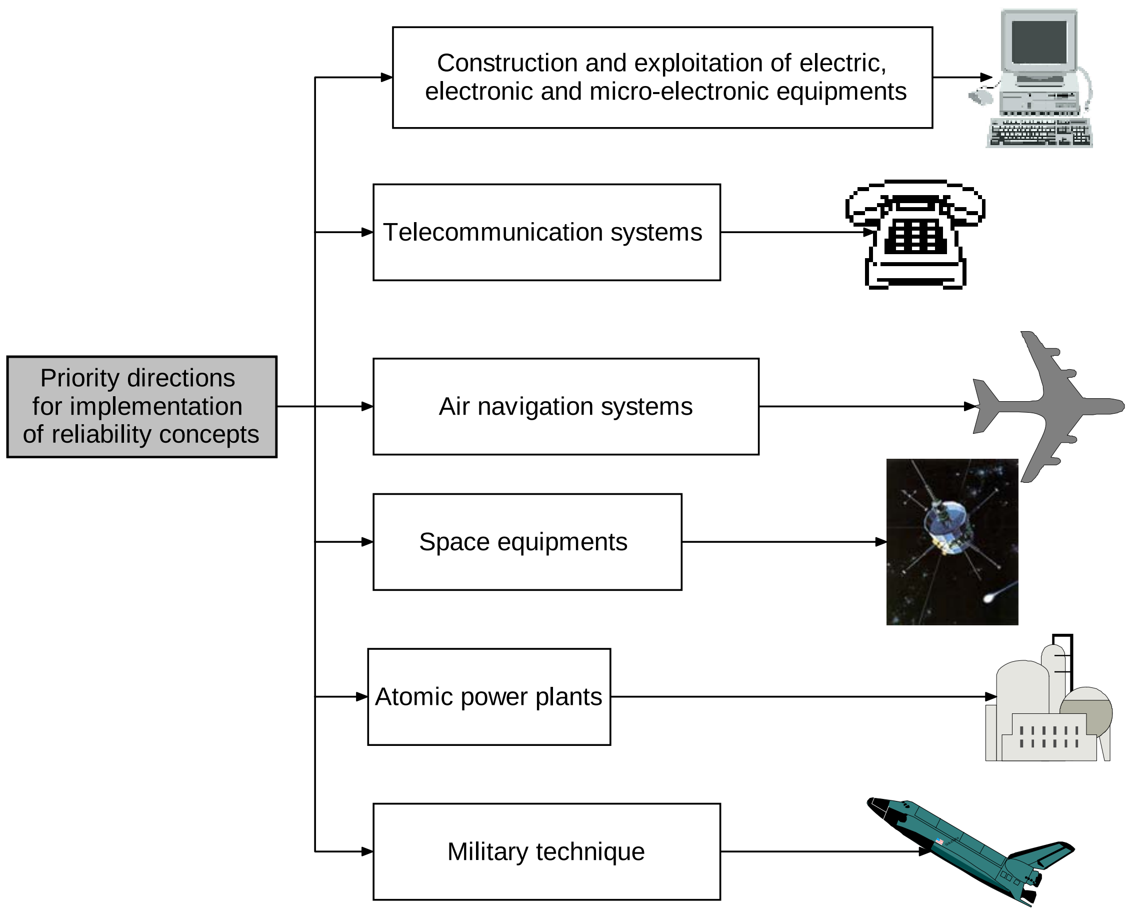


Fig. 1 Priority directions for implementation of reliability concepts [15]

The reliability objectives can be structured as in figure 2.

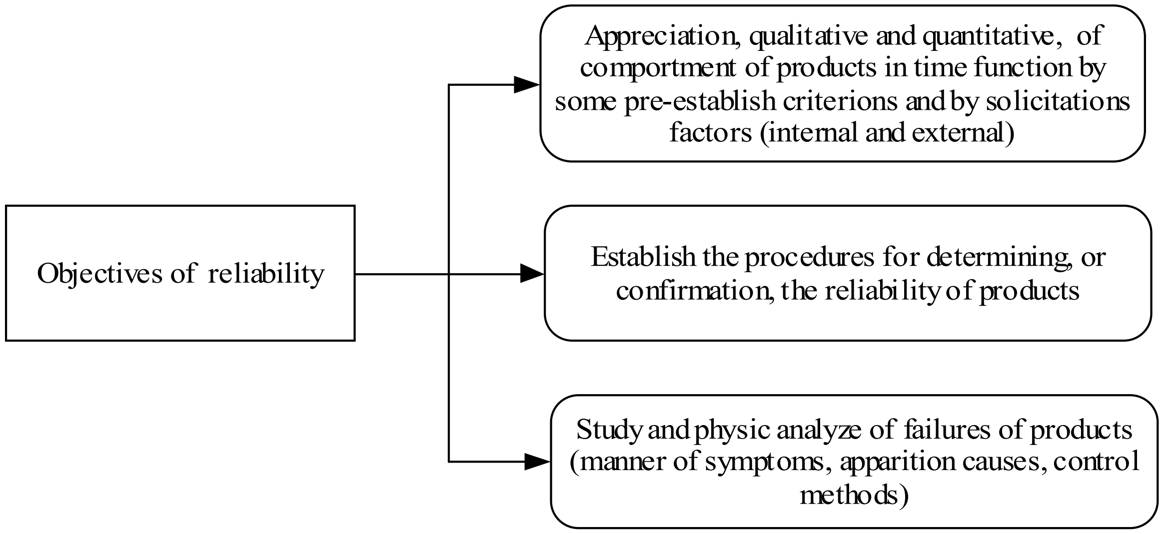


Fig. 2. The objectives of reliability

Reliability as science developed in the second part of XX century has many new basic concepts. In many countries this basic concepts were standardized [16][19][20][21] so that we can define:

- ***Functional unit*** – an entity of hardware or software, or both, capable of accomplishing a specific purpose

- ***Product assurance*** – provisions and activities for ensuring that the prescribed requirements have been taken into account starting with the design stage and that the final product holds the corresponding qualities throughout its life

- ***Reliability*** – the ability of a functional unit to perform a required function under given conditions for a given time interval.

- ***Durability*** – the ability of a functional unit to perform a required function under given conditions of use and maintenance, until limiting state is reached. A limiting state of a functional unit may be characterized by the end of the useful life, unsuitable for any economic or technological reasons or other relevant factors.

- ***Maintenance*** – a set of activities intended to keep a functional unit in, or to restore it to, a state in which it can perform a required function. Maintenance includes activities such as monitoring, measurements, replacements, adjustments, repairs, and in some cases administrative actions

- ***Maintainability*** – the ability of a functional unit, under given conditions of use, to be retained in, or restored to, a state it can perform a required function when maintenance is performed under given conditions and using stated procedures and resources

- ***Availability*** – the ability of a functional unit to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided.

- ***Error*** – a discrepancy between a computed, observed or measured value or condition and the true, specified or theoretically correct value or condition.

- ***Mistake*** (human error) a human action or inaction that can produce an unintended result.

- ***Fault*** – an abnormal condition that may cause a reduction in, or lose of, the capability of a functional unit to perform a required function.

- ***Failure*** – the termination of the ability of a functional unit to perform a required function.

- ***Redundancy*** (in reliability, maintainability and availability) - the existence of a means in addition to the means which would be sufficient for a functional unit to perform a required function or for data to represent information.

The arguments presented lead to idea that the reliability and maintainability theory, born from practical necessities, are now in position to be compulsory present in the design, in fabrication process and in utilization of machines.

All this demands a strong mathematic support, especially the probability theory and statistic mathematic, and some more knowledge's.

2. BASIC CONCEPTS OF RELIABILITY

This section introduces the most important concepts used in reliability engineering and shows the relationship between them.

> ***Reliability*** is, from qualitative point of view, the ability of a functional unit to perform a required function under given conditions for a given time interval.
>
> From quantitative point of view the ***reliability*** is the probability that the functional unit to perform a required function under given conditions for a given time interval

The definition, qualitative or quantitative, is constituted by three distinct elements (fig. 3):

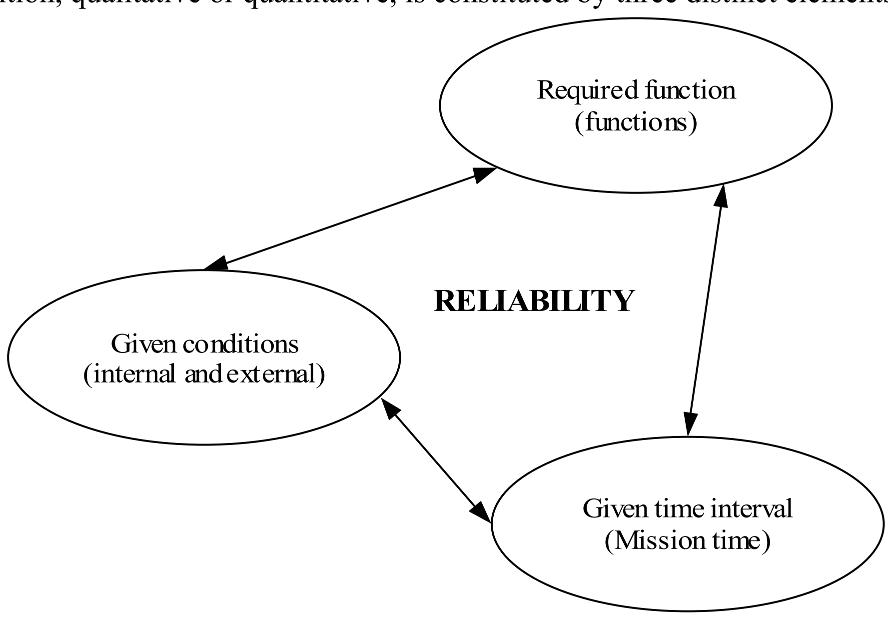


Fig. 3 Constitutive elements of reliability definition [14]

So for have a full characterization of reliability for a product is necessary to be specified:

- *required function or functions*, in acceptations of preservation of performances, qualities ascertained or mentioned at the moment of buying of product;
- *given time interval* in which the performances are preserved. The given time interval have also the name "mission time".
- *given condition, internal and external.* We talking about a complex of factors results from functioning of product (forces, movements, temperatures, pressures, et.) and from the environment (temperatures, humidity, dust, etc.).

The quantitative definition of reliability can be written under mathematic form:

$$p(t) = Prob(t > T) \tag{1}$$

Where:

- p(t) is the good function probability or reliability;
- t – time variable;
- T – maximum limit of mission time.

As any probability the quantitative expression of reliability have theoretic values in [0, 1] interval. Practically the interval is [0, 1). In functioning time the quantitative expression of reliability have variations depending by many factors but the general tendencies is to decrease. This dependencies between quantitative expression of reliability and time is called *reliability function*, generally designed by *R(t)*. The particular values of R(t) at particular moments is called shorten reliability.

On the subject of reliability function in practice can encounter some terms:

- ***Observed reliability***
  - For non-reparable products is the ratio between the number of products in functioning condition at the moment t=T (end of mission time) and initial number of products at the moment t=0.
  - For a reparable product is the ratio between the number of cases in which the product accomplish his required function and total number of requests
- **Estimated reliability**
  - Reliability for a product determined through observed reliability values for products selfsame.

  Prolusion:

    1. The source of data must be ascertainable;
    2. Results can be cumulated only in identical conditions;
- **Extrapolated reliability**
  - Reliability obtained through a definite extrapolate of observed or estimated reliability at differed mission time or differed given conditions against the observed or estimated reliability values.
- **Predicted reliability**
  - Calculated reliability of a product, starting from observed, estimated or extrapolated reliability of components of products. It's obligatory to indicate the given condition and some assumptions technical, statistical or some data bases.
- **Preliminary reliability**
  - Is the reliability established on base of some analogy's, generalizations or particularizations.

Between the terms is the correlation presented in figure 4.

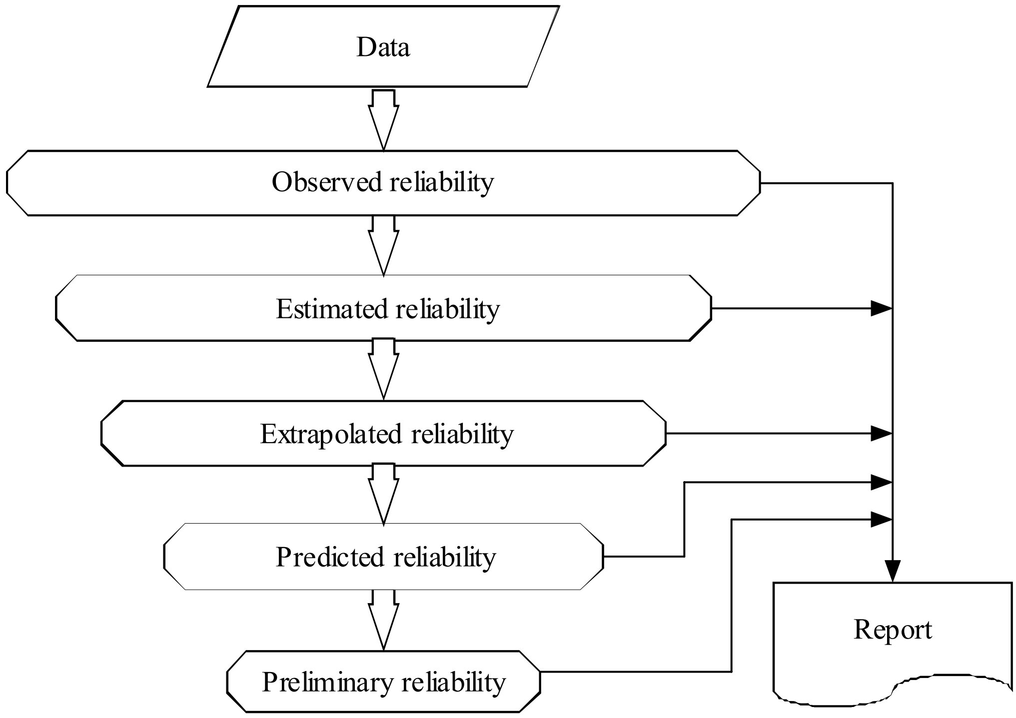


Fig. 4 General relations between reliability terms

2.1. Reliability indicators

Reliability indicators are measures expressive (quantitative or qualitative) of reliability. The most used are [1][10][15]:

- good functioning probability, R(t);
- failure probability , F(t);
- function of frequency (density of distribution), f(t);
- failure rate, z(t);
- mean time between failure, MTBF;
- dispersion, σ^2.

2.1.1. Good functioning probability

The definition of good functioning probability was given previous. For his numerical computation is necessary to analyze a statistic population N_0 over a time t. At the end of this time a number N of product are in good condition and n products are damaged.

The numerical computation relation for good functioning probability is (with these assumptions):

$$\hat{R}(t) = \frac{N_0 - n}{N_0} = \frac{N}{N_0} \tag{2}$$

2.1.2. Failure probability

Failure probability can be defined hereby:

$$F(t) = Prob(t < T) \tag{3}$$

Failure probability is a complementary concept to good functioning probability and between these two notions is the relation:

$$R(t) + F(t) = 1 \qquad (4)$$

The numerical computation relation for Failure probability is (with assumptions presented at 2.1.1):

$$\hat{F}(t) = 1 - \hat{R}(t) = 1 - \frac{N}{N_0} = \frac{n}{N_0} \qquad (5)$$

Time $\hat{t}_F$ for that a product functioning with certain probability:

$$Prob(t \le t_F) = F \qquad (6)$$

is called fractile of functioning time.

Relation (4) can be reinterpret graphic (figure 5).

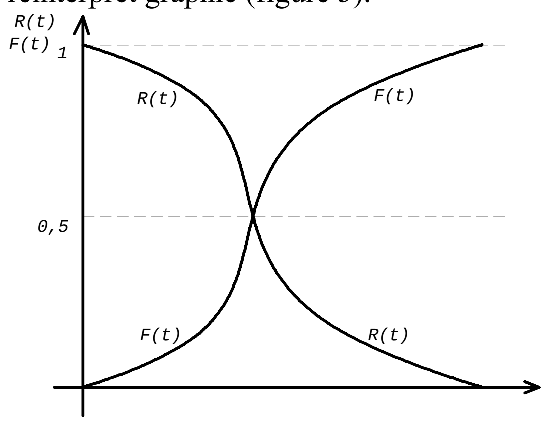


Fig. 5 Relation between R(t) and F(t)

2.1.3. Function of frequency (density of distribution)

Function of frequency or density of distribution *f(t)* is the indicator expressive of relative frequencies of failures Δn_i in a time interval Δt_i:

$$\Delta n_i = N(t) - N(t + \Delta t) \qquad (7)$$

$$\hat{f}(t_i) = \frac{\Delta n_i}{\Delta t_i \cdot N_0} \qquad (8)$$

If Δn_i is expressive of absolute frequencies f_i, product $\Delta t_i N_0 = T$ is total number of tests in considering time interval and the relation (IV-8) become:

$$f(t) = \frac{f_i}{T} \qquad (9)$$

Between the indicators R(t), F(t) and f(t) we can write the next relations:

$$F(t) = \int_0^t f(t)dt \qquad (10)$$

$$R(t) = 1 - \int_0^t f(t)dt = \int_t^\infty f(t)dt \qquad (11)$$

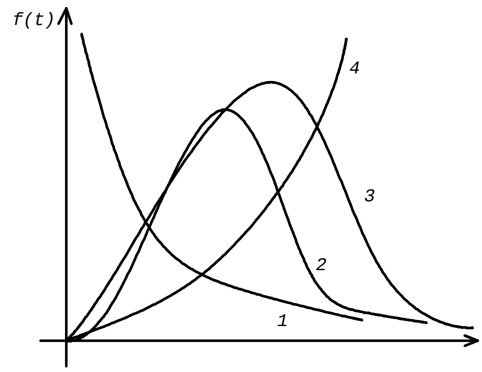


Fig. 6 Possible variations of function of frequency

2.1.4. Failure rate

Failure rate or intensity of breakdown is defined through relation:

$$z(t) = \frac{f(t)}{R(t)} \tag{12}$$

Experimental determination of failure rate for a time interval Δt_i function by absolute frequencies Δn_i is:

$$z(t_i) = \frac{\Delta n_i}{\Delta t_i \cdot N} \tag{13}$$

The measure unit for z(t) is h^{-1}.

The graphic variation of failure rate is known in specialty literature under the name "bath tube" (fig. 7).

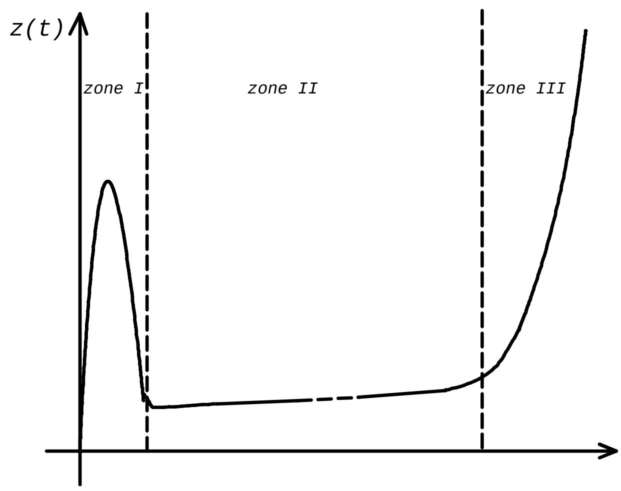


Fig. 7 Typical variation of failure rate

The significances for the notation in figure 7 are:

- Zone I is running in period. In this period the failures are numerous but small and easy to repair (many without intervention of specialists). In the running in period is possible to detect the failures due to hidden defects of material or some mistake in design. The increase of rate of failure is quick with a maximum in middle of interval fallow with a same quick decrease.
- Zone II is the active life period of product. This period is characterized by aleatory failures with a small increase, in time, of failure rate.
- Zone III is the take out period. In this period the number of failures is in continuous increase. Another aspect is the amplitude of failure who is the same in increase. The

reasons are the aqueing, the fatigue of material, the wear of product. Usual in this period the product are used just in extreme cases.

The link relation between good functioning probability and failure rate are:

$$R(t) = e^{-\int_0^t z(t)dt} \tag{14}$$

IV.2.1.5. Mean time between failure

Mean time between failure (MTBF) or mean time until the next failure is the mean of good functioning periods of elements or products from statistic population under surveillance.

For each element from the N_0's elements of statistic population corresponding a own time of good functioning. For non-reparable products the situation can be graphic illustrated (fig. 8):

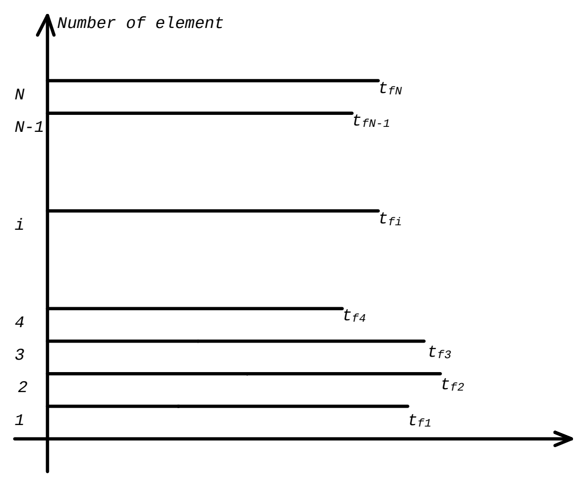


Fig. 8. Mean time between failures

The relation for MTBF is:

$$MTBF = \frac{t_{f1} + t_{f2} + ... + t_{fi} + ... + t_{fN_0}}{N_0} = \frac{\sum_{i=0}^{N_0} t_{fi}}{N_0} \tag{15}$$

If the axis of time it's divided in equal time intervals with Δt, in interval $t=(t_{i-1}-t_i)$ we have k_i elements and in the last interval $\Delta t=(t_{c-1}, t_c)$ we have k_c products we can write:

$$MTBF = \frac{\sum_{i=1}^{c} t_i \cdot k_i}{\sum_{i=1}^{c} k_i} = \frac{\sum t_i \cdot k_i}{N_0} = \frac{T}{N_0} \tag{16}$$

The unit measure for MTBF it's hour.

In specialty literature is used also the notation *m* for MTBF.

The link relation with others indicators is:

$$m = MTBF = \int_0^\infty t \cdot f(t)dt = \int_0^\infty F(t)dt \tag{17}$$

IV.2.1.6. Dispersion

Dispersion (σ^2 or D) is expressive of deflection of good functioning times from the mean of this. The measure unit is h^2.

$$\sigma^2 = D = \int_0^{\infty} (t-m)^2 \cdot f(t) \cdot dt \qquad (18)$$

Square mean deflection (σ) formulate the level of dispersal of good functioning times. For experimental data:

$$\sigma = \sqrt{\frac{1}{N_0 - 1} \sum_{i=1}^{N_0} (t_i - m)^2} = \sqrt{D} \qquad (19)$$

IV.2.1.7. Relations between the indicators

In practice is enough to determine one of reliability indicators, for determine the others are the connections related in table 1.

Nr. Crt.	Indicator	Function by:			
		F(t)	f(t)	z(t)	R (t)
1	$R(t) = \frac{N}{N_0}$	$1 - F(t)$	$\int_t^{\infty} f(u)du$	$\exp\left[-\int_0^t z(u)du\right]$	--
2	$F(t) = \frac{n}{N_0}$	--	$\int_0^t f(u)du$	1- $\exp\left[-\int_0^t z(u)du\right]$	$1 - R(t)$
3	$f(t) = \frac{\Delta n_i}{\Delta t_i N_0}$	$\frac{dF(t)}{dt}$	--	z(t) $\exp\left[-\int_0^t z(u)du\right]$	$-\frac{dR(t)}{dt}$
4	$z(t) = \frac{\Delta n_i}{\Delta t_i N}$	$\frac{1}{1-F(t)} \frac{dF(t)}{dt}$	$\frac{f(t)}{\int_0^{\infty} f(u)du}$	--	$-\frac{1}{R(t)} \frac{dR(t)}{dt}$
5	$m = \frac{\sum_{i=1}^{n_0} t_{fi}}{N_0}$	$\int_0^{\infty} [1 - F(t)]dt$	$\int_0^{\infty} tf(t)dt$	$\int_0^{\infty} \exp\left[-\int_0^{\infty} z(u)d\right.$	$\int_0^{\infty} R(t)dt$

Table 1. Relation between the reliability indicators

IV-18.

2.2. Reliability of systems

2.2.1. General concepts

For obtain of a certain function or for obtain a multiple different functions elements are jointly in blocks (subassembly). At their round the blocks are assemble in systems. All the connections among elements and block are functional.

The reliability of the system depends so the reliability of the elements and in the same measure by the connections between the elements and blocks. Also the reliability of the system depends by his interaction with the environment.

The cessation of the ability of achieves the function or functions of system can dress else many appearances:

- minor failure, without influences to the normal operation of system (example: burning of blinker lamp, scratch of paint, etc.). This type of failure is not considered for calculus of reliability indicators.
- major failure with influences to the normal operation of system but the attributions of damaged subassembly are take by another subassembly funded in reserve. This type of failure is considered for calculus of reliability indicators.
- major failure that lead to the non-operating status of system. This type of failure is considered too for calculus of reliability indicators.

As in the case of elements the reliability must be quantified with the help of reliability indicators. The most used are good functioning probability, R(t), failure probability , F(t), function of frequency (density of distribution), f(t),failure rate, z(t), mean time between failure, MTBF, and dispersion, σ^2.

IV.2.3.2. Determination of reliability of systems

For the determination of reliability of systems is necessary to make some assumptions: the failures of elements have independent character and for each element it's know the value of reliability. The starting point in determination of reliability of systems is the function (controller) construction diagram. The function diagram shows the position of each element in the frame of structure, the technologic function and the technical conditions (internal and external) for function. (example fig. 19)

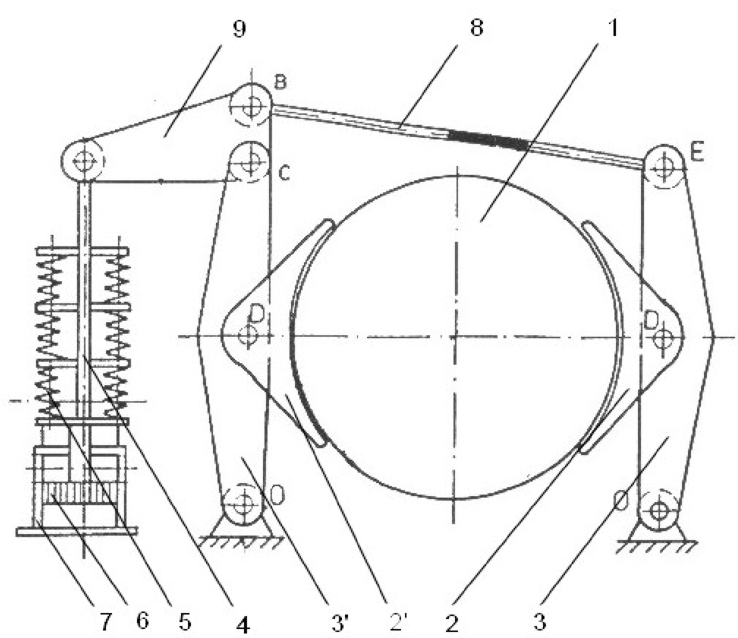


Fig. 19 Function diagram for a braking system for mining hoisting machine

The next step is the construction of logical reliability diagram (structural model). In the frame of this diagram the elements loss the personality (technical characteristic, size, weight, etc.) turn into elements characterized by only own value of reliability and the links with flank on elements. (figure 20)

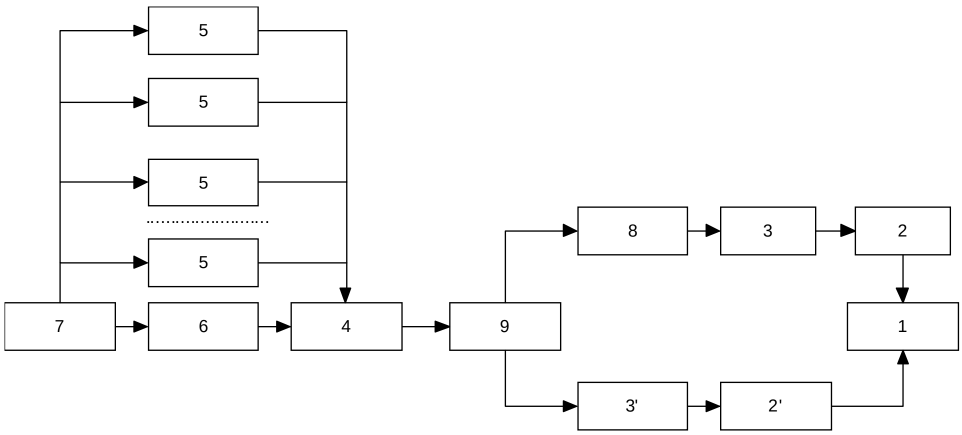


Fig. 20. Logical reliability diagram (structural model) for a braking system for mining hoisting machine

The individual values of reliability of elements and links with flank on elements have direct influences on entire system reliability. For correct determination of reliability of systems is necessary beside the cognition of value of reliability of element the cognition of influences of failures states over the system. Important mention: function by the complexity of system the logical reliability diagram can or cannot to correspond with function diagram.

For elaborate the logical reliability diagram consider that the signal (electrical, mechanical, etc.) will circulate trough the entire system so:

- for the elements serial connected the signal have just one way for propagation;
- for the elements parallel connected the signal have for propagation a number of ways equal with the number of elements connected.

As primary assumption we consider that all elements are in perfect function condition.

The next step is the elaboration of logical reliability formula. So if a system has *n* elements, each element has a number *r* of possible state (functioning or failure state). Because in the reliability studies it's using binary logics (0 for failure state, 1 for operating state) the system can have 2^n state, some operating state, some failure state.. The system of *n* elements can be called system by order *n* with the operating state define by a n-dimensional vector:

$$X = f(x_1, x_2, ..., x_n) \tag{36}$$

For each x_i, for each value of *i* from the interval [1,n] can exist just two values. So from the total of 2^n vector who define state of system some are vectors who define operating state and others are vectors who define the failure state.

$$2^n = m = m_1 + m_2 \tag{37}$$

The system can be at one moment in just one state from the 2^n total number state. If note down with E_{ij} the event with significance of operating state of element E_i, (i=1,….,n) from combination by order j, (j=1, 2, 3,….,2^n) we can obtain the logical reliability formula:

$$E = f(E_1, E_2, ...E_n) = \bigcup_{j=1}^{2^n} \left(\bigcap_{i=1}^{n} E_{ij}^{(h)} \right) \tag{38}$$

Note: h=1 if the element E_i is in operating state and h=0 if the element E_i is in failure state.

The formula IV-38 is recommended to be use in the case of n<6. For n>5 the number of possible state overgrow and is necessary the using strong PC.

The main logical reliability diagram (structural model) uses in practice are:

- serial diagram
- parallel diagram
- mixed diagram

2.2.3. Calculus of reliability for systems with serial diagram

Considering a system with n elements, each element with his own good functioning probability and with the elements connected as in logical reliability diagram presented in figure 21, the reliability of system can be calculate with the relation 39.

The notations from figure 21 :

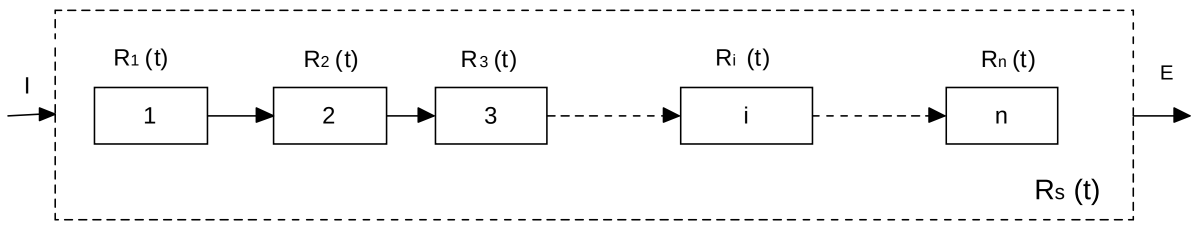


Fig. 21 Serial diagram

I – inputs of system;

- E – outputs of system:
- $R_i(t)$ – good function probability of element i;
- $R_s(t)$ – good function probability of system.

$$R_s(t) = R_1(t) \cdot R_2(t) \cdot R_3(t) \cdot ...... \cdot R_i(t) \cdot .... \cdot R_n(t) = \prod_{i=1}^{n} R_i(t) \tag{39}$$

In figure 22 was presented the variations of reliability for different systems with the assumption of equal good function probability of elements.

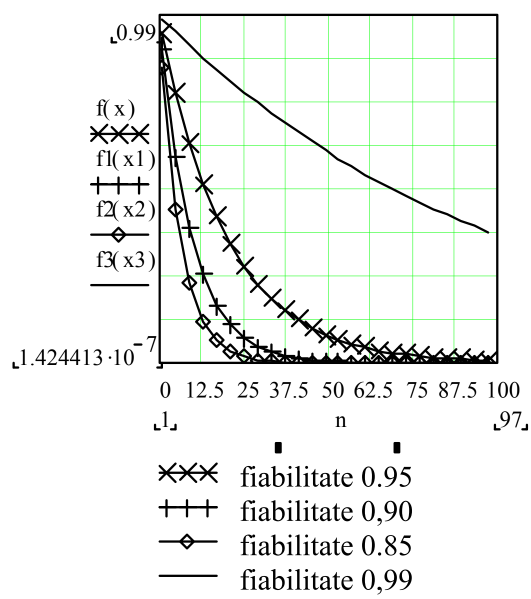


Fig. 22 Variations of serial system reliability with increase of number of elements

IV.2.3.4. Calculus of reliability for systems with parallel diagram

For the systems with the elements connected as in logical reliability diagram presented in figure IV-23 the failure probability can be calculate with relation:

$$F_s(t) = \prod_{i=1}^{m} F_i(t) \qquad (40)$$

where:

- F_s failure probability for system;
- F_i – failure probability for element i.

Using the relation between the good function probability and failure probability (IV-4) we can write the relation for calculus of good function probability:

$$R_s(t) = 1 - F_s(t) = 1 - \prod_{i=1}^{m} (1 - R_i(t)) \; (41)$$

It's possible to present the variations of reliability for different systems with the assumption of equal good function probability of elements. (fig. 24)

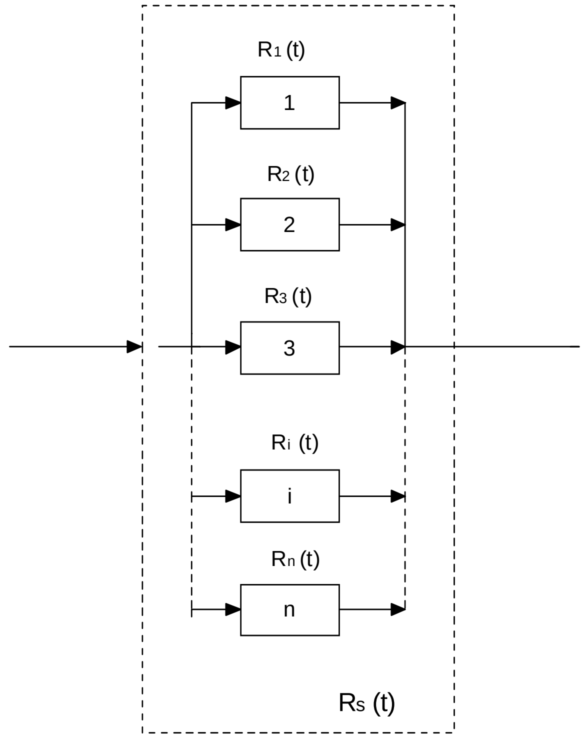
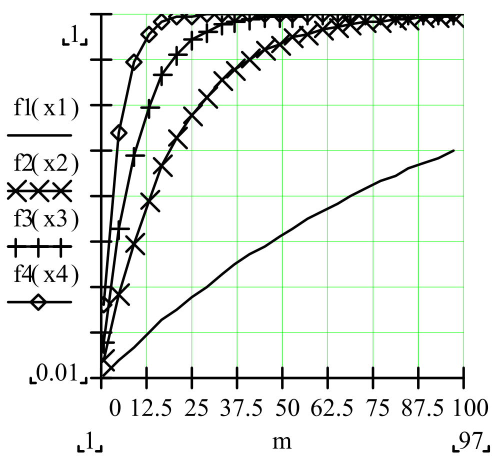


Fig. 23 Parallel diagram



probabilitate de buna functionare a elementelor 0.01
probabilitate de buna functionare a elementelor 0.05
probabilitate de buna functionare a elementelor 0.1
probabilitate de buna functionare a elementelor 0.2

Fig. 24 Variations of parallel system reliability with increase of number of elements

2.2.5. Calculus of reliability for systems with mixed diagram

The system with the elements connected in mixed diagram can have the structure presented in figure 25.

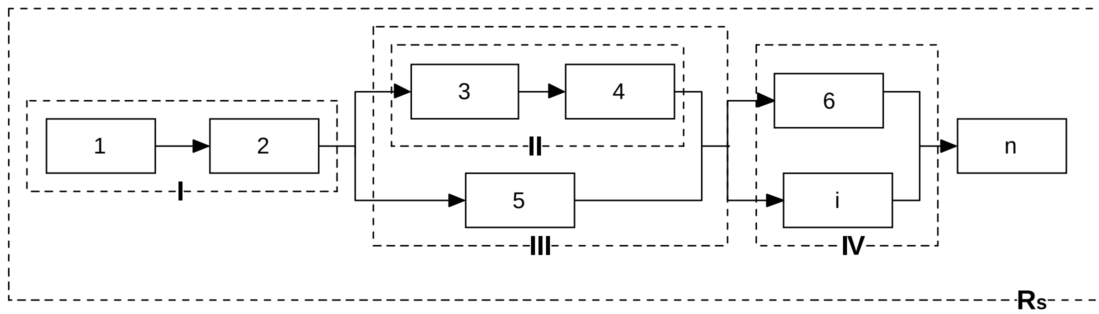


Fig. 25. Mixed diagram

The resolve of this type of diagram can be made splitting the main diagram in serial and parallel diagrams. For the diagram presented in figure 25 the solution is:

$$R_s = R_I \cdot R_{III} \cdot R_{IV} \cdot .... \cdot R_n \tag{42}$$

where:

$R_I = R_1 \cdot R_2$

$$R_{III} = 1-(1-R_5)(1-R_{II}) \tag{43}$$

$$R_{II} = R_3 \cdot R_4 \tag{44}$$

$$R_{IV} = 1-(1-R_6)\cdot .....\cdot (1-R_i) \tag{45}$$

2.3. Conclusions connected by the reliability assurance

For reliability assurance of systems in the design phase is necessary to conceive the function diagram (and implicitly the logic reliability diagram) prosperously. The diagram must have the advantages of serial and parallel diagram and must eliminate the disadvantages. The most used ways for increase the reliability of systems are:

- utilization of a small number of elements connected in diagrams with low complexity (avoid the big number of elements and high complexity if the required functions don't ask):
- for the elements the recommendation is to have a higher reliability, in concordance with the technical and economical objectives;
- utilization of parallel diagram, especially in case of elements with small reliability;
- assurance of joint technologies with high performances for avoid the advent of possible "weakly points";
- detection of possible ways of failure in the frame of tests and experiences;
- elaboration of books and technical instructions for employs.

3. DESIGN OF RELIABILITY

A designer usually uses a deterministic method to design a product. Standards prescribe discrete values of the loads on the product and of the allowable material stresses in the product. The standards guarantee, that the product will not fail, if the loads on the product do not exceed the allowable stresses. More precisely: the probability that a product will fail is acceptably small, if the designer follows the standards. In many cases this method was satisfactory, but now in the condition of growing of complexity this design method is not adequate. It appears that when a large number of reliable components are combined into a large product, the result is not necessarily a reliable structure. The effect of failure of these products can be extremely large. Failure can lead to loss of human lives, or large economic damage. Because of these effects, it is very important to analyze each phase of design of products and secure the reliability of these products.[41][3][8][11]

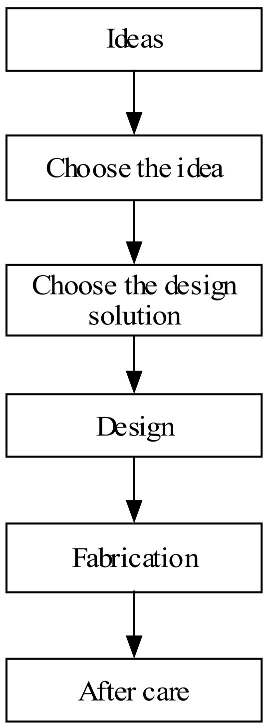


Fig. 33 Life cycle

In the most cases the cycle of life of product can be illustrated by figure 33.

Each phase in the life cycle is characterized by specific criteria:

- Phase 1, Ideas, have as principal task understanding customer requirements;
- Phase 2, choose the idea, have as principal task the selection of the best idea (fig. 34).

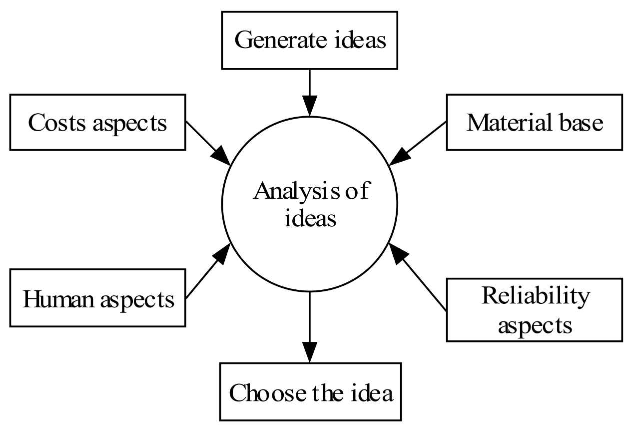


Fig. 34 Choose the idea

- Phase 3, choose the design solution, have as principal task the optimization of design process function by (fig. 35):

- static analysis;
- dynamic analysis;
- reliability influence factors;
- cost analysis.

For each product we must establish some reliability and maintainability objectives.

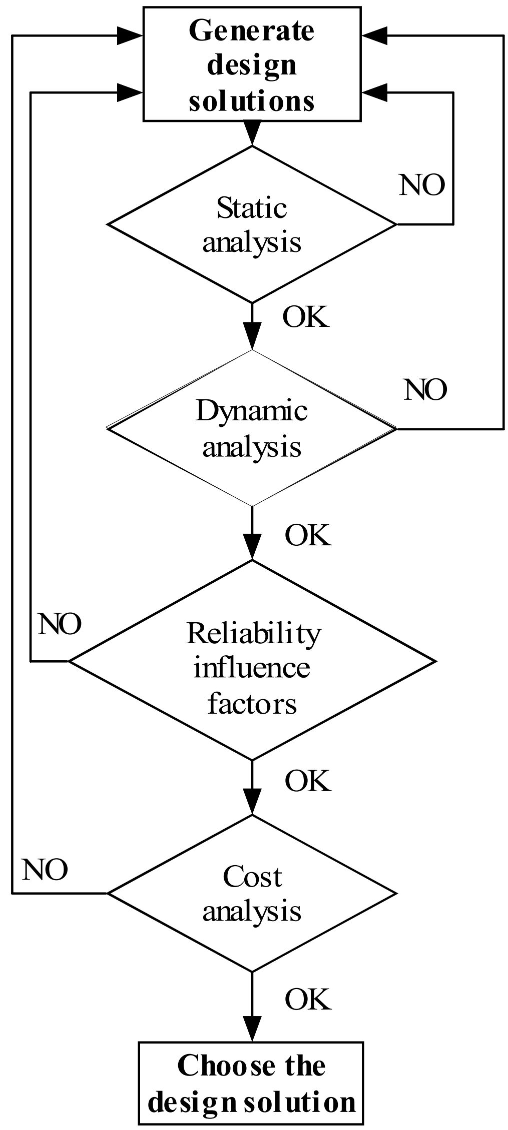


Fig. 35 Choose the design solution

Reliability and maintainability objectives need to be set with due regard to the customer's design and operating requirements and financial constraints. After establish of the reliability and maintainability objectives it's to find the engineering design specification. It should specify the engineering requirements in full: functions factors, human factors, environment, standards, life factors, ergonomic restrictions, etc. These factors are presented in figure 36.

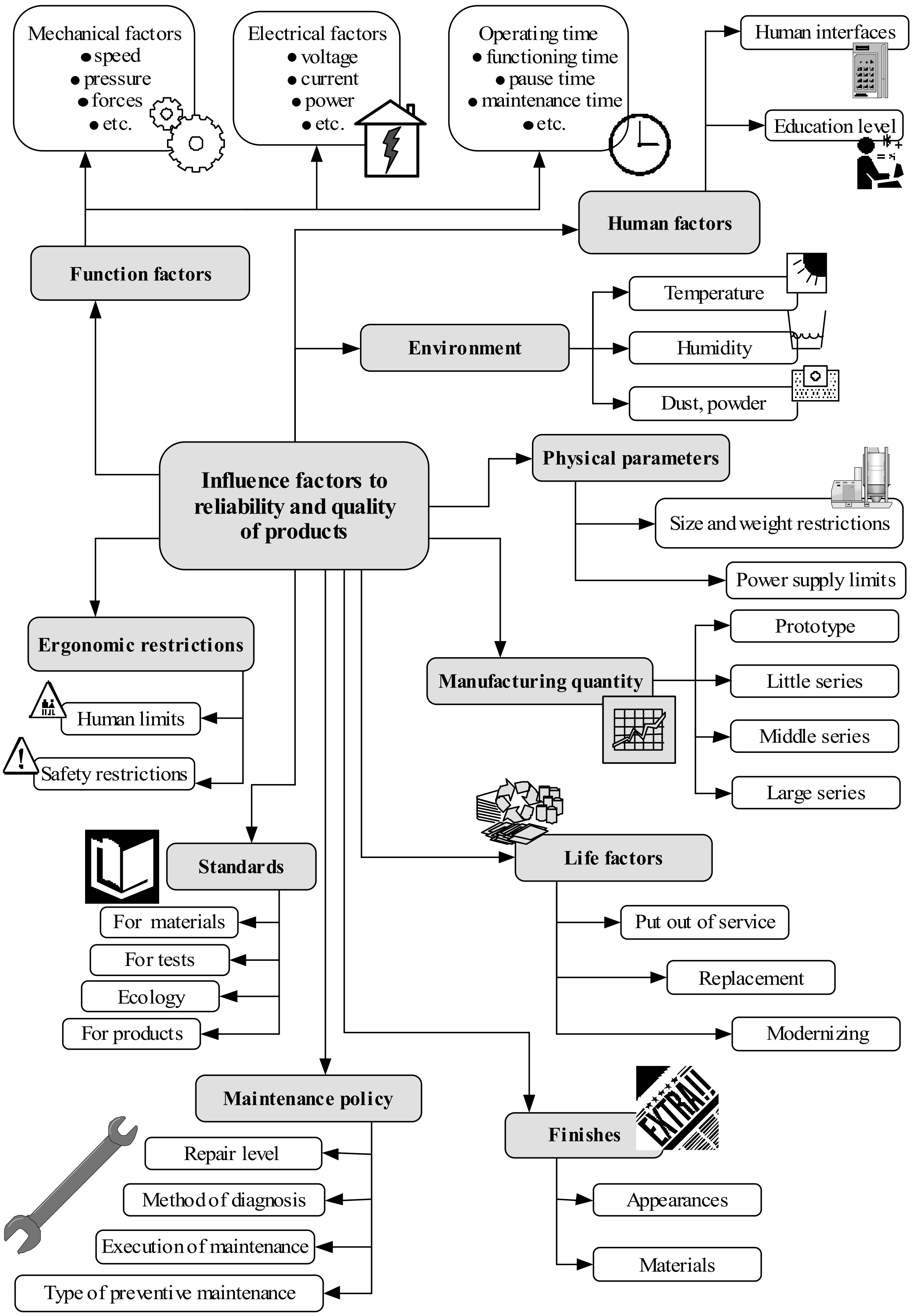


Fig. 36 Influence factors to reliability and quality

- Phase 4, design. In the design phase the chosen variant is developed further. A designer determines the dimensions of the details of the chosen solution. He validates these dimensions with a static analysis, and optimizes the structure to reduce the costs. For some structures, a risk analysis expert executes a fault tree analysis, after the designer has determined all the details. The result of this phase is a detailed (set of) drawings, a detailed static analysis report, an accurate cost estimate, and sometimes a fault tree analysis report.
- Phase 5, fabrication. In the construction phase a contractor is chosen. During the construction phase, the contractor works on further detailing of the design, and builds the infrastructural work. The contractor submits the detailed drawings and calculations for the approval of the project team. At the end of this phase, the contractor delivers the structure to the project manager, and the project manager delivers the structure to the principal. Separate for parts of product and for complete products are made reliability tests. (figure 37).

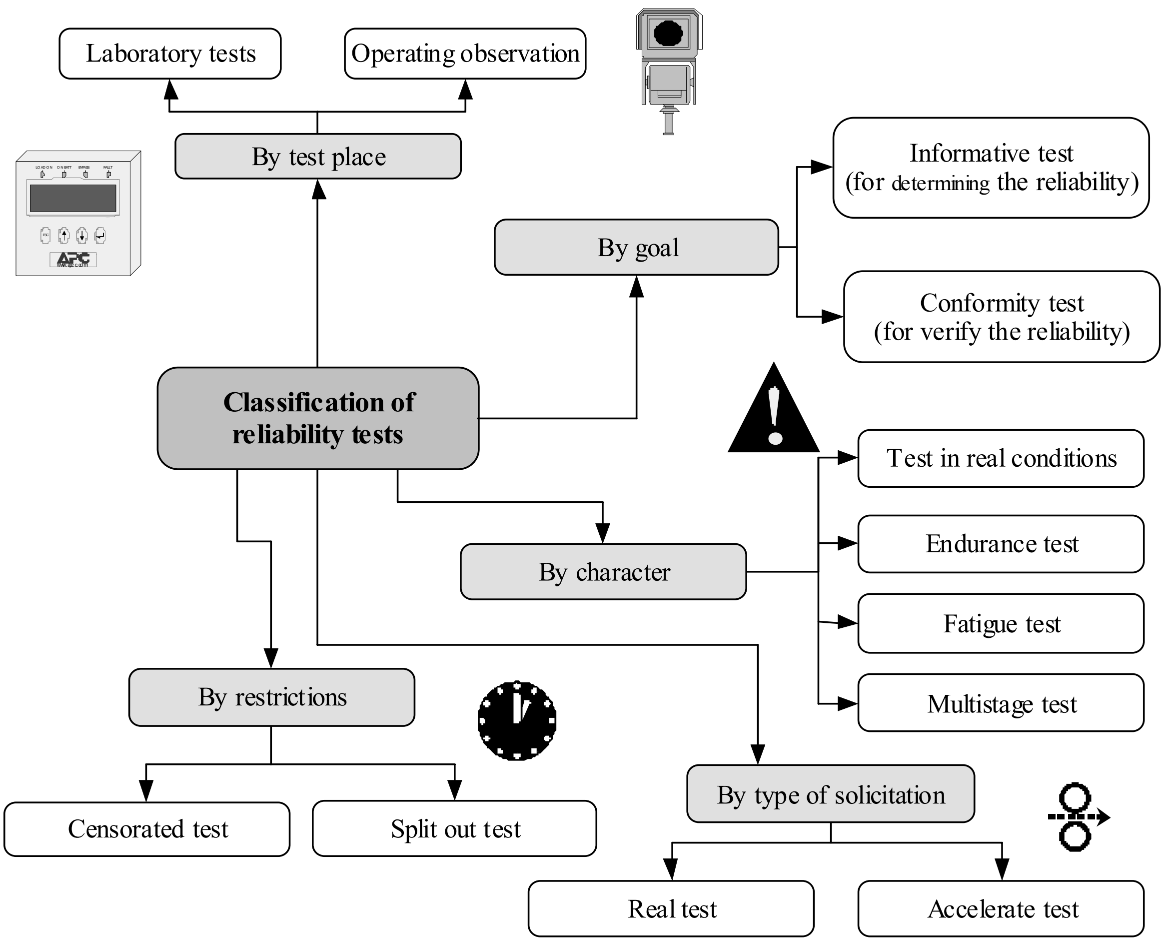


Fig. 37 Reliability tests

OBSERVATION For a good reliability of product it’s not enough to establish the influence factors to reliability. It’s necessary to have a program for surveillance the design process, the production and the active life of product, of course from the reliability and maintainability point of view.

This program can have the form presented in figure 38

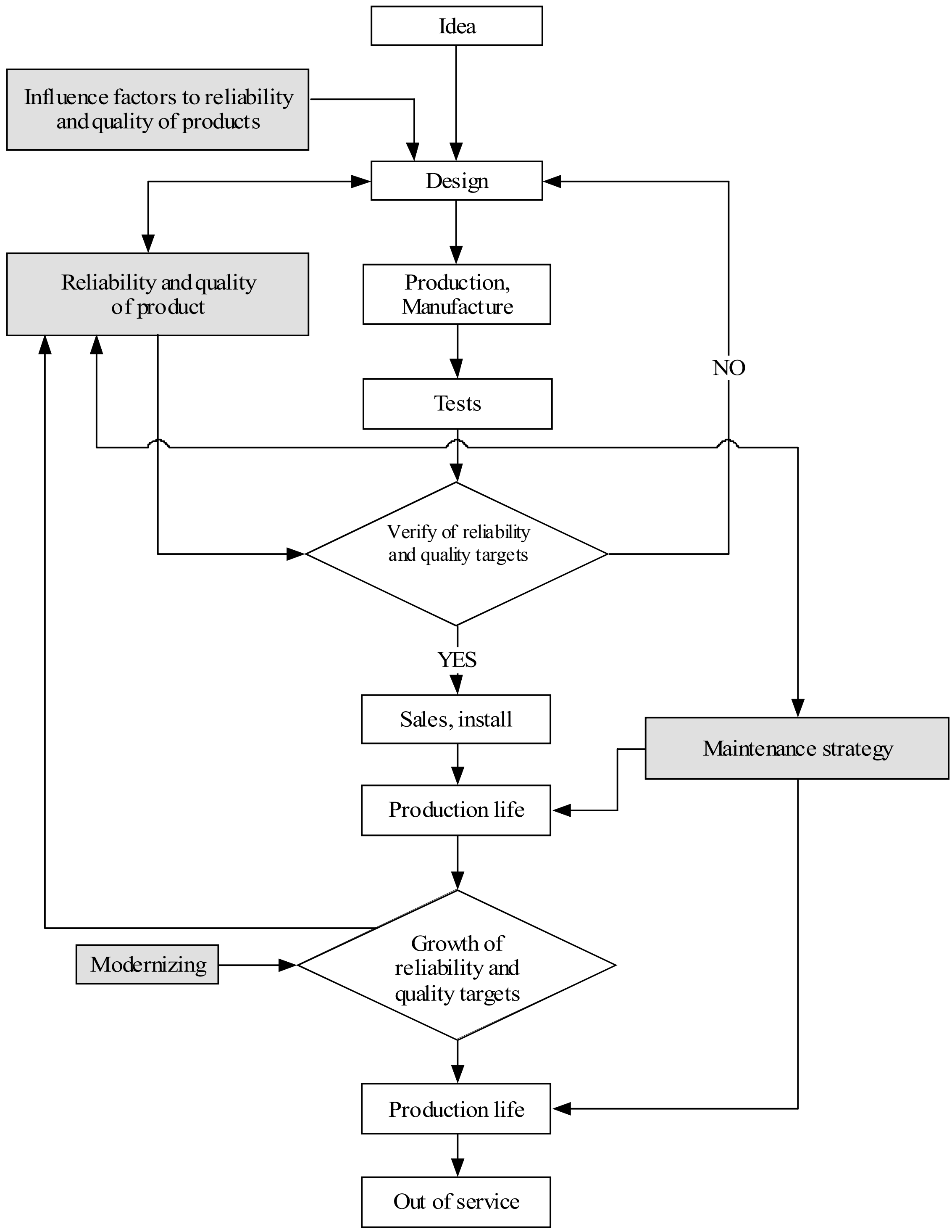


Fig. 38 Surveillance of reliability and maintainability targets

- Phase 6, after care. In the after care phase the project team composes a maintenance plan. This plan advises the principal about maintenance and replacement intervals of components, and a conservation schedule for steel parts. In this phase in important to study the variation of reliability of product. Along the life cycle of products (marketing, design, fabrication, utilization) the reliability of products have variations due to different factors. The general tendency it's decreasing. The reason is simple: the fatigue of materials conjunct with the wear. The theoretic curve of variation of reliability is presented in figure 39. [6][7]

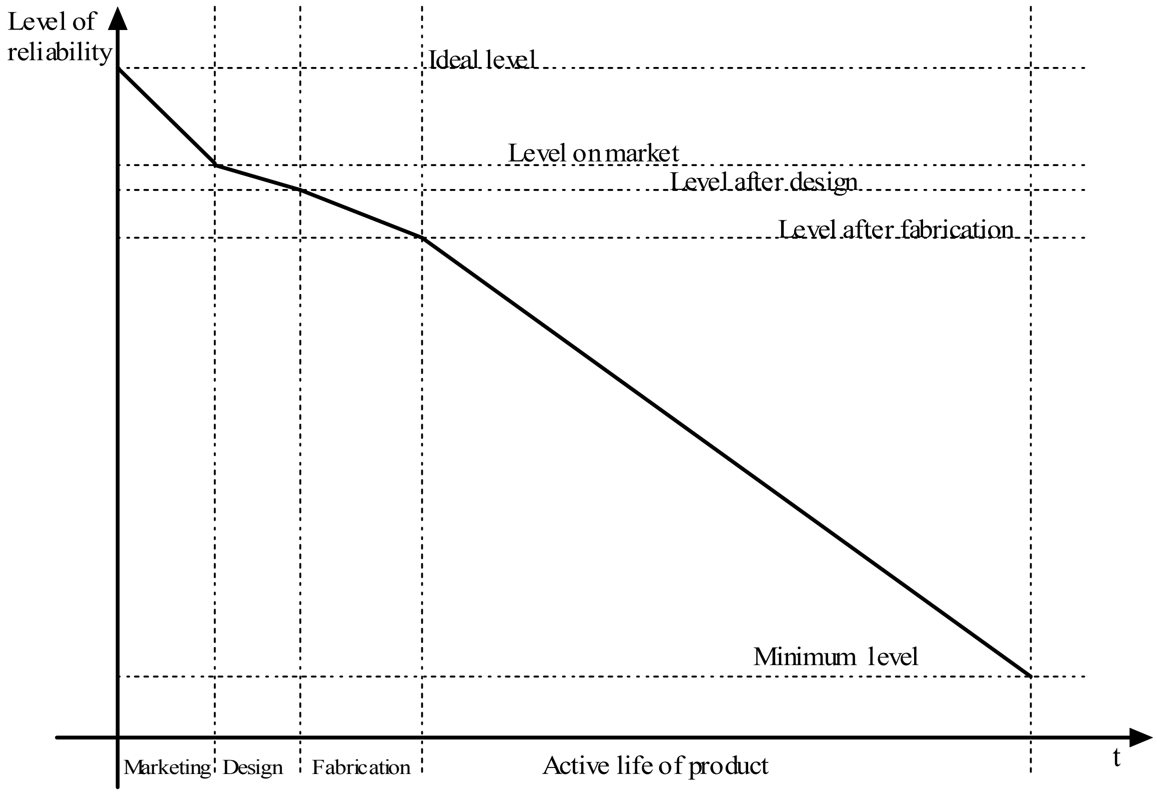


Fig. 39 The theoretic curve of variation of reliability

However in practice it's possible to have periods with increasing of reliability: modernization of products, current operations of maintenance, repair periods, etc. (figure 40). The variation of reliability in real situations is presented in two situations:

- Maintenance system with technical revision, mender type 1 (RC 1), mender type 2 (RC 2) and capital repair (RK), (fig. 41);
- Maintenance system with periodical verification (Vp), periodical repair (Rp) and general repair (Rg), (fig 42);

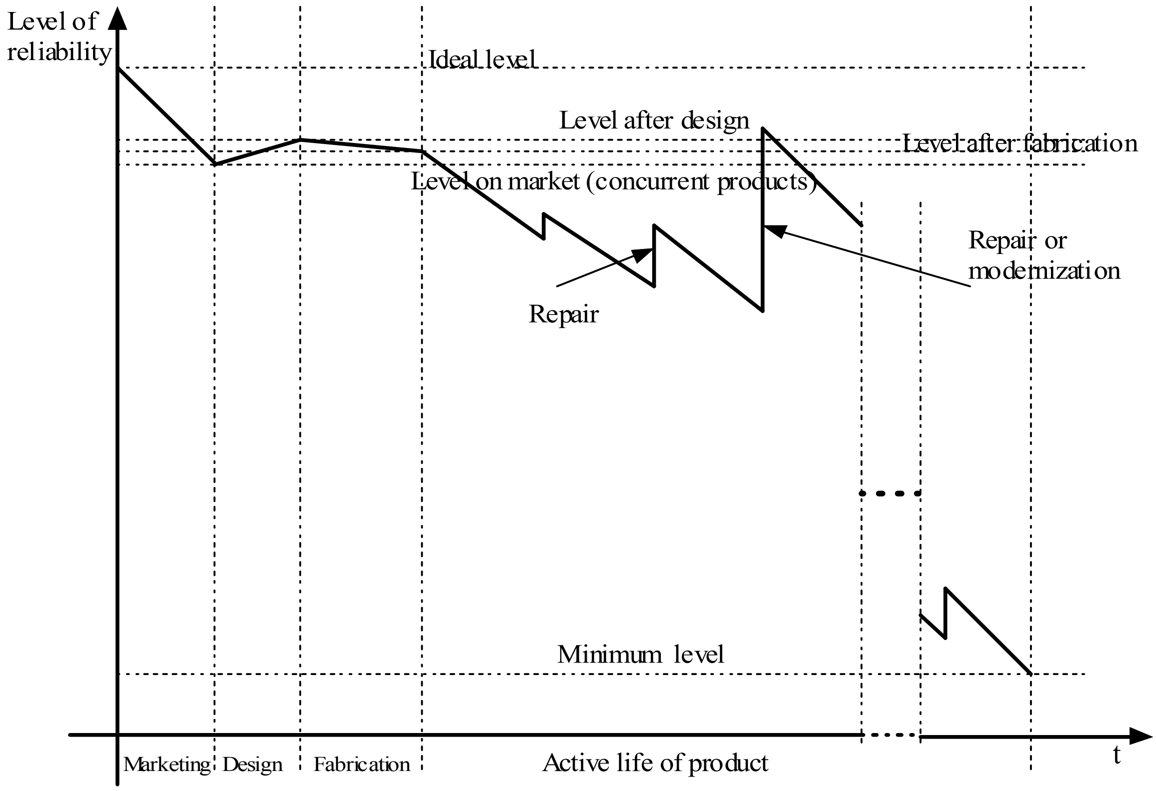


Fig. 40 Real variation of reliability of products

The figures 41 and 42 represent just the active life of products.

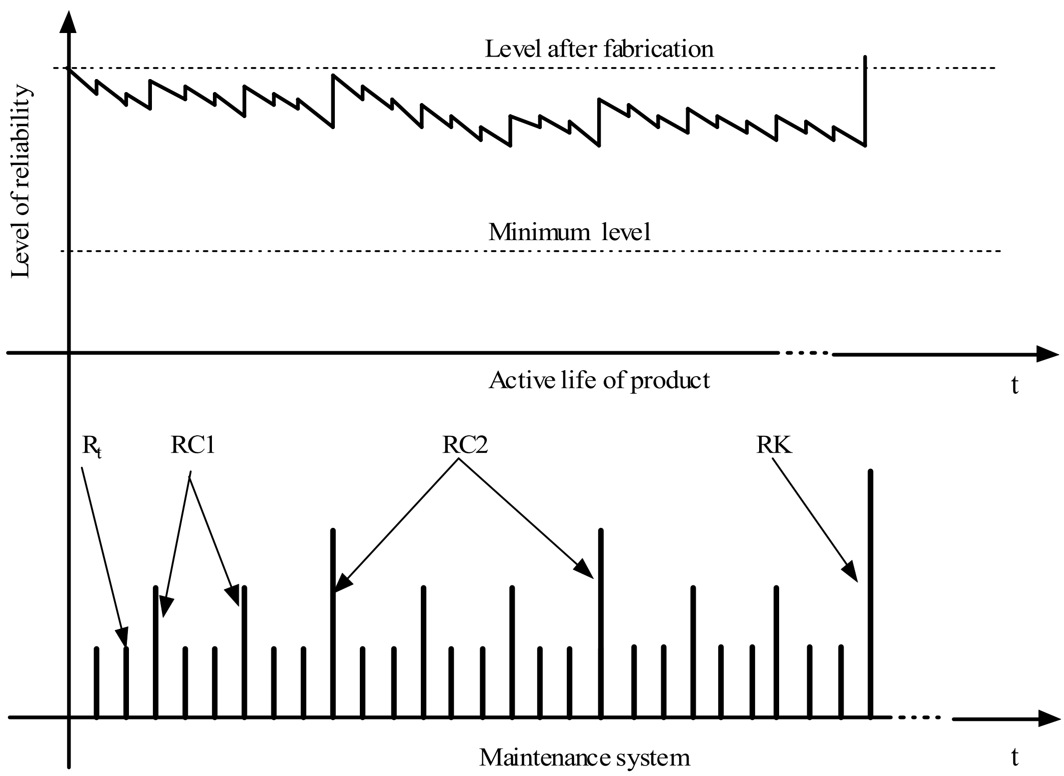


Fig. 41 Variations of reliability for specific maintenance system (Rt, RC1, RC2, RK)

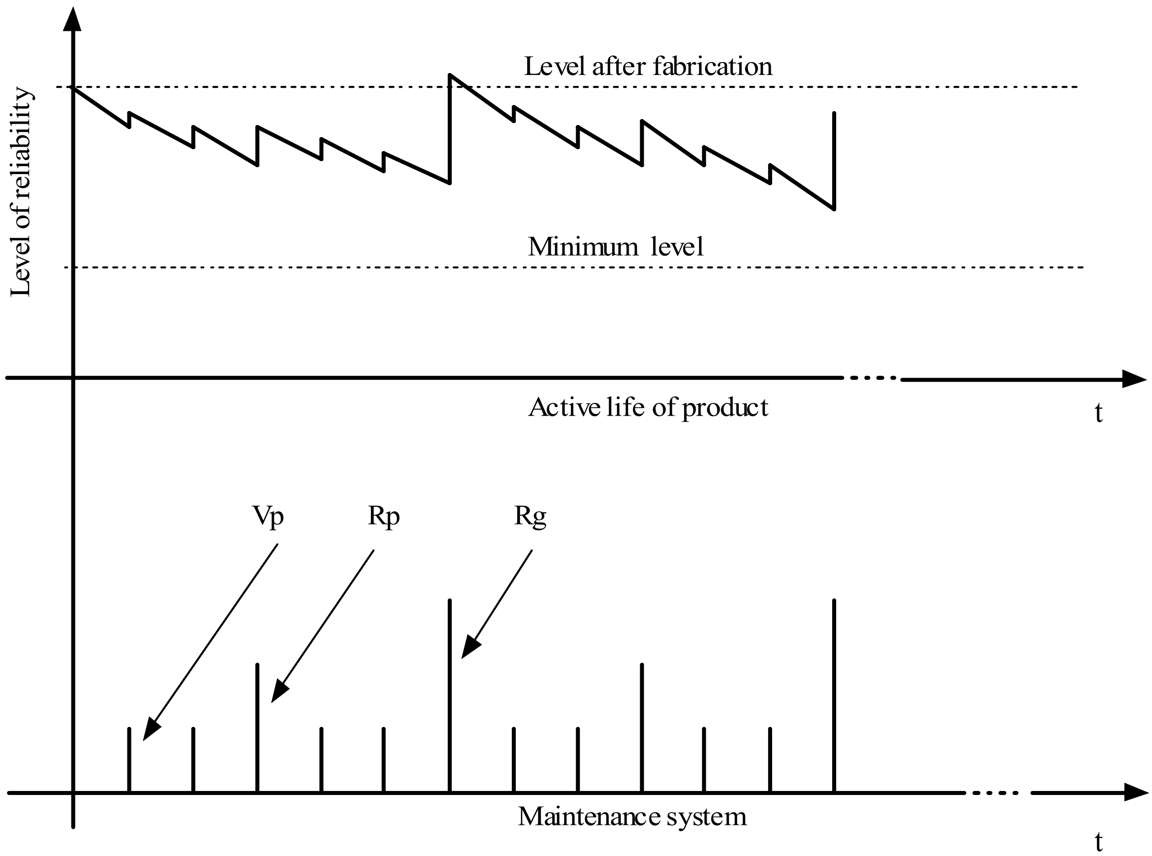


Fig. 42 Variations of reliability for specific maintenance system (Vp, Rp, Rg)

3. Planning and Scheduling of Maintenance

Planning and scheduling are two of decision-making processes that are used in manufacturing and service industries on a regular basis. These forms of decision-making play an important role in procurement and production, in transportation and distribution, and in information processing and communication. The planning and scheduling functions in a company are based on mathematical techniques and heuristic methods to allocate limited resources to the activities that have to be done. This allocation of resources has to be done in such a way that the company optimizes its objectives and achieves its goals. Resources may be machines, materials and specialised work-team in industrial factories. Another example of resources is the knowledge in some special field. Activities may be operations in a workshop, stages in a mechanical project, or computer programs that have to be executed. Each activity may have a priority level, an earliest possible starting time and a due date. Objectives can take many different forms, such as minimizing the time to complete all activities, minimizing the number of activities that are completed after the committed due dates, and so on.

Planning and scheduling in either a manufacturing or a service organization must interact with the other functions of industrial organisation. These interactions are typically system-dependent and may differ substantially from one setting to another; they often take place within a computer network. For this reason is not so easy to apply the examples from one factory to another. Sometime if only one of influence factors are different is not possible to apply the model.

The purpose of scheduling is to provide a ‘‘roadmap’’ that represents how and when the project will deliver the products defined in the project scope and by the project team. The dynamic nature of a project's execution is best served by a tool that allows for *modeling* of the plan and analysis due to the impact of progress and unforeseen developments.

4.1. Planning and Scheduling in Manufacturing.

One of the most important field where planning and scheduling have a important position is manufacturing of machines. Orders that are released in a manufacturing setting have to be translated into jobs with associated due dates. These jobs often have to be processed on the machines in a work center in a given order or sequence. The processing of jobs may sometimes be delayed if certain machines are busy. Pre-emption's may occur when high priority jobs are released which have to be processed at once. Unexpected events on the shop floor, such as machine breakdowns or longer-than-expected processing times, also have to be taken into account, since they may have a major impact on the schedules.

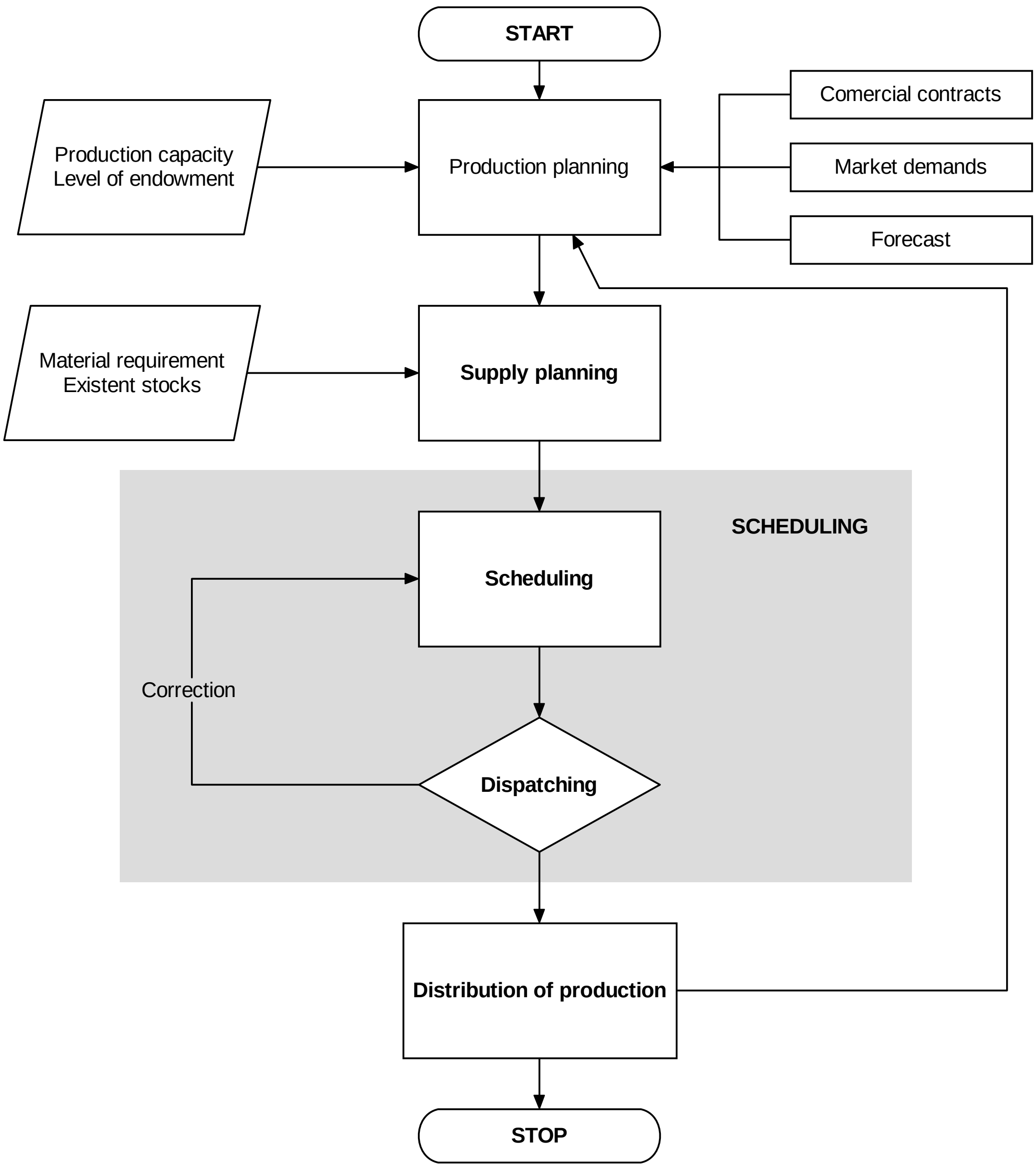


Figure 43. Diagram of the information flow in a manufacturing system

Developing, in such an environment, a detailed schedule of the tasks to be performed helps maintain efficiency and control of operations. The shop floor is not the only part of the organization that impacts the scheduling process. The scheduling process also interacts with the production planning process, which handles medium- to long-term planning for the entire organization. This process intends to optimize the firm's overall product mix and long-term resource allocation based on inventory levels, demand forecasts and resource requirements. Decisions made at this higher planning level may impact the more detailed scheduling process directly.

In manufacturing, planning and scheduling has to interact with other decision making functions in the plant. One popular system that is widely used is the **Material Requirements Planning (MRP)** system. After a schedule has been set up it is necessary that all the raw materials and resources are available at specified times. The ready dates of the jobs have to be determined by the production planning and scheduling system in conjunction with the MRP system. MRP systems are normally fairly elaborate. Each job has a Bill Of Materials (BOM) itemizing the parts required for production. The MRP system keeps track of the inventory of each part. Furthermore, it determines the timing of the purchases of each one of the materials. In doing so, it uses techniques such as lot sizing and lot scheduling that are similar to those used in planning and scheduling systems. There are many commercial MRP software packages available. As a result, many manufacturing facilities rely on MRP systems. In the cases where the facility does not have a planning or scheduling system, the MRP system may be used for production planning purposes. However, in a complex setting it is not easy for an MRP system to do the detailed planning and scheduling satisfactorily. Modern factories often employ elaborate manufacturing information systems involving a computer network and various databases. Local area networks of personal computers, workstations and data entry terminals are connected to a central server, and may be used either to retrieve data from the various databases or to enter new data. Planning and scheduling is usually done on one of these personal computers or workstations. Terminals at key locations may often be connected to the scheduling computer in order to give departments access to current scheduling information. These departments, in turn, may provide the scheduling system with relevant information, such as changes in job status, machine status, or inventory levels. Companies nowadays rely often on elaborate Enterprise Resource Planning (ERP) systems, that control and coordinate the information in all its divisions and sometimes also at its suppliers and customers. Decision support systems of various different types may be linked to such an ERP system, enabling the company to do long range planning, medium term planning as well as short term scheduling.

4.2. Planning and Scheduling in Services.

Describing a generic service organization and its planning and scheduling systems is not as easy as describing a generic manufacturing system. The planning and scheduling functions in a service organization may often face many different problems. They may have to deal with the reservation of resources (e.g., machines, workers, workshops or other resources), the allocation, assignment, and scheduling of equipment (e.g., planes) or the allocation and scheduling of the workforce (e.g., the assignment of shifts in call centers). The algorithms tend to be completely different from those used in manufacturing settings. Planning and scheduling in a service environment also have to interact with other decision making functions, usually within elaborate information systems, much in the same way as the scheduling function in a manufacturing setting. These information systems typically rely on extensive databases that contain all the relevant information regarding the availability of resources as well as the characteristics of current and potential customers.

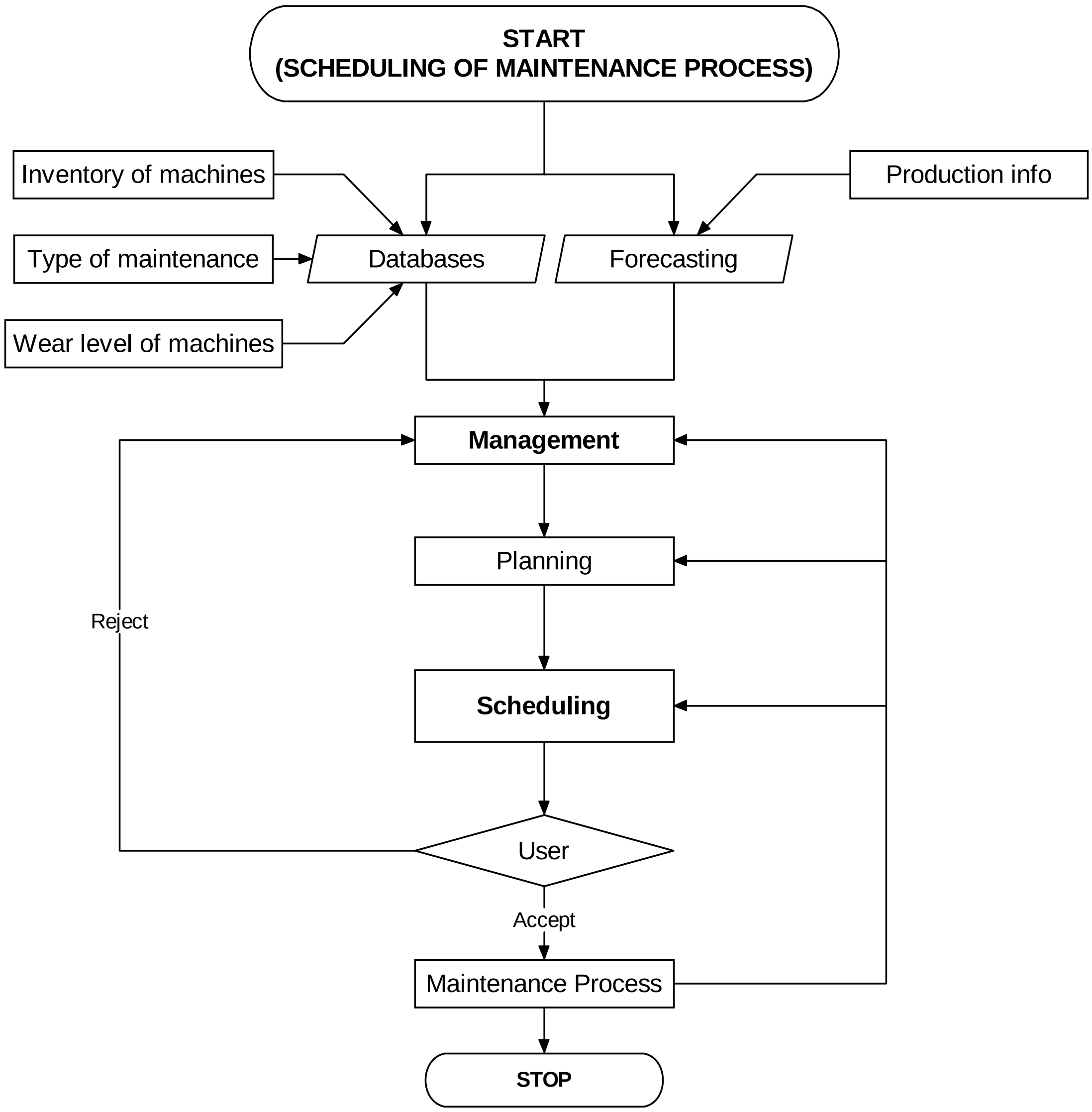


Figure 44 The information flow in a scheduling of maintenance of systems.

A planning and scheduling system may interact with a forecasting module; it may also interact with a yield management module (which is a type of module that is not very common in manufacturing settings). On the other hand, in a service environment there is usually no MRP system.

Scheduling models

Manufacturing systems can be characterized by a variety of factors: the number of resources or machines, their characteristics and configuration, the level of automation, the type of material handling system, and so on. The differences in all these characteristics give rise to a large number of different planning and scheduling models. In a manufacturing model, a resource is usually referred to as a "**machine**"; a task that has to be done on a machine is typically referred to as a "**job**". In a production process, a job may be a single operation or a collection of operations that have to be done on various different machines. Considering the complexity of manufacturing process that must be planned and scheduled is possible to obtain five class of models:

a). the first class of models are the project planning and scheduling models. Project planning and scheduling is important whenever a large project, that consists of many stages, has to be carried out. A project, such as the construction of an large industrial equipment or a factory, typically consists of a number of activities or jobs that may be subject to precedence constraints. A job that is subject to precedence constraints cannot be started until certain other jobs have been completed. In project scheduling, it is often assumed that there are an unlimited number of machines or resources, so that a job can start as soon as all its predecessors have been completed. The objective is to minimize the completion time of the last job, commonly referred to as the make span. It is also important to find the set of jobs that determines the make span, as these jobs are critical and cannot be delayed without delaying the completion of the entire project. Project scheduling models are also important in the planning and scheduling of services. Consider, for example, the planning and scheduling of a large consulting project.

b). the second class of models include single machine, parallel machine and job shop models. In a single machine or parallel machine environment, a job consists of one operation that can be done on any one of the machines available. In a full-fledged job shop, a job typically consists of a number of operations that have to be performed on different machines. Each job has its own route that it has to follow through the system. The operations of the jobs in a job shop have to be scheduled to minimize one or more objectives, such as the make span or the number of late jobs. Job shops are prevalent in industries that make customized industrial hardware. However, they also appear in service industries (e.g., maintenance). A special case of a job shop is a setting where each one of the jobs has to follow the same route through the system. In industrial environment this type of models can be retrieve under the name technological datasheet.

c). the third class of models focuses on production systems with automated material handling. In these settings a job also consists of a number of operations. A material handling or conveyor system controls the movement of the jobs as well as the timing of their processing on the various machines. Examples of such environments are flexible manufacturing systems, flexible assembly systems, and paced assembly lines. The objective is typically to maximize throughput. Such settings are prevalent in the automotive industry and in the consumer electronics industry.

d).the fourth class of models are known as lot scheduling models. These models are used for medium term and long term production planning. In contrast to the first three classes, the production and demand processes are now continuous. In this class, there are a variety of different products. When a machine switches from one product to another, a changeover cost is incurred. The goal is usually to minimize total inventory and changeover costs. These models are important in the process industries, such as oil refineries and paper mills.

e). the fifth class of models consists of supply chain planning and scheduling models. These models tend to be hierarchical and are often based on an integration of the lot scheduling models (the fourth class of models) and the job shop scheduling models (the second class of models). The objective functions in supply chain planning and scheduling take into account inventory holding costs at the various stages in the chain as well as costs of transportation between the stages. There are restrictions and constraints on the production quantities as well as on the quantities that have to be transported from one stage to another. The manufacturing models described above can be classified as either discrete or continuous. Some of the models are discrete, whereas others are continuous. The project scheduling models, job shop models, and flexible assembly systems are discrete models. The lot scheduling models are continuous. The models for supply chain planning and scheduling can be continuous or discrete. A discrete model can usually be formulated as an integer program or disjunctive program, whereas a continuous model can be formulated as a linear or nonlinear program.

From another point of view the schedule development process includes selecting a scheduling method and scheduling tool, followed by incorporating project specific data within that scheduling tool to develop a project specific schedule model. The general project schedule model is used to generate project schedule(s). This process results in a model for project execution which reacts predictably to progress and changes. Once developed, the schedule model is regularly updated to reflect progress and changes, such as scope or schedule logic.

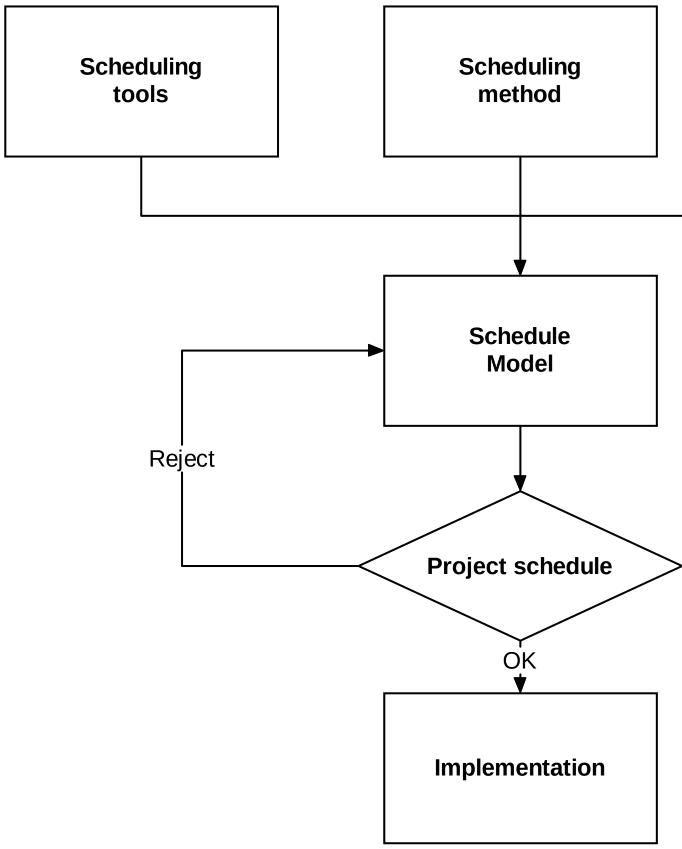


Fig. 45 General scheduling process

During project planning, a process to develop a schedule model that meets the needs of the project and its stakeholders begins. Activities must be described uniquely, including a verb, at least one object, and any useful, clarifying adjectives. The resources required to complete each activity should be considered to determine the duration of each activity. Constraints must not be used in the schedule model to replace schedule logic. When the schedule model is complete, a baseline must be established to permit comparison of progress against the original plan. For this is necessary to make some definitions and hypothesis:

- All information relating to time management of the project must be reviewed and serves as the basis for defining each activity.
- Each element of the project scope, must be supported by an activity, or activities, that will result in the completion of that part of the project scope. Activities must be described uniquely, including a verb, at least one object, and any useful clarifying adjectives.
- Once the activity list is defined, the order in which the activities will be performed must be determined and recorded.
- To avoid creating artificial or incorrect activity relationships, initial activity sequencing should be determined independent of resource availability. After initial activity sequencing is complete, discretionary dependencies, inserted to address resource availabilities, may be used during the Schedule Development process.

The logical diagram of process can looks as in the next figure:

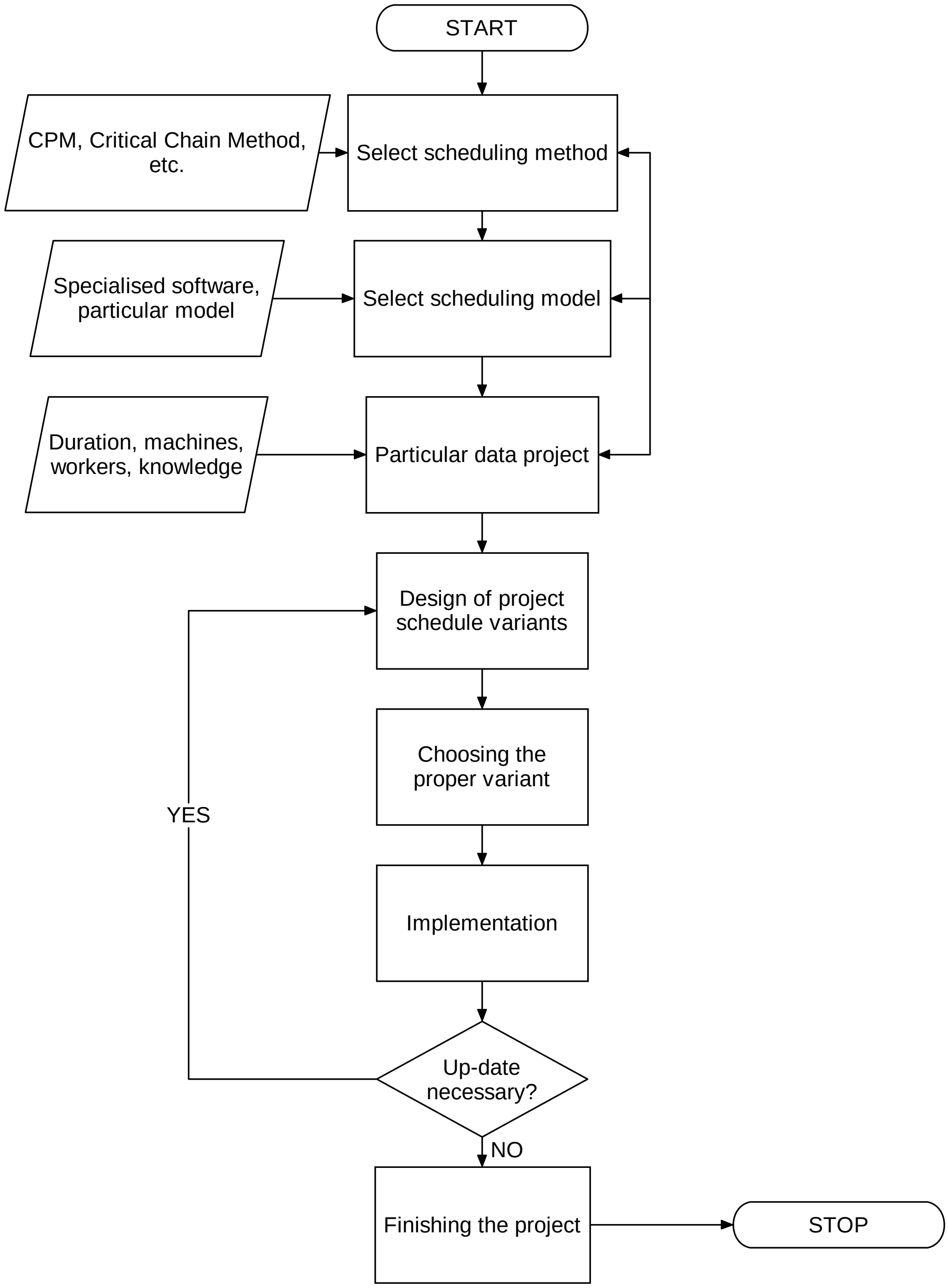


Fig. 46 Scheduling process

The Scheduling Method

Scheduling methods provide the framework within which schedule models are developed. One of the most common is the critical path method (CPM) The first step in the Schedule Development process is the selection of an appropriate method. Some organizations have chosen to standardize on a specific software tool. In this case, the scheduling method decision has already been made and does not need to be made again. Since it is the most commonly used method, this practice standard focuses on CPM.

The Critical Path Method (CPM) is a schedule network analysis technique used to determine the minimum total project duration and the earliest possible finish date of the project as well as the amount of scheduling flexibility (the amount of float) in the schedule network. Early start and finish

dates are calculated by means of a forward pass, using a specified start date. Late start and finish dates are determined by means of a backward pass, starting from a specified completion date. This date may be the project early finish date determined during the forward pass calculation or a target date. To be practical, users should utilize the CPM calculation algorithms provided by their project management scheduling software. These tools automate the calculation of the mathematical forward pass and backward pass during the critical path analysis,
generally using either the Precedence Diagramming Method (PDM), the Arrow Diagramming Method (ADM), or the Critical Chain Method.

To establish a meaningful critical path, it is necessary to develop a logic-based network of activities with empirically derived durations for execution in a realistic and practical manner. Therefore, there must not be any open ends other than the project start and finish milestones. Constraints must be restricted to those that represent external or internal conditions that cannot be feasibly accomplished with activity logic. If overall resources and their availability are not considered, the critical path method calculation can sometimes produce unachievable schedules. To prevent this, resources should be identified and assigned, and resource leveling methods employed. Resource lag defines a fixed period of time that will occur between the start of the activity and the use of the resource.

The Scheduling Tool

The scheduling tool contains schedule components and the rules for relating and using the components to represent the process for completing a project. This is easily visualized by running a scheduling program and, before the addition of any activities or other project specific data, observing the various components in that tool which are available to build the schedule model. The scheduling tool is used to assemble the schedule model and provide the means of adjusting various parameters and components that are typical in a modeling process.

Typically, it includes the capability to:

- Select the type of relationship (such as finish-to-start or finish-to-finish)
- Add lags and leads between activities
- Apply resources and use that information along with resource availability to adjust the scheduling of activities
- Add constraints where logic (precedence relationships with other activities) alone is not adequate to meet the project requirements
- Capture a specific schedule as a baseline or target schedule
- Change various parameters within the schedule model such as imposing a different project completion date in an attempt to shorten the overall project duration to analyze the impact that these changes would have on the project schedule
- Compare the most recent schedule against the previous one or against a target or baseline to identify and quantify trends or variances.

The Schedule Model

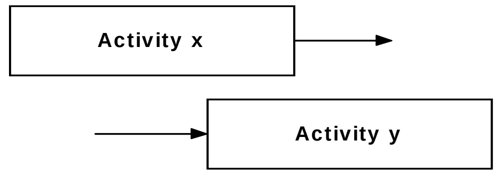
The introduction of project-specific data, such as the activities, durations, and resources, into the scheduling tool creates a schedule model that is specific to a particular project. This schedule model, in turn, is used to generate various sets of dates, depending on the intent of a specific modeling iteration. Thus the schedule model produces a project schedule, which contains the planned dates for completing project activities.

The schedule model provides a tool for analyzing alternatives. The project team utilizes the schedule model to predict outcomes and to compare changes in the model with the project team's expectations of the consequences of variation such as progress or scope. The schedule model can be used to produce critical paths and instances of schedules, as well as other outputs such as resource profiles, task assignments, and records of accomplishment. It will provide time-based forecasts, reacting to inputs and adjustments made throughout the project's life cycle.

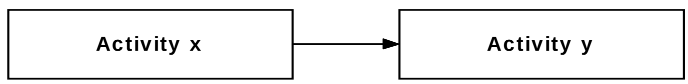
4.3. Relation between elements of scheduling

Connecting the activities of project is the base of any schedule model. The method of connection is defined as a relationship. Every activity and milestone except the first and last must be connected to at least one predecessor and one successor. With the exception of the start milestone, something must occur prior to an activity starting, and in turn, that activity must be totally or partially completed to allow another activity to start. Ensuring compliance with this practice will prevent the schedule from containing open ends, where activities or milestones are missing predecessors or successors. For most instances, each activity would finish prior to the start of its successor activity (or activities) (known as a finish-to-start (FS) relationship), but that is not always possible. If it is necessary to overlap activities, the scheduler may elect to use start-to-start (SS), finish-to-finish (FF) or start-to-finish (SF) relationships.

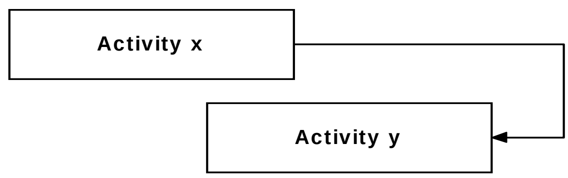
START ACTIVITY / STOP ACTIVITY
only one connection with another activities



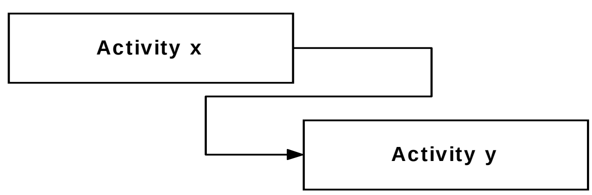
FINISH to START (FS)
serial activities



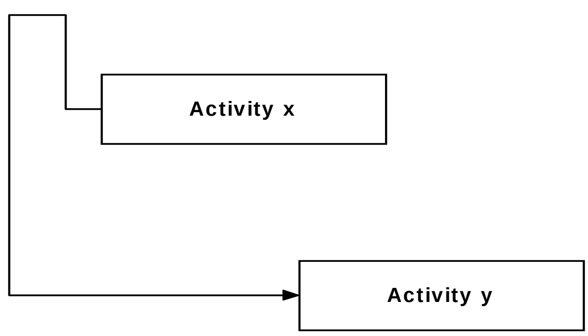
FINISH to FINISH (FF)
parallel activities with simultaneous end



START to START
parallel activities with simultaneous start



START to FINISH
interaction between the start and finish
of different activities



4.4. Scheduling concepts

In the scheduling process are used many concepts. For each is necessary to define some elements:

- Component Name
- Definition
- Required or Optional Use
- Manual or Calculated
- Data Format
- Conditional Note/Associated Component

The most important concepts was selected in the next table:

Name	Definition	Required /Optional	Data format
Activity Calendar	The work periods and non-work periods in calendar format regarding the activities of projects	R	Date/time
Project Calendar	A calendar of working days or shifts that establishes those dates on which schedule activities are worked and nonworking days that determine those dates on which schedule activities are idle. Typically defines holidays, weekends, and shift hours. The calendar initially assigned to schedule activities and resources.	R	Date/time
Resource Calendar	A calendar of working days and nonworking days that determines those dates on which each specific resource is idle or can be active. Typically defines resource specific holidays and resource availability periods.	O	Date/time
As Late As Possible	A constraint placed on an activity that will cause it to be scheduled to finish on the last date before the project finish date and without delaying successor activities.	O	Alphanumeric
As Soon As Possible	A constraint placed on an activity that will cause it to be scheduled to finish on the earliest date after the project start date after any predecessor activities and without delaying successor activities.	O	Alphanumeric
Expected Finish	A date constraint placed on both the activity early and late finish dates of an in-progress schedule activity that affects when the schedule activity can be scheduled for completion and is usually in the form of a fixed imposed date. This constraint requires the activity remaining duration to be set equal to the difference between the activity expected finish date and the data date to force the schedule activity to be scheduled to finish upon the	R	Date/time

	imposed date.		
Finish Not Earlier Than	A schedule constraint placed on the schedule activity that affects when a schedule activity can be scheduled and is usually in the form of a fixed imposed date. A Finish Not Earlier Than constraint prevents the activity from being scheduled to finish earlier than the imposed date.	O	Date/time
Finish Not Later Than	A schedule constraint placed on the schedule activity that affects when a schedule activity can be scheduled and is usually in the form of a fixed imposed date. A Finish Not Later Than constraint prevents the activity from being scheduled to finish later than the imposed date.	O	Date/time
Finish On	A schedule constraint placed on the schedule activity that affects when a schedule activity can be scheduled and is usually in the form of a fixed imposed date. A Finish On constraint prevents the activity from being scheduled to finish earlier as well as later than the imposed date. Finish On constraints are a combination of a Not Earlier Than and Not Later Than constraints. These impact both the forward and the backward pass calculation and hence both early and late dates.	O	Date/time
Project Start Constraint	A limitation or restraint placed on the project early start date that affects when the project must start and is usually in the form of a fixed imposed date.	O	Date/time
Project Finish Constraint	A limitation or restraint placed on the project late finish date that affects when the project must finish and is usually in the form of a fixed imposed date.	O	Date/time
Start Not Earlier	A schedule constraint placed on the schedule activity that affects when a schedule activity can be scheduled and is usually in the form of a fixed imposed date. A Start Not Earlier Than constraint prevents the schedule activity from being scheduled to start earlier than the imposed date.	O	Date/time
Start Not Later Than	A schedule constraint placed on the schedule activity that affects when a schedule activity can be scheduled and is usually in the form of a fixed imposed date. A Start Not Later Than constraint prevents the schedule activity from being scheduled to start later than the imposed date.	O	Date/time

Activity Actual Duration	The total number of work periods in calendar units between the activity actual start date of the schedule activity and either the data date of the project schedule, if the schedule activity is in progress, or the activity actual finish date, if the schedule activity is complete.	R	Numeric
Activity Baseline	The total number of work periods in calendar units between the activity baseline start date and activity baseline finish date of a schedule activity as determined by its approved project schedule baseline.	R	Numeric
Activity Original Duration	The activity duration originally assigned to a schedule activity and not updated as progress is reported on the activity. Typically used for comparison with activity actual duration and activity remaining duration when reporting schedule progress. The activity original duration is normally developed with a reliance on historic data, specialists, resource availability, financial considerations, and volume of work to be performed. May also be called ‘‘planned duration.’’	R	Numeric
Activity Remaining Duration	The total number of work periods in calendar units, (a) equal to the Original Duration for an activity that has not started or (b) between the data date of the project schedule and the early finish date of a schedule activity that has an activity actual start date. This represents the time needed to complete a schedule activity where the work is in progress.	R	Numeric
Activity Total Duration	The total number of work periods in calendar units to complete a schedule activity. For schedule activities in progress, it includes the activity actual duration plus the activity remaining duration.	O	Numeric
Project Actual Duration	The total number of work periods in calendar units between the project actual start date of the project and either the data date of the project schedule, if the project is in progress or the project actual finish date if the project is complete	R	Numeric
Project Baseline Duration	The total number of work periods in calendar units needed to execute the approved project schedule baseline* for the project.	R	Numeric
Project Original	The initial estimate of the total number of	R	Numeric

Duration	work periods in calendar units needed to complete a project. The Project Original Duration is typically determined from the initial longest network path though the project.		
Project Remaining Duration	The total number of work periods in calendar units, between the data date of the project schedule and the project early finish date of a project that has at least one activity actual start date. This represents the time needed to complete a project where the work is in progress.	R	Numeric
Activity Actual Finish Date	The point in time work actually ended on the schedule activity.	R	Date
Activity Baseline Finish Date	The point in time associated with the completion of the schedule activity in an approved project schedule baseline.	R	Date
Activity Early Finish Date	The earliest possible point in time when the uncompleted portion of the schedule activity can be completed.	R	Date
Activity Late Finish Date	The latest possible point in time when the schedule activity can be completed without violating a schedule constraint or delaying the project end date.	R	Date
Project Actual Finish Date	The point in time associated with the activity actual finish date of the last schedule activity in the project.	R	Date
Project Baseline Finish Date	The point in time associated with the completion of the last schedule activity in an approved project schedule baseline.	R	Date
Project Early Finish Date	The earliest possible point in time associated with the completion of the last schedule activity of the project.	R	Date
Project Late Finish Date	The latest possible point in time associated with the completion of the last schedule activity of the project.	R	Date
Free Float	The amount of time that a schedule activity can be delayed without delaying the early start of any immediately following schedule activities.	R	Numeric
Total Float	The total amount of time that a schedule activity may be delayed from its activity early start date or **activity early finish date** without delaying the project end date, or violating a schedule constraint. Calculated using the critical path method technique and by subtracting the activity early finish date from the activity late finish date, with that difference expressed in calendar units. A total float value less than zero indicates that the activity late finish date is scheduled prior to the activity early finish date and the	R	Numeric

	calculated critical path is not feasible. A total float value of zero or greater indicates the calculated critical path may be feasible and some schedule activities may be able to be delayed.		
Activity Duration Percent Complete	An estimate, expressed as the percentage that the activity actual duration represents, of the activity total duration for a schedule activity that has work in progress.	O	Numeric
Project Physical Percent Complete	An estimate, expressed as a percent, of the amount of work that has been completed on the project, measured in terms of physical work progress.	R	Numeric
Resource Assignment	The linkage of one or more resources to a schedule activity and identification of the amount of each resource that is needed to accomplish the work on that schedule activity.	O	Alphanumeric
Resource Availability	The dates and number of work periods in calendar units that a given resource is available according to the appropriate resource calendar.	O	Alphanumeric
Resource Description	A phrase that describes a resource by type, role, or individual.	O	Alphanumeric
Resource ID	A short unique numeric or text identification assigned to each specific resource to differentiate that resource from other resources. The Resource ID is typically unique within any one project.	O	Alphanumeric
Resource Library/Dictionary	A documented tabulation containing the complete list, including resource attributes, of all resources that can be assigned to project activities. Also known as a resource dictionary.	O	Alphanumeric
Resource Rates/Prices	The unit cost rate assigned to a specific resource, including known rate escalations.	O	Numeric
Resource Type	A unique designation that differentiates a resource by skills, capabilities or other attributes.	O	Alphanumeric
Activity Most Likely Duration	The total number of work periods in calendar units assigned to perform the schedule activity, considering all of the variables that could affect performance, and is determined to be the most probable activity duration.	O	Numeric
Activity Actual Start Date	The point in time at which work actually began on the schedule activity.	R	Date
Activity Baseline Start Date	The point in time associated with the beginning of the schedule activity in an approved project schedule baseline	R	Date
Activity Early Start Date	The earliest possible point in time when the schedule activity can begin.	R	Date

Activity Late Start Date	The latest possible point in time when the schedule activity can begin without violating a schedule constraint or delaying the project end date.	R	Date
Project Actual Start Date	The point in time associated with the activity actual start date of the first schedule activity in the project.	R	Date
Project Baseline Start Date	The point in time associated with the start of the first task in an approved project schedule.	R	Date
Project Early Start Date	The earliest possible point in time associated with the beginning of the first schedule activity of the project.	R	Date
Project Late Start Date	The latest possible point in time associated with the beginning of the first schedule activity of the project.	R	Date
Activity Code	One or more numerical or text values that identify characteristics of the work or in some way categorize the schedule activity that allows filtering and ordering of activities within reports.	O	Alphanumeric
Activity ID	A short unique numeric or text identification assigned to each schedule activity to differentiate that project activity from other activities. The Activity ID is typically unique within any one project schedule network diagram.	R	Alphanumeric
Activity Label	A short phrase or label for each schedule activity used in conjunction with an activity identifier to differentiate that project schedule activity from other schedule activities. The activity description normally describes the scope of work of the schedule activity.	R	Alphanumeric
Critical Path	The longest path through the project.	R	Alphanumeric
Milestone	A significant point or event in the project.	R	Graphical
Project Manager	The person assigned by the performing organization to achieve the project objectives.	O	Alphanumeric
Project Name	A short phrase or label for each project, used in conjunction with the project identifier to differentiate a particular project from other projects in a program. Sometimes also known as project title.	R	Alphanumeric
Project Schedule ID	A short unique numeric or text identification assigned to each schedule model to differentiate that schedule model from others. Also known as project identifier.	R	Alphanumeric
Unit of Measure	A designation of the type of quantity being measured, such as work-hours, cubic yards, or lines of code.	R	Alphanumeric

Update Cycle	The regular interval at which the project activities have their status reported to the current known state.	R	Dates

Questions:
1. Which are the reliability indicators? **2.** What is design of reliability? **3.** Explain the importance of reliability in maintenance process? **4.** What is the difference between planning and scheduling? **5.** Show some examples of planning in maintenance?

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Module M08

Prevision and Forecast for Logistics and Maintenance Activities

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Learning objectives:
⇒ to understand importance of forecasting and planning process
⇒ to understand hierarchy of planning
⇒ to understand factors affecting capacity decisions
⇒ to get familiar with aggregate planning techniques
⇒ to know principles and to use them for master production scheduling

1. PLANNING AS RESULT OF FORCASTING PROCESS

1.1. DEFINITIONS

Planning in organizations and public policy is both the organizational process of creating and maintaining a plan; and the psychological process of thinking about the activities required to create a desired goal on some scale. As such, it is a fundamental property of intelligent behavior. This thought process is essential to the creation and refinement of a plan, or integration of it with other plans, that is, it combines forecasting of developments with the preparation of scenarios of how to react to them. (Wikipedia.org)

The term is also used to describe the formal procedures used in such an endeavor, such as the creation of documents diagrams, or meetings to discuss the important issues to be addressed, the objectives to be met, and the strategy to be followed. Beyond this, planning has a different meaning depending on the political or economic context in which it is used.

1.2. IMPORTANCE OF THE PLANNING PROCESS:

A plan can play a vital role in helping to avoid mistakes or recognize hidden opportunities. Preparing a satisfactory plan of the organization is essential. The planning process enables management to understand more clearly what they want to achieve, and how and when they can do it.

A well-prepared business plan demonstrates that the managers know the business and that they have thought through its development in terms of products, management, finances, and most importantly, markets and competition.

Planning helps in forecasting the future, makes the future visible to some extent. It bridges between where we are and where we want to go. Planning is looking ahead.

Two attitudes to planning need to be held in tension: on the one hand we need to be prepared for what may lie ahead, which may mean contingencies and flexible processes. On the other hand, our future is shaped by consequences of our own planning and actions.

- A good planning system must answer four questions of **priority** and **capacity**.
  - What are we going to make?
  - What does it take to make it?
  - What do we have?
  - What do we need?

- **Priority-** as established by the marketplace
- **Capacity -**is the capability of manufacturing to produce goods and services

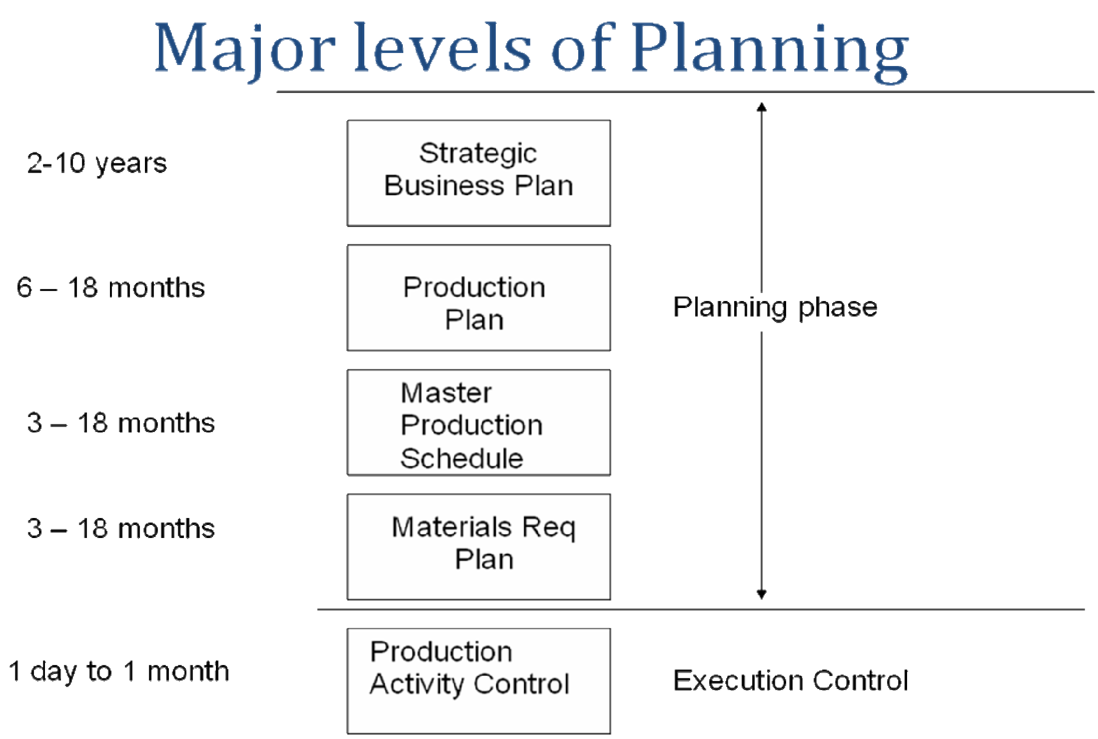


Fig. 1. Major levels of planning

1.3. PRODUCTION PLANNING DECISIONS

- Strategic Planning
  - Top Management
  - Long-Range Planning Horizon:
    >18 months – 10 years
  - Long-Range Planning Activities:
    - Business Forecasting
    - Sales & Operations Planning
    - Production Planning
    - Manufacturing Resource Requirements Planning
    - Financial Planning

- **Tactical Planning**
  - Middle Management
  - Medium-Range Planning Horizon:

  1-18 months
  - Medium-Range Planning Activities:
    - Distribution Requirements Planning (DRP)
    - Demand Management
    - Master Production Scheduling (MPS)
    - Rough Cut Capacity Planning (RCCP)
    - Material Requirements Planning (MRP)
    - Capacity Requirements Planning (CRP)

- **Operational Planning**
  - Short-Range Planning Horizon: **1 day – 1 month**
  - Involve priorities (i.e., determining and meeting due dates) and capacities
  - Short-Range Planning Activities:
    - Input/Output Planning & Control
    - Production Activity Control
    - Purchase Planning & Control
    - Project Management
    - Total Quality Control (TQC) and Preventive Maintenance

1.4. TYPES OF PLANNING:

- **Sales and Operations Planning** (SOP) **–** is a process for continually revising the strategic business plan
- **Manufacturing Resource Planning** (MRP II) **–** The manufacturing planning and control system described here, is a master game plan for all departments in the company and works from the top down with feedback from the bottom up
- **Enterprise Resource Planning** (ERP) **–** is an accounting oriented information system for identifying and planning the enterprise---wide resources needed to make, ship, and account for customer orders

1.5. PRODUCTION PLANNING (PP):

- Matches market demand to company resources
- Plans production 6 months to 12 months in advance
- Expresses demand, resources, and capacity in general terms

- Develops a strategy for economically meeting demand
- Establishes a companywide game plan for allocating resources

Production Planning Stages

- Defining objectives
- Setting priorities to attain objectives
- Examining internal & external environments of planned system
- Determining achievable targets
- Determining inputs needed to achieve targets

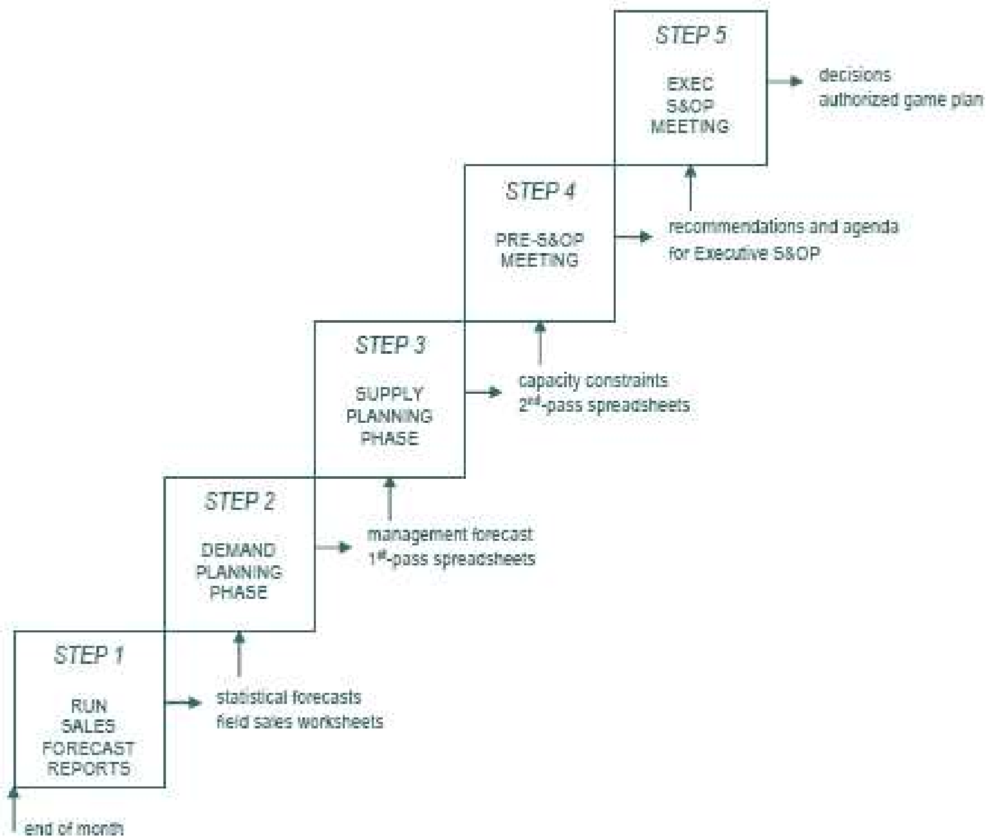


Fig. 2. The Monthly Sales & Operations Planning Process

Objectives

- Effectiveness: goods to fulfill customers' needs
- Maximising output: maximum output with minimum input
- Quality control: Product/service quality meets planned quality specifications
- Minimise throughput time: conversion of raw materials to finished goods in minimum time
- Capacity: full utilisation of men & machines
- Minimise cost: minimum cost of production
- Maintaining inventory: optimal inventory
- Flexibility: flexibility in production operations
- Coordination: between men & machines
- Capacity: plan for current & future needs
- Reduce bottlenecks: solve production problems early
- Maximise profit: minimise cost
- Production schedules: as per plan
- Routes & schedules: to optimise use of men, material & machinery
- Maintain performance: maintain standards

1.6. FUNCTIONS OF PRODUCTION PLANNING

- Product selection & design
- Process selection & planning
- Facility location
- Facility layout & materials handling
- Capacity planning
- Systems & procedures
- Estimating quantity/costs of production, men
- Routing operation sequence
- Job scheduling & loading

<u>Benefits of Production Planning</u>

- Higher quality
- Better resource utilization
- Reduced inventory
- Reduced manufacturing cycle time
- Faster delivery
- Better customer services
- Lower production costs
- Lower capital investment
- Improved sales turnover
- Improved market share
- Improved profitability
- Competitive advantage
- Flexibility
- Dependability
- Lower prices

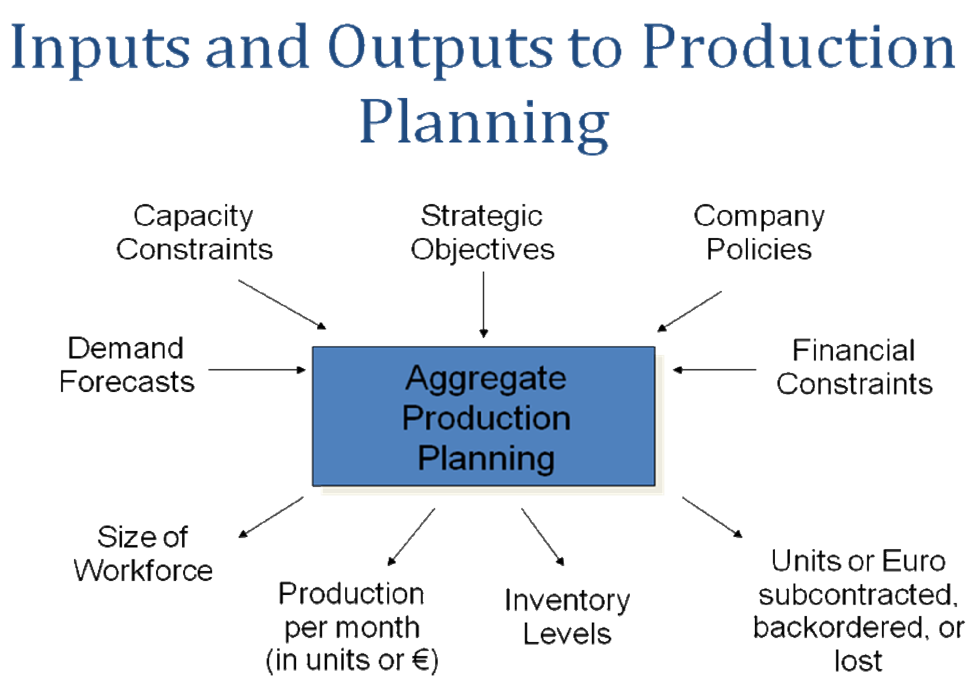


Fig. 3. Inputs and outputs of production planning

1.7. REQUIREMENTS FOR EFFECTIVE PRODUCTION PLANNING

- Sound organisational structure
- Delegation of authority
- Reliable, up-to-date feedback
- Standardisation
- Trained people
- Flexibility to adapt
- Appropriate management policies
- Accurate assessment of manufacturing/procurement lead times
- Adequate plant capacity

Limitations of Production Planning

- Based on assumptions
- Resistance to change
- Time consuming
- Difficult due to rapid environment changes

2. HIERARCHICAL PRODUCTION PLANNING

2.1. DIFFERENCES OF PP AND HPP

- Production Planning
  - A set of decisions that aim to minimize costs and production time while maximizing efficiency and customer satisfaction
- ***Hierarchical* Production Planning (HPP)**
  - A practice within production planning that matches each planning decision to the appropriate level in the organization

Production Planning refers to manufacturing planning decisions in aggregate. These decisions include ERP systems, scheduling, spreadsheet models, factory specific plans, etc. Hierarchical Production Planning is simply a philosophy arguing that not all decisions should be made by top management. Rather, each decisions should be made by the appropriate organizational entity. For example, a specific factory plan should be made primarily by the managers of the factory, not solely the corporate officers located hundreds of miles away.

Nuts and Bolts

- Decisions are disaggregated (broken up) sub-problems and assigned to the appropriate level in the organization
- Higher –level restrictions impose constraints upon lower-level decisions
- Detail increases the further decisions move down the hierarchy
- Communication breakdowns between levels is common; independent committees are useful in monitoring progress

According to Vollman, Berry, Whybark, and Jacobs, one of the biggest problems facing production planning is understand how the overall production plan relates to the day-to-day detail of specific product production. One approach to solving this problem is disaggregation: breaking up the planning process into smaller pieces an assigning those pieces to the right level in the organization. This processes helps the day-to-day production be in line with the aggregate production plan. At each stage of disaggregation, detail increases while influence decreases. For example, at the highest level, a lawn-mowing company could assign several production lines at multiple factories assigned. At the lowest level, specific detail and schedules about how a specific model will be produced could be given. The challenge is to maintain constant communication between lines so that the detailed plans fit within g the framework given by the hierarchical structure.

2.2. MAJOR BENEFITS OF HIERARCHICAL PRODUCTION PLANNING

- Decreased Data Collection Costs
- Increased Data Accuracy
- Easier to implement planning decisions at each level
- Lower-level planning decisions provide valuable feedback to upper management
- Widely adaptable to different organizations

Briton and Tirupati from the MIT Sloan School of Management argue that HPP decreases data collection costs because those collecting and send the data up the chain already have access to it; thus, top management does not have to go searching for it. In addition, if decisions are made at each level, then it is easier for companies to implement their overall production plans because each level has already “bought in” to their piece of it, since they made the decisions about their part. Finally, HPP naturally provides an excellent forum for feedback and adjustments to the overall production plan can be made if needed.

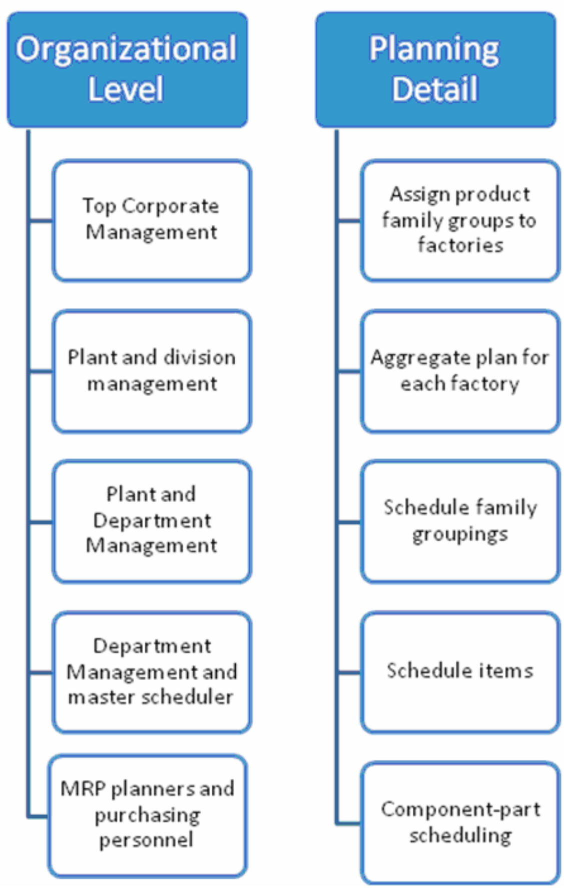


Fig. 4. HPP: A Conceptual View

2.3. HOW IT WORKS

Step 1

- Top Management decides which products will be produced at which factories
  - Products are combined into family groupings
  - Primary considerations in factory assignment is cost minimization

In this step, products are "assigned into family groupings to facilitate aggregation, assignment to factories, and modeling processes. Assignment to factories is based on minimizing capital investment cost, manufacturing cost, and transportation cost."

Step 2

- Division Management specifies production plan for each factory
  - Includes inventory levels, overtime, production capacity, etc.

This step is constrained by the specific volumes set by top corporate management, but provides more detail regarding inventory and production levels for each factory.

Step 3

- Plant Management schedules product family groupings at the factory
  - Constrained by aggregate plan created by higher level

The primary purpose of this stage is to achieve cost minimizing by grouping product families together during production. This step can often be skipped if no economies of scale are achieved. Plant management is constrained in this step by the inventory levels and production levels set by the previous step, but lays out the schedule for each product family, not getting into detail about specific products

Step 4

- Department Management schedules individual products
  - Schedules usually based on mathematical models
  - Constrained by the previously scheduled family groupings

This step is similar to making a master production schedule for a factory. This step may cover a shorter planning horizon that the previous steps. Many times, mathematical models are used to develop this master schedule, but that subject is out of the scope of this training.

Step 5

- Purchasing Personal completes component-part scheduling
  - Completed through inventory systems or mathematical modeling

This is the most detailed portion of the decision process. Specific detail about inventory purchasing and assembly is given

2.4. A PRACTICAL EXAMPLE

Smlack and Becker produces and sells tools. The company is currently evaluating the best production planning method to decrease costs and maximize efficiency. It has decided to implement a hierarchical production planning model and will take the following steps

Smlack and Becker—Step 1

- The corporate officers in Bethesda, MD assign product families to its 10 different factories around the country.
  - Example: saws will be produced in one factory, generators in another, and drills in another
  - This step requires the least amount of detail

Smlack and Becker—Step 2

- Division Managers will develop and aggregate plan for each factory
  - Production and inventory levels for each family is established
  - These managers are constrained to plan within the corporate officers limitations. (for example, they cannot assign saws to be made at the drill factory)

Smlack and Becker—Step 3

- Factory Managers schedule how family groups will be manufactured
  - Focus will be on generating cost savings by combining manufacturing processes with similar products (families)

Smlack and Becker—Step 4

- Department Managers will schedule each item for production
  - Production of specific tool models will be planned

Smlack and Becker—Step 5

- Procurement with plan product components
  - Purchase and assembly of product parts will be planned
  - This step requires the most amount of detail

Smlack and Becker—Step 6

- All Feedback is submitted to Smlack and Becker Headquarters in Bethesda to feed into the aggregate production plan.
- Committees evaluate communication stream to make sure information is being passed up the chain

Exercise

You work for a Fertilizer Company and are responsible for implementing a hierarchical production plan by July '09. You have been given the appropriate levels within your organization and the necessary planning steps. Your job on the next slide is to connect the planning detail with the correct level within the organization:

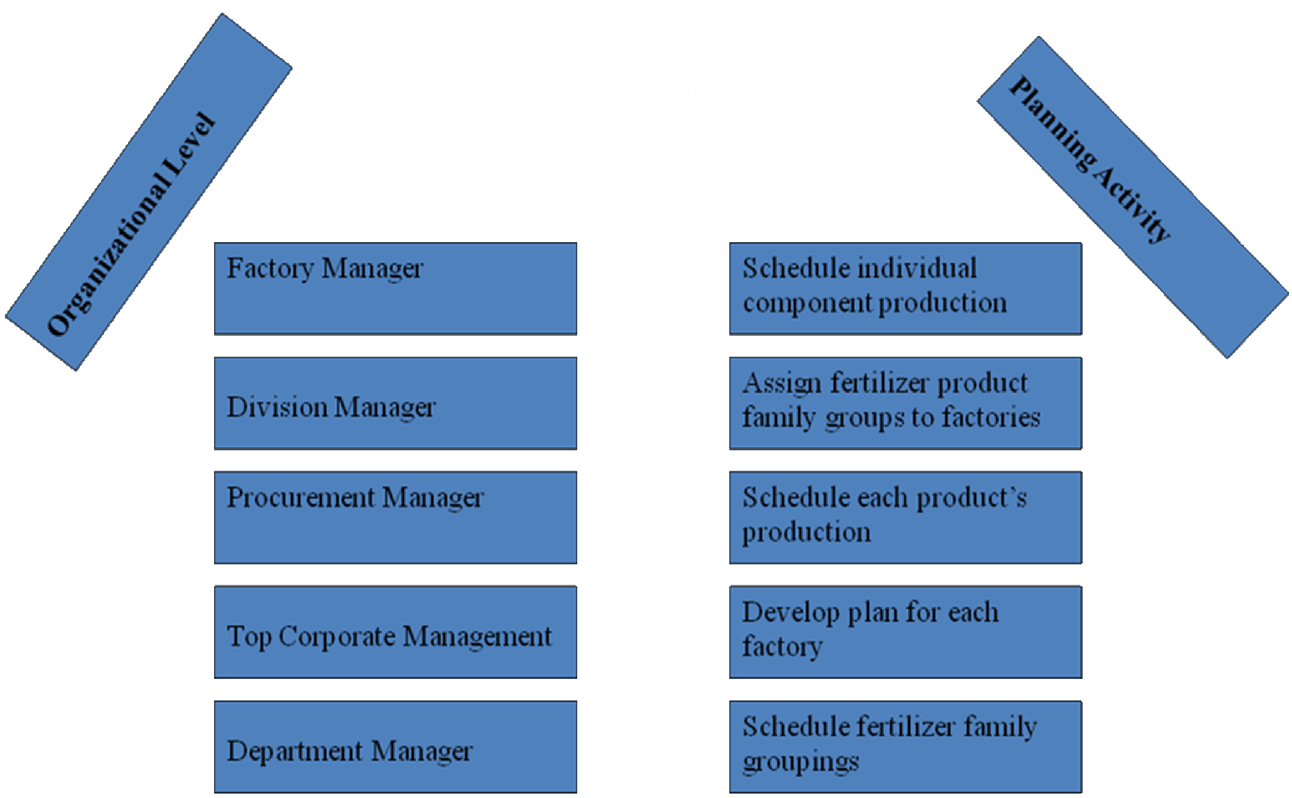


Fig. 5. For exercise: Connect the Boxes

References

Vollmann, Berry, and Whybark. Manufacturing Planning and Control Systems for Supply Chain Management. McGraw-Hill 2005, Fifth Edition

3. PREVISION AND FORECAST OF CAPACITY

3.1. CAPACITY DEFINED

• The amount of work that can be done in a period of time.

• The capability of a worker, machine, work center, plan, or organization to produce output per period of time

Kinds of Capacity

• Capacity available – the capacity of a system / resource to produce a quantity of output in a given period of time.

• Capacity required- the capacity needed to produce a desired output in a given period of time.
– Load – closely related to Capacity requirements – the amount of work assigned to a center / facility for a period of time.

3.2. CAPACITY FORCAST

– Determining which level of capacity to operate at to meet customer demand in a cost efficient manner.
– Forecast sales for each product line.
– Forecast sales for individual products within each line.
– Calculate labor and equipment requirements to meet product line forecasts.
– Project labor and equipment availabilities over the planning horizon.

Other definitions

•Capacity management – *Determining the capacity* needed to achieve the plan.

•Capacity control – the process of monitoring output, comparing it to capacity plans and taking corrective action when needed.

3.3. FACTORS AFFECTING CAPACITY DECISIONS

- External Factors
  - Government regulations
  - Union agreements
  - Supplier capabilities

- Internal Factors
  - Product and service design
  - Personnel and jobs
  - Plant layout and process flow
  - Equipment capabilities and maintenance
  - Materials management
  - Quality control systems
  - Management capabilities

Capacity Decisions

- Production System Capacity Affects:
  - Response rate to market changes
  - Overall product cost structure
  - Composition of the workforce
  - Level of production technology utilized
  - Extent of management and staff support
  - General inventory strategy

Capacity Utilization and Service Level

- Balancing Capacity and Demand
  - Demand exceeds capacity, customers are turned away.
  - Demand exceeds optimum capacity, customers receive poor service.
  - Demand equals optimum capacity, customers are service properly.
  - Demand is less than optimum capacity, there is idle capacity.
- *Too much capacity—costs rise.*
- *Too little capacity—customers are lost.*

Capacity can be increased through introducing new techniques, equipment and materials, increasing the number of workers or machines, increasing the number of shifts, or acquiring additional production facilities.

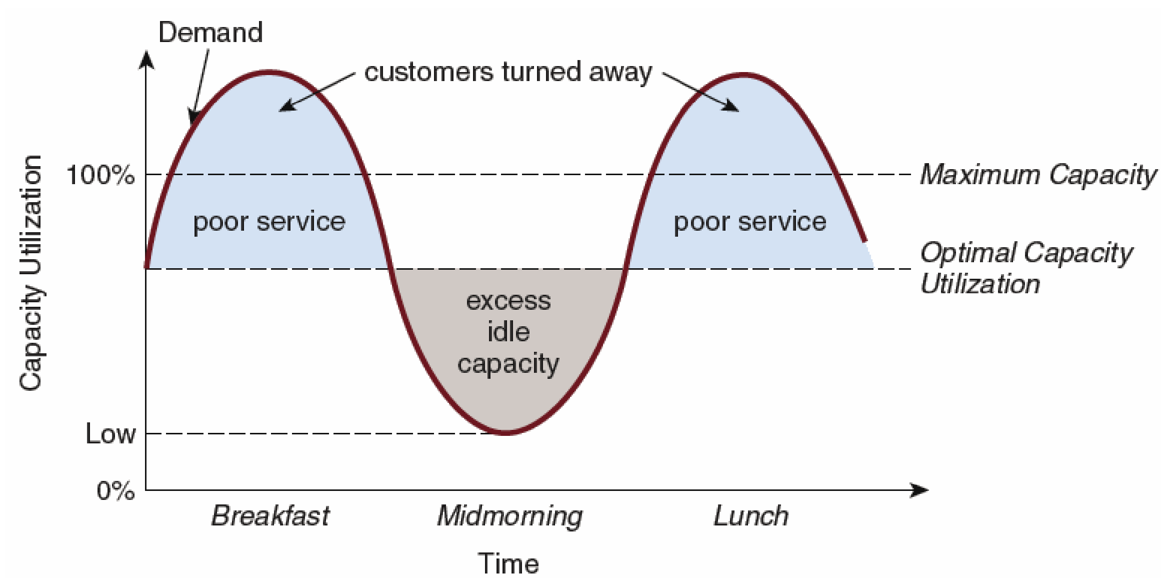


Fig. 6. Comparing Capacity and Demand for a Food Service Facility

3.4. IMPORTANT CAPACITY CONCEPTS

- Best Operating Level

– The capacity (production volume) for which the average unit cost of output is at a minimum.

- Economies of Scales

– The output range in which average units costs decrease as unit production volumes increase.

• Diseconomies of Scale

– The output range in which average unit costs rise due to added costs incurred at operating levels exceeding the best operating level.

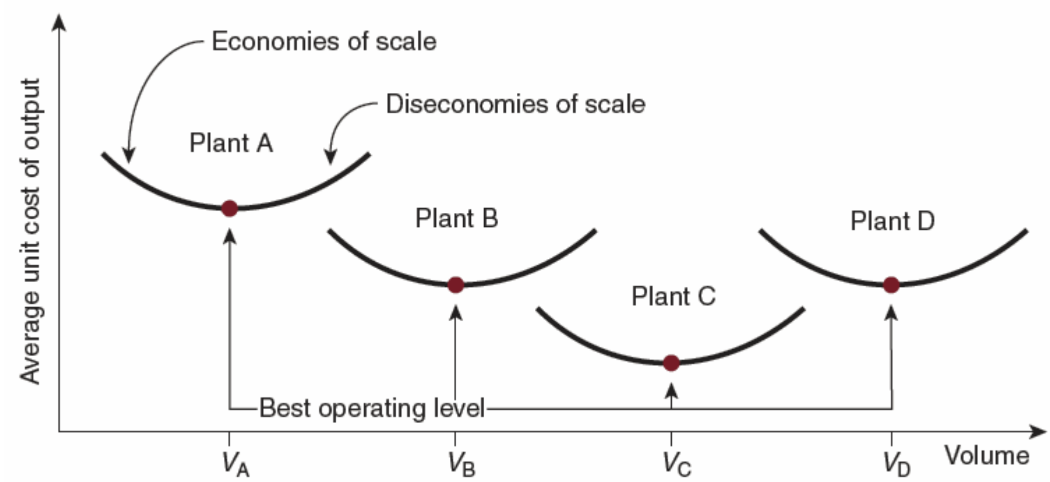


Fig. 7. Economies of Scale

• Capacity Flexibility

– Ability to provide a wider range of products and volumes with short lead times.

• Flexible plants • Flexible processes

• Flexible workers • Use of External Capacity

• Subcontracting • Sharing capacity

Agile Manufacturing

– The capability of a manufacturing process to respond quickly to marketplace changes.

• Capacity Balance

– Balanced internal operational capacities

3.5. CAPACITY STRATEGIES

• Proactive

– Anticipating future growth and building a facility so that it is up and running when the demand is there.

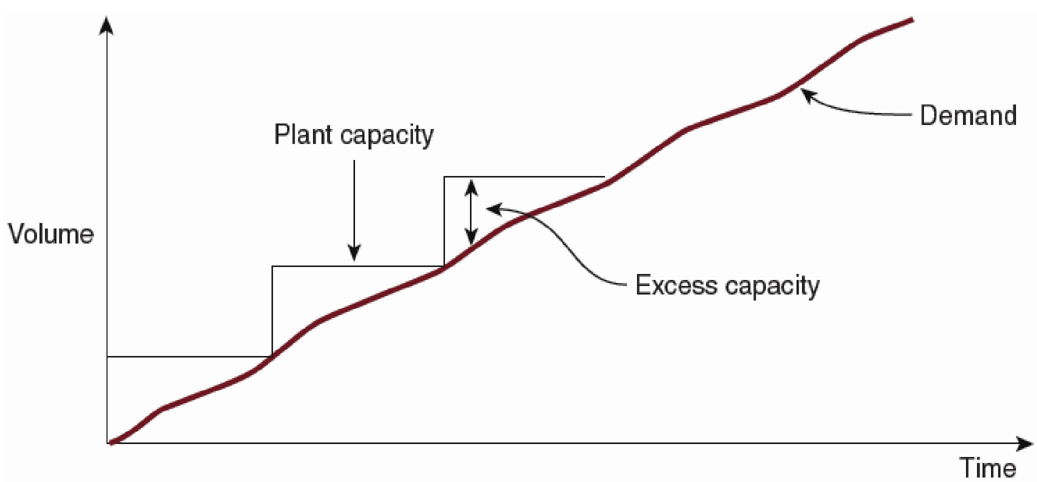


Fig. 8. Proactive Capacity Strategy

• Neutral
– Additional capacity becomes available when demand is about 50 percent of planned added capacity. The issue is how best to satisfy demand before the plant is up and operating.

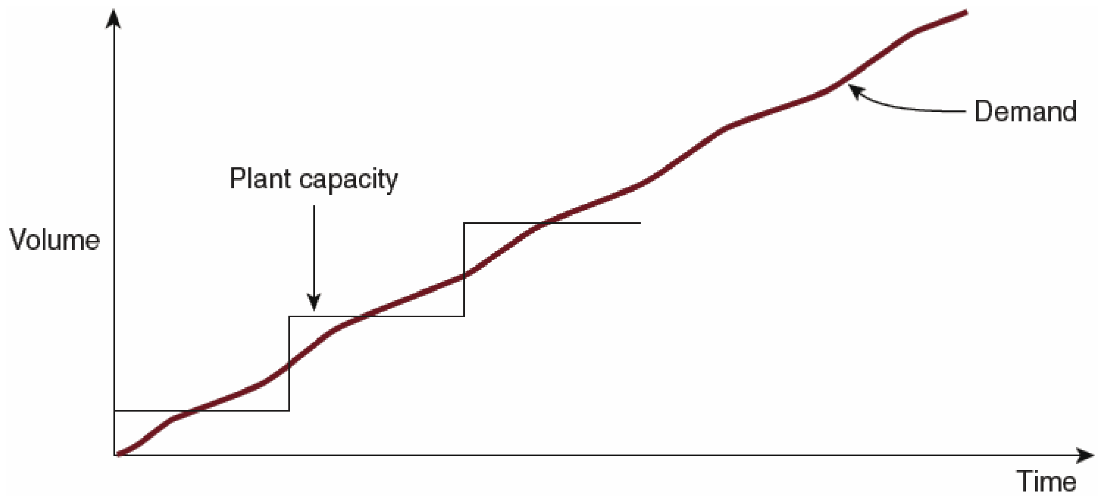


Fig. 9. Neutral Capacity Strategy

• Reactive
– plant capacity is not added until all of the planned output from the facility can be sold.

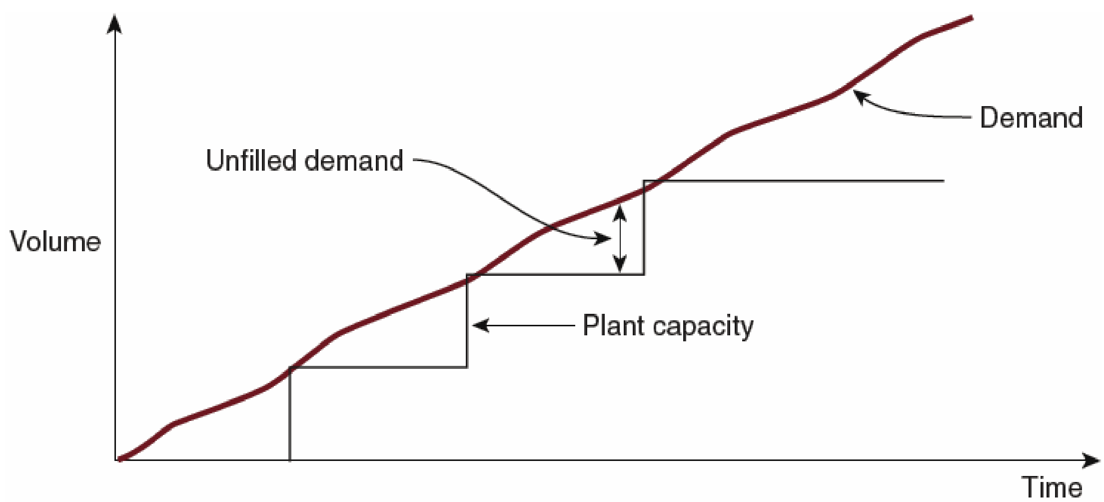


Fig. 10. Reactive Capacity Strategy

<u>Discussion</u>

FENNER: EXPANDING CAPACITY TO MEET GLOBAL DEMAND

Fenner is the world's largest manufacturer of industrial conveyor belts. In 2005 it produced over five million metres of conveyor belting in its twelve manufacturing facilities on five continents. Its belts are used material handling operations in a vast range of industries, including underground and hardrock mining aggregates, power generation, grain, forestry, package handling, food processing, baggage handling moving walkways, paper handling, computer peripherals, copiers, electrical/mechanical equipment agricultural machinery, heating, ventilating and air conditioning,

truck/bus, pharmaceuticals, machine too mobile hydraulics, off-highway machines, mechanical handling, construction equipment, process industries, oil, gas and aerospace.
Currently business is booming for the company which is headquartered in Yorkshire, England. Announcing its half-year results to 28 February 2006, the company announced a more than doubling of its pre-tax profits up to £11.9 million from £4.2 million a year earlier. As the Financial Times (FT) reported on 11 May 2006 'buoyant energy markets helped the company to produce a very strong set of interim results'. Revenues jumped 33 per cent to £182 million from £137 million and earnings per share rose to 5.34p from 2.58p.
The FT commented:
'Demand for conveyor belts, which account for about two-thirds of (Fenner's) turnover, is booming with the order flow more than double that of two to three years ago. These results clearly demonstrate the operational gearing of Fenner's business and, with the coal sector seemingly entering a super-cycle with oil prices so high, the prospects look very good'.
The FT went on to note that Fenner was the latest supplier to benefit from the booming oil and mining sectors. This was particularly the case in China, where coal consumption to feed its power stations had doubled in the past few years to about 2 billion tonnes of coal a year - twice that of the USA. The high oil price was also driving more coal mining projects elsewhere in Asia and North America. The company was also supplying the large oil-sands projects in Canada.
Mark Abrahams, Fenners' Chief Executive said, 'I have been with the group for 16 years now and this is the best [trading] I have seen.' Mr Abrahams announced that Fenner planned to expand its manufacturing capacity by as much as a third over the next three years. The company would be making capital investments of about £18 million a year on expanding its factories and building at least one new factory in China. He said a third of the investment would be targeted at China, the world's fastest growing economy. The company already has one plant near Shanghai with a second due to come on stream towards the end of 2006. It was now planning a third factory for China.

Questions
1. What are the most important factors influencing Fenner's growth?
2. How might Fenner set about forecasting demand for its products over the next 5 years?
3. What capacity strategy is using Fenner?

3.6. CAPACITY MEASURES

- Capacity
    - The output of a process or facility over a given time period.
    - By units of output (litres of beer , # of cars)
    - Standard time – time to produce a product by a qualified operator at a normal pace
- Capacity Utilization
    - The percentage of the available capacity that is actually being used.

All these different times?
- **Move time –** time normally needed to move material from one WC to another.
- **Wait time –** time a job waits at a WC after completion and before it’s been moved.
- **Queue time –** time a job waits at a work center before being handled.
- **Lead time –** sum of queue, setup, run, wait and move times.

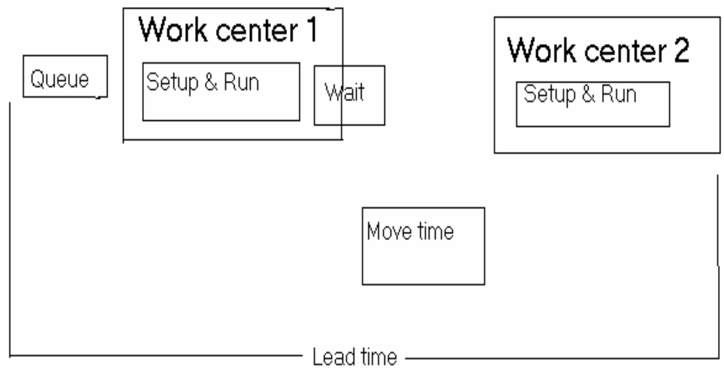


Fig. 11. Lead time

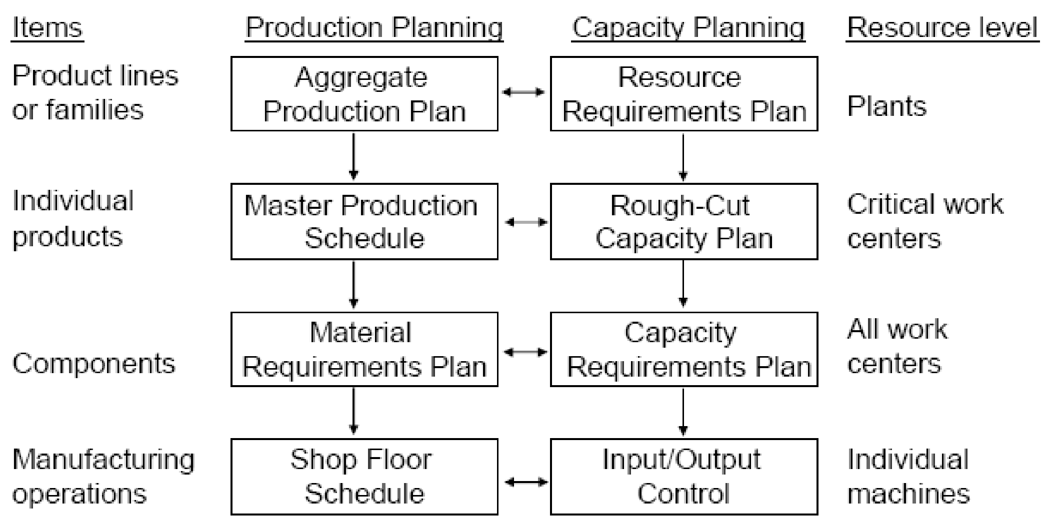


Fig. 12. Hierarchical Planning Process

Levels of Capacity

- Must be measured at these three levels
  - Machine or individual worker
  - Work center
  - Plant

Determining Capacity Available

- Measurement
  - Demonstrated capacity comes from historical data

- Calculation
  - Calculated or rated capacity is based on available time , utilization and efficiency.
- Available time - # hours a work center can be used in maximum terms.
- Utilization - % of time the the work station is active compared to available time.
  - Utilization = hours actually worked/available hours x 100%.

- Efficiency – actual rate / standard rate
  - Can be higher than 100%
- Rated Capacity – is based on available time , utilization and efficiency.

= available time X utilization X efficiency.

Example problem

4 machines X 8 hours daily X 5 days = 160 days
RC = 160 X .85 x 1.10 = 149.6 standards hours

Demonstrated Capacity

- Historical in nature
  - 4 weeks of 120, 130, 150 & 140 Standard hours
  - DC = 120+130+150+140/4 = 135 standard hours
  - Notice it's and average not maximum

Capacity Requirement

- Load determination

– Determine time needed for each order at each center.
– Sum the CR for individual orders to obtain a load.
- Time needed for order
-Sum of Setup and Run times
-Example 150 gear shafts with a setup of 1.5 hours and run time of 0.2 hours
-Standard time = 1.5 + (150 x 0.2)

	Order Quantity	Setup Time	Run Times	Total Time
		(hours)	(hours/piece)	(hours)
Released Orders				
222	100	0	0.2	
333	150	1.5	0.2	
Planned Orders				
444	200	3	0.25	
555	300	2.5	0.15	
222	0+ (100 x 0.2)	20		
333	1.5 + (150 x 0.2)	31.5		
444	3 + (200 x 0.25)	53		
555	2.5 (300 x 0.15)	47.5		
	Total	152		

Fig. 13. Example

Week	20	21	22	23	24	Total
Released Load	51.5	45	30	30	25	181.5
Planned Load	100.5	120	100	90	100	510.5
Total Load	152	165	130	120	125	692
Rated Capacity	140	140	140	140	140	700
(Over)/ Under Capacity	-12	-25	10	20	15	8

Fig. 14. Example

3.7. SCHEDULING CAPACITY

- According the ninth edition of the APICS Dictionary, scheduling is : “a timetable for planned occurrences”

Back Scheduling

- Back Scheduling – starting with the due date and work backwards to find the start date for each operation.

- Items needed
  - Quantity and dates
  - Sequence of operations
  - Setup ,run times, queue, wait and move
  - Work center capacity available

- Information needed is obtained from
  - Order file
  - Route file
  - Work center file

		All inDays					
Operation number	**Work Center**	**Arrival Date**	**Queue**	**Operation time**	**Wait**	**Finish Date**	***Move time***
10	12	95	4	4	1	103	*104*
20	14	105	3	5	1	113	*114*
30	17	115	5	1	1	121	*122*
40	3	123	8	2	1	133	*134*
50	Stores	135					

Fig. 15. Example

Balancing Capacity

- Alter the load
  - Shifting orders ahead or back in the plan

- **Change capacity**
  - Schedule overtime
  - Hiring or Firing
  - Shift workforce to more overloaded centers
  - Alternate routings
  - Subcontract , outsource or farm-out

Discussion

CAPACITY HITS THE BUFFERS FOR US RAILWAYS

Surging freight volumes have been causing serious congestion across the US rail network in the last few /ears. The country's ageing system has been struggling to cope with surging freight volumes generated by robust economic growth and has been operating close to full capacity.
Railroads remain the backbone of North America's freight transportation network. In the US, railroads account for more than 40 per cent of all freight transportation, more than from any other single mode of transportation. The country's vast distances mean that any bulky cargoes (cars, steel, coal, grain, lumber, cement, etc.) are moved most cost effectively by rail. US freight railroads are the world's busiest, moving more freight than any rail system in any other country. US railroads move more than four times as much freight as do all of Western Europe's freight railroads combined.
The four years between 2002 and 2006 have seen explosive growth for US railway companies. Industry executives say they see no signs of a slowdown, with all the big operators predicting continuing volume growth. As the US economy has rebounded from recession, a range of factors have pushed more freight on to the rails. Rail companies have been benefiting from surging energy prices because freight trains are three times more fuel-efficient than trucks. A nationwide shortage of truck drivers and worsening road congestion have also spurred the shift in freight from road to rail. The resurgence of coal as a source of electricity means that railroads are carrying record amounts of coal. Rising volumes and limited capacity have also enabled the railroads to up their prices to reinforce their profit margins. Union Pacific, the biggest operator more than doubled its net profits during 2005 to $311 million. Norfolk Southern revealed a 57 per cent increase in net

earnings to $305 million and BNSF increased its net profits by 28 per cent to $410 million during the same period. Underlying profits at CSX rose 56 per cent.
In response to the capacity constraints, rail companies have sharply increased their investments in infrastructure. According to industry body the Association of American Railroads, the biggest US freight railroads plan to spend more than $8.2 billion in 2006 laying new track, buying new equipment and improving infrastructure. This would raise the industry's capital expenditure 21 per cent from the previous year and shatter the previous record for infrastructure spending in one year.
Freight railroads are capital intensive businesses. Between 1995 and 2004, they put an average of 17.8 per cent of their revenues into capital expenditures. This compares with an average of 3.5 per cent for manufacturing. In addition, railroads spend $10 billion to $12 billion each year to repair and maintain their infrastructure and equipment, a total spending of nearly $360 billion since 1980. The $15 billion to $17 billion railroads typically spend each year on their infrastructure and equipment is equal, on average, to approximately 45 per cent of their operating revenue.
However, many customers believe the industry is still not doing enough to tackle congestion on the railroads. Entergy, a large electricity generator, is suing Union Pacific for coal supply disruptions. Others see the railroads' record profits as proof that capacity shortages are being used to inflate prices. Pointing to the near-monopoly enjoyed over entire regions of North America by the biggest six operators (Union Pacific, CSX, Norfolk Southern, BNSF, Canadian Pacific and Canadian National), many have been lobbying Congress for legislation to force the industry to behave more competitively.
Rail industry executives argue that the only way to expand capacity is to make sure the companies are making enough money to invest. Investment has been held back in the past by the industry's traditionally low return on capital. Improvements promised include double tracking of bottleneck sections of the line and investments in new technology like satellite tracking to allow trains to travel closer together safely, thereby increasing track utilization by up to 20 per cent.
Unclogging US railways will be a slow process say railroad executives. They promise that services will eventually improve but customers must accept the days of unlimited rail capacity are gone. One said, This industry used to be like a light switch. If you needed more railroad cars you just flipped a switch and they were available. That switch is no longer working'.

Questions
1. What capacity management strategy do US freight railroads use, and why?
2. What other actions are open to the railroads to manage capacity?

4. AGGREGATE PLANNING

Managerial Issues

- Translating long-range strategic plans into daily work schedules for the shop floor.
- Using aggregate planning to develop intermediate-range plans that link the long-range strategic plan and the short-range operational plan.
- Developing aggregate plans that match the demand for products with the firm’s ability to supply the products and to do so at minimum cost.
- Coordinating marketing management and operations to develop an aggregate plan that is both effective and efficient.

4.1. OVERVIEW OF OPERATIONAL PLANNING ACTIVITIES

•*Long-Range Planning*

–Focuses on strategic issues relation to capacity, process, selection, and plant location.

•*Intermediate-Range Planning*

–Focuses on tactical issues pertaining to aggregate workforce and material requirements for the coming year.

•*Short-Range Planning*

–Addresses day-to-day issues of scheduling workers on jobs at assigned work stations.

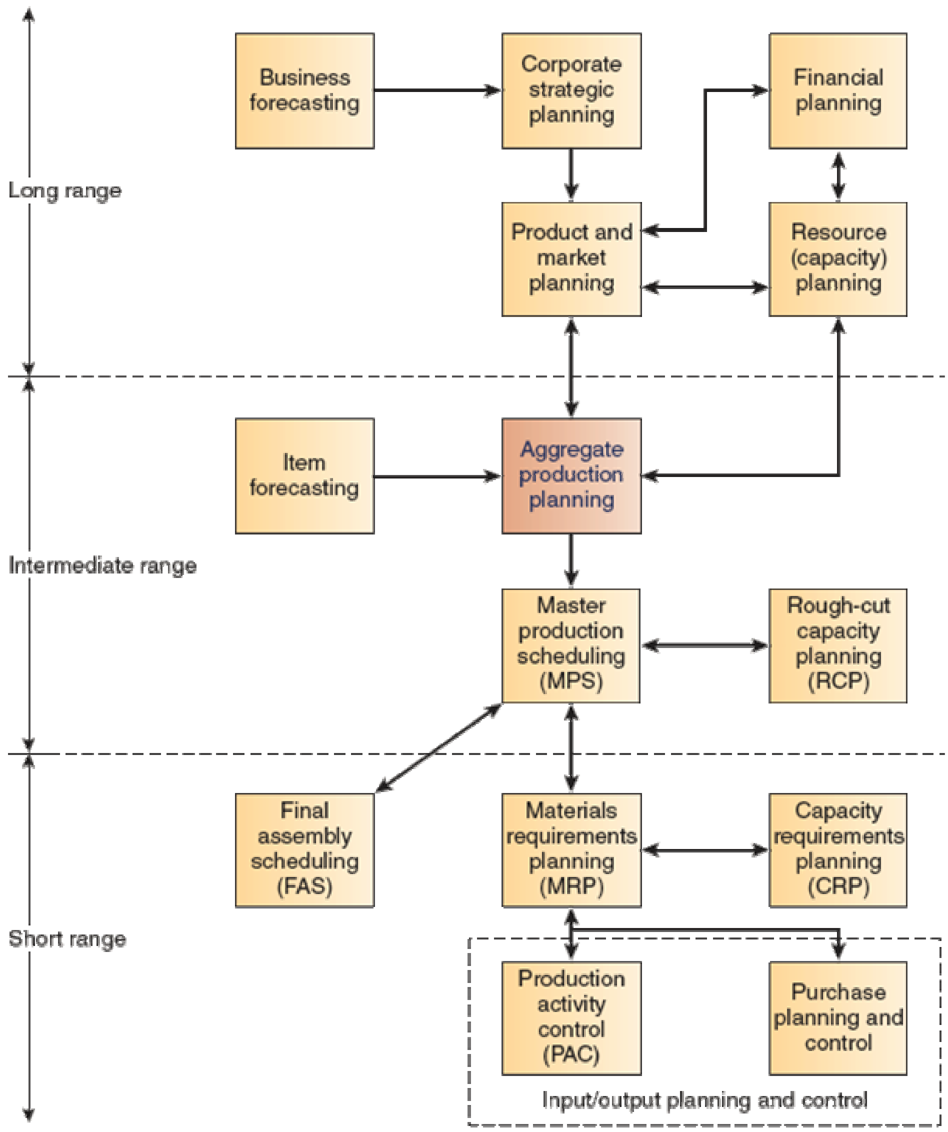


Fig. 16. Overview of Manufacturing Planning Activities

<u>Intermediate-Range Planning</u>

•*Aggregate Production Planning*

–The process for determining the most cost effective way to match supply and demand over the next 12–18 months.

•*Item Forecasting*

–Estimating specific products (and replacement parts), which, when integrated with the aggregate production plan, becomes the output requirement for the master production schedule (MPS).

–The process of monitoring and integrating this information is termed *demand management*.
•*Master Production Scheduling (MPS)*
–Short-term scheduling of specific end product requirements for the next several quarters.
•*Rough-Cut or Resource Capacity Planning*
–Determining that adequate production capacity and warehousing are available to meet demand.

Aggregate Production Planning
•*Production Rate*
–The capacity of output per unit of time (such as units per day or units per week.
•*Workforce Level*
–Number of workers required to provide a specified level of production.
•*Inventory on Hand*
–The surplus of units that results when production exceeds demand in a given time period.
•*Backlog (or Stockout)*
–The deficit in units that results when demand exceeds the number of units produced in a given time period.

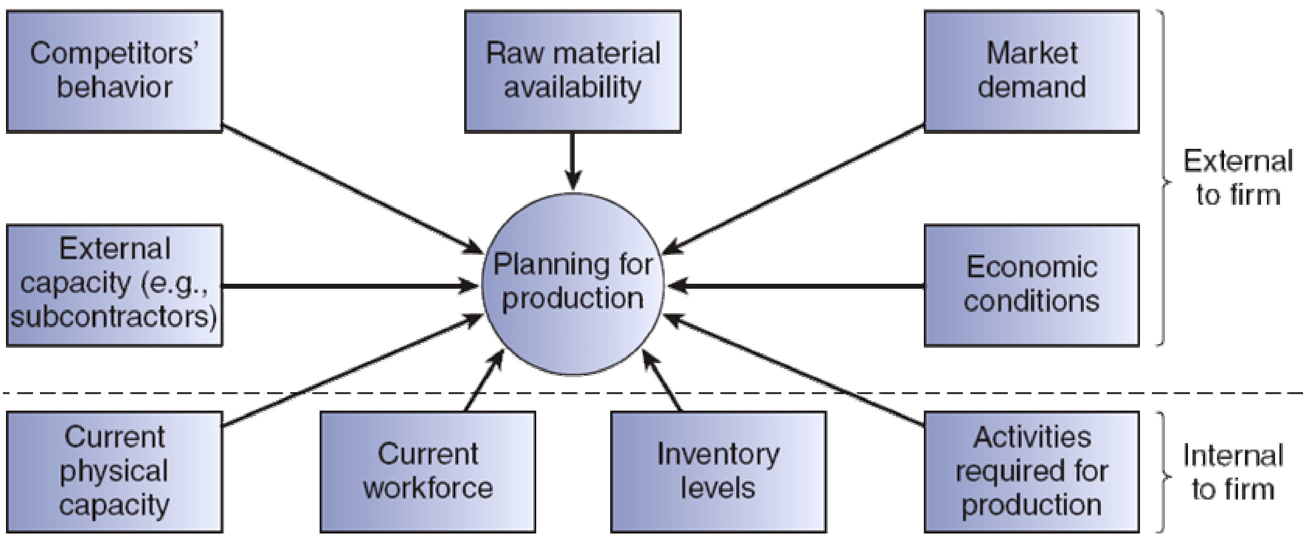


Fig. 17. Required Inputs to the Production Planning System

Strategies for Meeting Demand
1. *Use inventory to absorb fluctuations in demand (level production)*
2. *Hire and fire workers to match demand (chase demand)*
3. *Maintain resources for high demand levels*
4. *Increase or decrease working hours (over & under time)*
5. *Subcontract work to other firms*
6. *Use part-time workers*
7. *Provide the service or product at a later time period (backordering)*

4.2. PRODUCTION PLANNING STRATEGIES

•*Chase Strategy*
–Matching the production rate to exactly meet the order rate by hiring and laying off workers as the order rate varies.

–Maintaining resources for high demand levels - ensures high levels of customer service
–Overtime & undertime - common when demand fluctuations are not extreme

•*Stable Workforce—Variable Work Hours*
–Varying output by varying the number of hours worked through flexible schedules or overtime.

•*Level Strategy*
–produce at constant rate & use inventory as needed to meet demand
–Maintain a stable workforce working at constant output rate; absorb demand variations with inventory, backlogs, or lost sales.

Strategy Details

- ***Subcontracting*** *- useful if supplier meets quality & time requirements*
- ***Part-time workers*** *- feasible for unskilled jobs or if labor pool exists*
- ***Backordering*** *- only works if customer is willing to wait for product/services*
- ***Hybrid Strategy*** *– a mixture of any of the basic strategies.*

•*Pure Strategy*
–Either a chase strategy when product exactly matches demand or a level strategy when production remains constant over a specified number of periods.

•*Mixed Strategy*
–A combination of chase and level strategies to match supply and demand

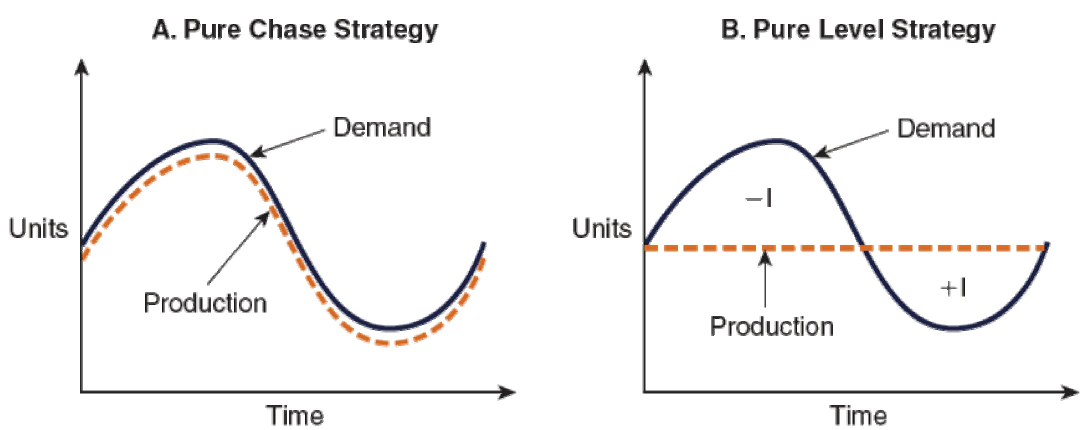


Fig. 18. Chase Demand and Level strategies

•*Relevant Costs*
–Basic production costs (fixed and variable)
–Costs associated with changes in the production rate (e.g., labor costs)
–Inventory holding costs
–Backlog (stockout) costs
•
•*Budgets*
–Aggregate planning helps justify requests for organizational resources.

4.3. AGGREGATE PLANNING TECHNIQUES

- *Trial and Error*
  - Costing out the production alternatives and choosing the one with the lowest cost.
- *Linear Programming*
- *Linear Decision Rule*
- *Various Heuristic Methods*

- *Full Costs*
  - All of the actual, out-of-pocket costs associated with a particular aggregate plan.
  - Used for developing a labor and material budget.

- *Marginal (Incremental) Costs*
  - Unique costs attributable to a particular aggregate plan that are above and beyond those required to build the product by its most economical means

Examples

Quarter	Sales Forecast (kg)
Spring	80,000
Summer	50,000
Autumn	120,000
Winter	150,000

Hiring cost = €100 per worker
Firing cost = € 500 per worker
Inventory carrying cost = € 0.50 kg per quarter
Production per employee = 1,000 kg per quarter
Beginning work force = 100 workers

Level Production Strategy

Quarter	*Sales Forecast*	*Production Plan*	*Inventory*
Spring	*80,000*	*100,000*	*20,000*
Summer	*50,000*	*100,000*	*70,000*
Autumn	*120,000*	*100,000*	*50,000*
Winter	*150,000*	*100,000*	*0*
	400,000		***140,000***

Cost = 140,000 kg x 0.50 per kg = ***€70,000***

Chase Demand Strategy

Quarter	*Sales Forecast*	*Production Plan*	*Workers Needed*	*Workers Hired*	*Workers Fired*
Spring	*80,000*	*80,000*	*80*	*-*	*20*
Summer	*50,000*	*50,000*	*50*	*-*	*30*
Autumn	*120,000*	*120,000*	*120*	*70*	*-*
Winter	*150,000*	*150,000*	*150*	*30*	*-*
				100	***50***

Cost = (100 workers hired x €100) + (50 workers fired x € 500)
= € 10,000 + 25,000 = ***€ 35,000***

Level Production Plan Procedure

Total Production = total forecast + back orders + ending inventory – opening inventory

Total Production = What do they want + BO + What we want to have – What we currently have

Period	1	2	3	4	5	**Total**
Forecast Cases	**110**	**120**	**130**	**120**	**120**	**600**

Opening inventory = 100
Back orders (BO) = 80
Ending inventory= 0

a. How much should be produced each period?

Planned production = *total forecast + back orders – opening inventory*

= + – = / =

b. What is the ending inventory for each period?

1 period = *opening inventory + planned production – forecast =*

2 period =

3 period =

4 period =

5 period =

Period	1	2	3	4	5	**Total**
Planned Production						
Ending inventory						

Example

Opening inventory = 600
Back orders (BO) = 200
Ending inventory= 0

Period	Jan	Feb	Mar	Apr	May	Jun	Total
Working Days	20	22	20	20	18	19	
Forecast	1200	1300	800	700	700	900	
Planned Production							
Planned Inv 600							

Planned production =

Each working day should be produced =

Planned production:

Jan =

Feb =

Mar =

Apr =

May =

Jun =

Planned inventory:

Jan =

Feb =

Mar =

Apr =

May =

Jun =

Discussion

Britvic soft drinks

The Britvic Soft Drinks canning operation at Rugby, central England, is one of the highest capacity and most automated factories of its type in Europe, supplying the market with a range of Britvic drinks such as Tango, and also canning and distributing Pepsi Cola. The factory is linked by underground conveyor to Continental Can's can-making operation on an adjacent site, which also supplies vast quantities of cans every day to other drinks manufacturers.

The operations manager, Bob Pursley, emphasizes the enormous potential output of the plant.

'We have four state-of-the-art high-speed canning lines, each producing 1500 cans per minute, giving a combined output of 6000 cans per minute. Our theoretical capacity over a 24-hour period, with no change-overs or downtime, would equate to an incredible 8.5 million cans, which would then occupy 1000 square metres of warehouse space to a height of 4.5 metres. These products are bulky and have a limited shelf life. We have only enough space for five days' output, so we need to respond rapidly in production to fluctuation in demand.
"In Northern Europe, the consumption of canned drinks is always seasonal, especially in the UK where the biggest problem is the unpredictability of the weather! A few very hot and sunny days have a dramatic effect on demand and we must respond without delay or we would run out of stock of many of our products within days. The way that we run the factory addresses both seasonality and the shorter-term weather-related fluctuations. The canning lines are normally run 24 hours a day, as adjacent pairs, a system we call 'back-to-back', so that a crew of employees can operate one line (in periods of predicted low demand) or almost instantly two, to meet peak demand. In hot weather we can also boost production by up to 40 percent for a period with no change in the numbers of employees. This is achieved by changing from five to seven days a week, thanks to the co-operation of our employees. This arrangement can boost capacity to around 40 million cans a week, but there are obviously limits to the length of time that is possible, as everyone needs a break, eventually. In periods of lower demand, particularly in winter, staff are switched into training and development activities. We don't need the maximum capacity, so we utilize some of the time to train, develop and prepare employees to cope more effectively in the following summer peak. Employees are also encouraged to take some of their annual leave in the winter. Major maintenance projects are planned for completion during these quiet periods and smaller more routine maintenance in short blocks of time is carried out in the summer to minimize the impact on productive time".
Figure 19 indicates how production volumes and sales at the Britvic plant vary throughout the year.

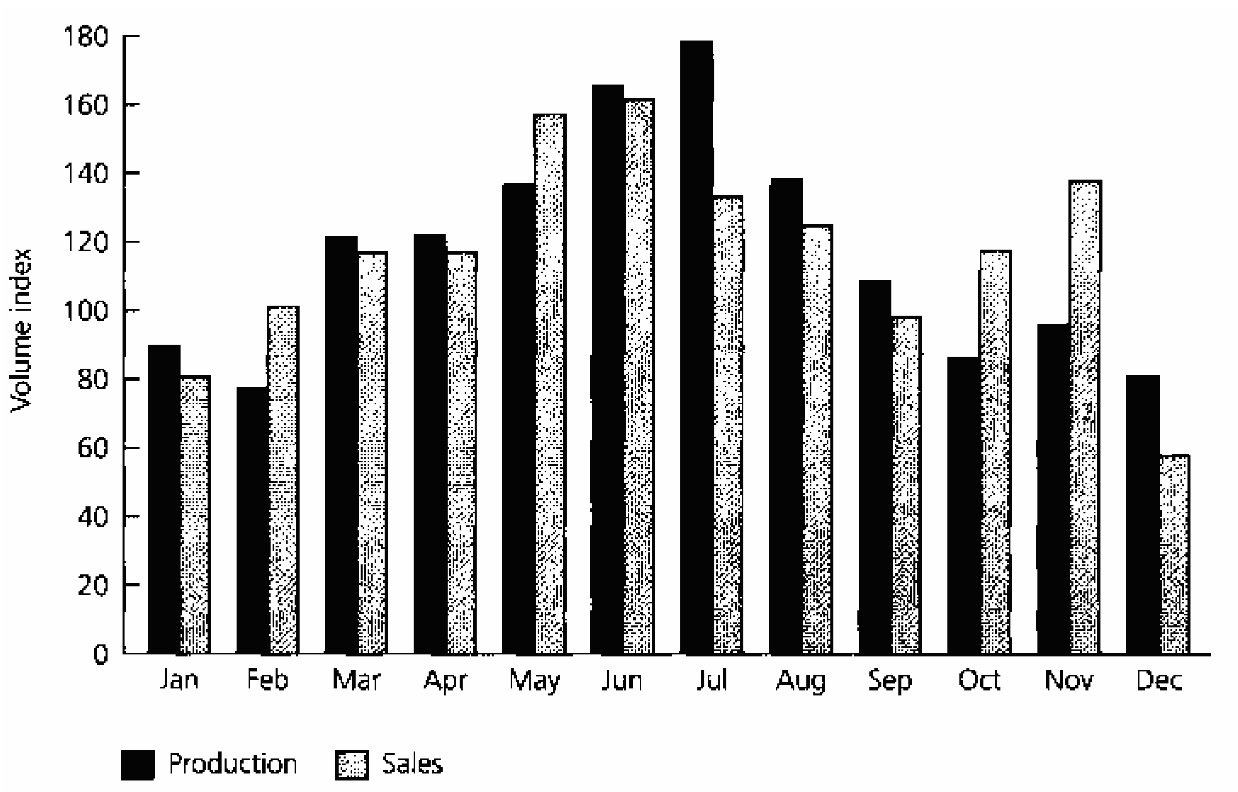


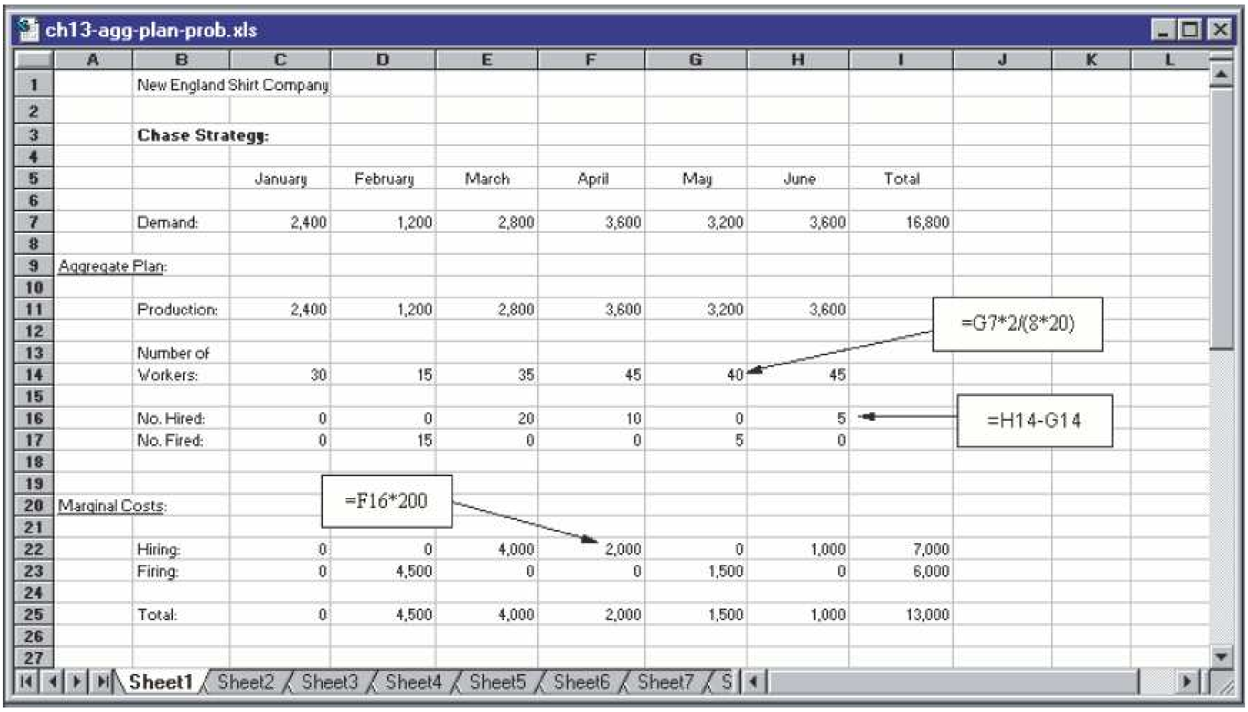
Fig. 19. Britvic drinks- sales and production (index of 100 = previous year's average sales)

Questions

1. What are the factors which seem to influence the demand fluctuation for this operation?
2. How does the company vary its output levels?
3. The company “chases demand” rather than using a “level capacity” strategy or a “change demand” strategy. Why do you think this is?

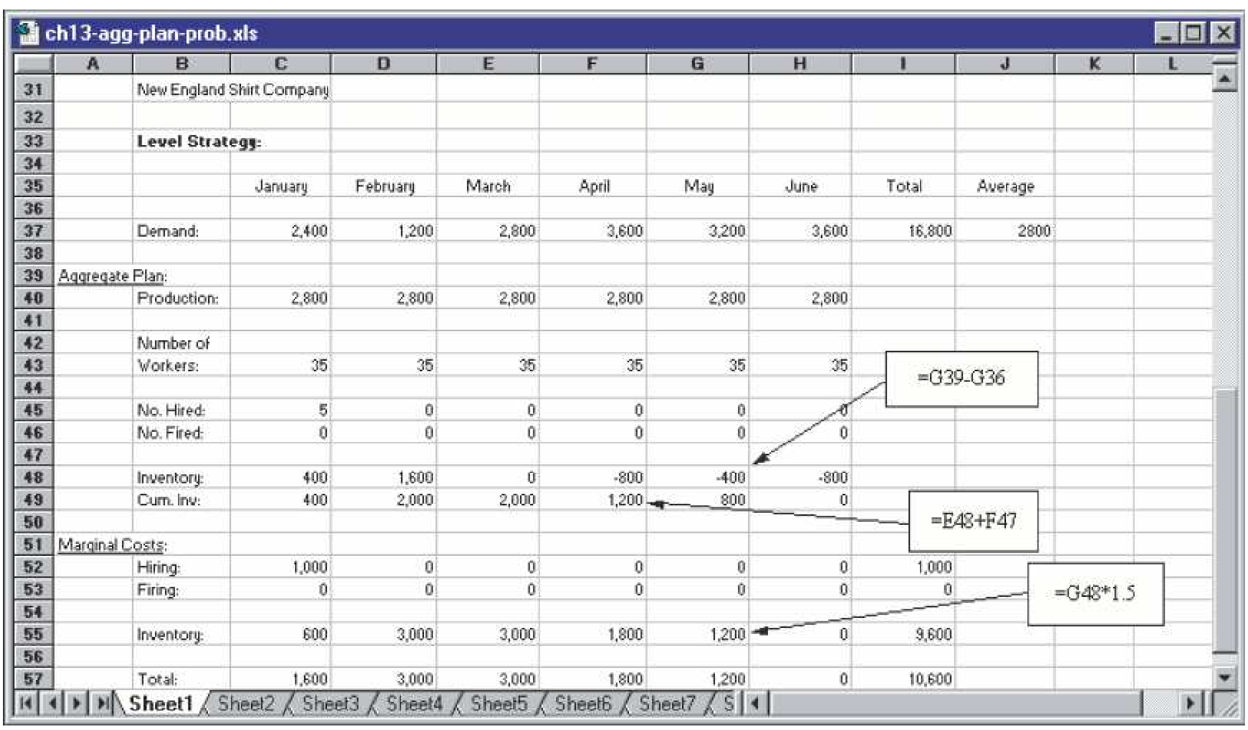
<u>Example</u>

New England Shirt Company



ch13-agg-plan-prob.xls

	A	B	C	D	E	F	G	H	I	J	K	L
1		New England Shirt Company										
2												
3		**Chase Strategy:**										
4												
5			January	February	March	April	May	June	Total			
6												
7		Demand:	2,400	1,200	2,800	3,600	3,200	3,600	16,800			
8												
9	Aggregate Plan:											
10												
11		Production:	2,400	1,200	2,800	3,600	3,200	3,600				
12												
13		Number of										
14		Workers:	30	15	35	45	40	45				
15												
16		No. Hired:	0	0	20	10	0	5				
17		No. Fired:	0	15	0	0	5	0				
18												
19												
20	Marginal Costs:											
21												
22		Hiring:	0	0	4,000	2,000	0	1,000	7,000			
23		Firing:	0	4,500	0	0	1,500	0	6,000			
24												
25		Total:	0	4,500	4,000	2,000	1,500	1,000	13,000			
26												
27												



ch13-agg-plan-prob.xls

	A	B	C	D	E	F	G	H	I	J	K	L
31		New England Shirt Company										
32												
33		**Level Strategy:**										
34												
35			January	February	March	April	May	June	Total	Average		
36												
37		Demand:	2,400	1,200	2,800	3,600	3,200	3,600	16,800	2800		
38												
39	Aggregate Plan:											
40		Production:	2,800	2,800	2,800	2,800	2,800	2,800				
41												
42		Number of										
43		Workers:	35	35	35	35	35	35				
44												
45		No. Hired:	5	0	0	0	0	0				
46		No. Fired:	0	0	0	0	0	0				
47												
48		Inventory:	400	1,600	0	-800	-400	-800				
49		Cum. Inv:	400	2,000	2,000	1,200	800	0				
50												
51	Marginal Costs:											
52		Hiring:	1,000	0	0	0	0	0	1,000			
53		Firing:	0	0	0	0	0	0	0			
54												
55		Inventory:	600	3,000	3,000	1,800	1,200	0	9,600			
56												
57		Total:	1,600	3,000	3,000	1,800	1,200	0	10,600			

<u>Discussion</u>

4.4. WORKING BY THE YEAR

One method of fluctuating capacity as demand varies throughout the year without many of the costs associated with overtime or hiring temporary staff is called the Annual Hours Work Plan. This involves staff contracting to work a set number of hours per year rather than a set number of hours per week. The advantage of this is that the amount of staff time available to an organization can be varied throughout the year to reflect the real state of demand. For example, figure 20 shows the total number of hours worked by staff in a photo-processing company throughout the year.

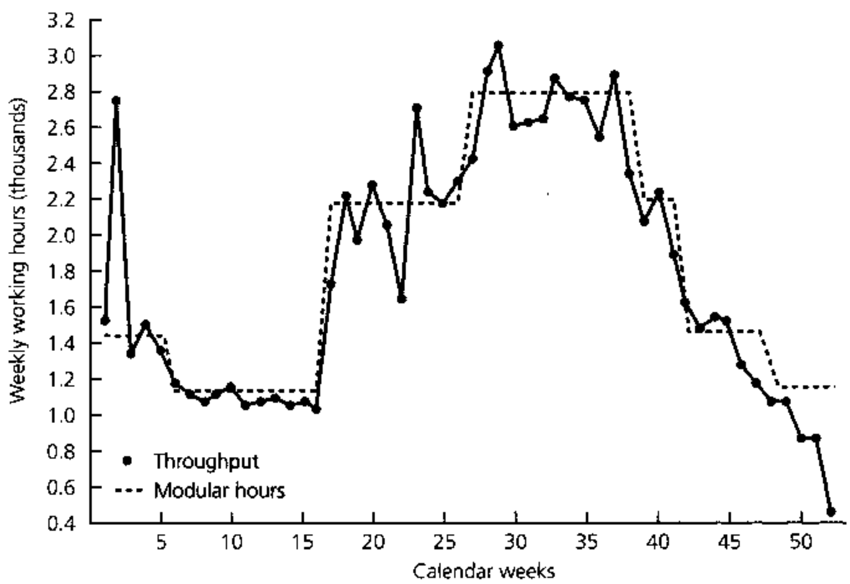


Fig. 20. The use of annualized hours to reflect seasonal demand at a photo-processing company

Annual hours plans can also be useful when supply varies throughout the year. For example, a UK cheese factory of Express Foods, like all cheese factories, must cope with processing very different quantities of milk at different times of the year. In spring and during early summer cows produce large quantities of milk, but in late summer and autumn the supply of milk slows to a trickle. Before the introduction of annualized hours, the factory had relied on overtime and hiring temporary workers during the busy season. Now the staff are contracted to work a set number of hours a year with rotas agreed more than a year in advance and after consultation with the union. This means that at the end of July staff broadly know exactly what days and hours they will be working until the September of the next year. If an emergency should arise, the company can call in from a group of 'super crew' who work more flexible hours in return for higher pay but can do any job in the factory. However, not all experiments with annualized hours have been as successful. Especially when demand is very unpredictable, staff can be asked to come in to work at very short notice. This can cause considerable disruption to social and family life. For example, at ITN, a UK news-broadcasting company, the scheme caused some initial problems. Some journalists and camera crew who went to cover the Gulf War found that they had worked so many hours that they were asked to take the whole of one month off to compensate. Since they had no holiday plans, many would have preferred to work.

Question

1. What do you see as being the major advantages and disadvantages both to the company and to the staff of adopting the Annual Hours Work Plan?

Forecast Demand and Workdays for the D&H Company

	Jan.	Feb.	Mar.	Apr.	May	June	Total
Demand forecast (units)	2,200	1,500	1,100	900	1,100	1,600	8,400
Working days (per month)	22	19	21	21	22	20	125
			Costs				
Material cost			$200/unit				
Inventory holding cost			$2.00/unit-month				
Stockout cost			$5/unit/month				
Subcontracting cost			$375/unit				
Hiring and training cost			$200/worker				
Layoff cost			$250/worker				
Labor required per unit			5 hours				
Labor cost (first 8 hours each day)			$12/hour				
Overtime cost (time and a half)			$18/hour				
			Inventory				
Beginning inventory			400 units				
			Workforce				
Number of workers currently employed			30				

First Alternative: Pure Chase Strategy

	A	B	C	D	E	F	G	H	I
1		January	February	March	April	May	June	TOTAL	
2	Demand Forecast (units)	2,200	1,500	1,100	900	1,100	1,600	8,400	
3	Working Days (per month)	22	19	21	21	22	20	125	
4	Working Hours (per day)	8	8	8	8	8	8	8	
5									
6			Costs						
7	Material Cost		300	per unit					
8	Inventory holding cost		2	per unit-month					
9	Stockout cost		5	per unit per month					
10	Subcontracting cost		375	per unit					
11	Hiring and training cost		200	per worker					
12	Layoff cost		250	per worker					
13	Labor required per unit		5	hours					
14	Labor cost, regular		12	per hour					
15	Labor cost, overtime		18	per hour					
16									
17	Beginning inventory		400	units					
18									
19	Workers currently employed		30	workers					
20									
21									
22	**Pure Chase Strategy**								
23		January	February	March	April	May	June	TOTAL	
24	Demand Forecast (units)	2,200	1,500	1,100	900	1,100	1,600	8,400	
25	Initial Inventory	400							
26	Production Requirements	1,800	1,500	1,100	900	1,100	1,600	8,000	
27									
28	**Aggregate Plan**								
29	Workers required	51	49	33	27	31	50		
30	Workers hired	21	-	-	-	4	19		
31	Workers fired	-	2	16	6	-	-		
32	Units produced	1,800	1,500	1,100	900	1,100	1,600	8,000	
33									
34	**Costs -- Full**								
35	Regular production	108,000	90,000	66,000	54,000	66,000	96,000	480,000	
36	Material costs	540,000	450,000	330,000	270,000	330,000	480,000	2,400,000	
37	Hiring costs	4,200	-	-	-	800	3,800	8,800	
38	Firing costs	-	500	4,000	1,500	-	-	6,000	
39	Total full costs	652,200	540,500	400,000	325,500	396,800	579,800	**2,894,800**	
40									
41	**Costs -- incremental**								
42	Hiring costs	4,200	-	-	-	800	3,800	8,800	
43	Firing costs	-	500	4,000	1,500	-	-	6,000	
44	Total incremental costs	4,200	500	4,000	1,500	800	3,800	**14,800**	
45									
46									
47									

=(B29*B$3*B$4/$C$13)

=+$C$14*F32*$C$13

=G30*$C$11

Second Alternative: Pure Level Strategy

	A	B	C	D	E	F	G	H	I
21									
22	**Pure Level Strategy**								
23		January	February	March	April	May	June	TOTAL	
24	Demand Forecast (units)	2,200	1,500	1,100	900	1,100	1,600	8,400	
25	Initial Inventory	400							
26	Production Requirements	1,800	1,500	1,100	900	1,100	1,600	8,000	
27									
28	**Aggregate Plan**								
29	Workers required	40	40	40	40	40	40		
30	Workers hired	10	-	-	-	-	-		
31	Workers fired	-	-	-	-	-	-		
32	Units produced	1,408	1,216	1,344	1,344	1,408	1,280	8,000	
33	Monthly inventory	(392)	(284)	244	444	308	(320)		
34	Cumulative inventory	(392)	(676)	(432)	12	320	-		
35									
36	**Costs -- Full**								
37	Regular production	84,480	72,960	80,640	80,640	84,480	76,800	480,000	
38	Material costs	422,400	364,800	403,200	403,200	422,400	384,000	2,400,000	
39	Hiring costs	2,000	-	-	-	-	-	2,000	
40	Firing costs	-	-	-	-	-	-	-	
41	Inventory carrying costs	-	-	-	18	480	-	498	
42	Stockout costs	1,960	3,380	2,160	-	-	-	7,500	
43	Total full costs	510,840	441,140	486,000	483,858	507,360	460,800	**2,889,998**	
44									
45	**Costs -- incremental**								
46	Hiring costs	2,000	-	-	-			2,000	
47	Firing costs	-	-	-	-	-	-	-	
48	Inventory carrying costs	-	-	-	18	480	-	498	
49	Stockout costs	1,960	3,380	2,160	-	-	-	7,500	
50	Total incremental costs	3,960	3,380	2,160	18	480	-	**9,998**	

=+B32+B25-B24

=+E34+F33

=-(IF(D34>0,0,D34*$C$9))

Third Alternative: Minimum Workforce with Subcontracting Strategy

	A	B	C	D	E	F	G	H
22	**Minimum Workforce with Subcontracting**							
23		January	February	March	April	May	June	TOTAL
24	Demand Forecast (units)	2,200	1,500	1,100	900	1,100	1,600	8,400
25	Initial Inventory	400						
26	Production Requirements	1,800	1,500	1,100	900	1,100	1,600	8,000
27								
28	**Aggregate Plan**							
29	Workers required	27	27	27	27	27	27	
30	Workers hired	-	-	-	-	-	-	
31	Workers fired	3	-	-	-	-	-	
32	Units produced	950	821	907	907	950	864	5,399
33	Monthly inventory	-	-	-	7	-	-	
34	Units subcontracted	850	679	193	-	143	736	2,601
35								
36	**Costs – Full**							
37	Regular production	57,000	49,260	54,420	54,420	57,000	51,840	323,940
38	Material costs	285,000	246,300	272,100	272,100	285,000	259,200	1,619,700
39	Hiring costs	-	-	-	-	-	-	-
40	Firing costs	750	-	-	-	-	-	750
41	Inventory carrying costs	-	-	-	11	-	-	11
42	Subcontracting costs	318,750	254,625	72,375	-	53,625	276,000	975,375
43	Total full costs	661,500	550,185	398,895	326,531	395,625	587,040	**2,919,776**
44								
45	**Costs – incremental**							
46	Hiring costs	-	-		-	-	-	-
47	Firing costs	750	-	-	-	-	-	750
48	Inventory carrying costs	-	-	-	11	-	-	11
49	Subcontracting costs	12,750	10,185	2,895	-	2,145	11,040	39,015
50	Total incremental costs	13,500	10,185	2,895	11	2,145	11,040	**39,776**

=B34*$C$10

Fourth Alternative: Constant Workforce with Overtime Strategy

	A	B	C	D	E	F	G	H	I
20									
21									
22	**Constant Workforce with Overtime**								
23		January	February	March	April	May	June	TOTAL	
24	Demand Forecast (units)	2,200	1,500	1,100	900	1,100	1,600	8,400	
25	Initial Inventory	400							
26	Production Requirements	1,800	1,500	1,100	900	1,100	1,600	8,000	
27									
28	**Aggregate Plan**								
29	Workers required	35	35	35	35	35	35		
30	Workers hired	5	-	-	-	-	-		
31	Workers fired	-	-	-	-	-	-		
32	Units produced -regular	1,232	1,064	1,176	1,176	1,232	1,120	7,000	
33	Units produced - overtime	568	436	-	-	-	72	1,076	
34	Monthly inventory	-	-	-	276	132	(408)		
35	Cumulative Inventory	-	-	-	276	408	-		
36									
37	**Costs – Full**								
38	Regular production	73,920	63,840	70,560	70,560	73,920	67,200	420,000	
39	Overtime production	51,120	39,240	-	-	-	6,480	96,840	
40	Material costs	540,000	450,000	352,800	352,800	369,600	357,600	2,422,800	
41	Hiring costs	1,000	-	-	-	-	-	1,000	
42	Firing costs	-	-	-	-	-	-	-	
43	Inventory carrying costs	-	-	-	414	612	-	1,026	
44	Total full costs	666,040	553,080	423,360	423,774	444,132	431,280	**2,941,666**	
45									
46	**Costs – incremental**								
47	Overtime production	17,040	13,080	-	-	-	2,160	32,280	
48	Hiring costs	1,000	-	-	-	-	-	1,000	
49	Firing costs	-	-	-	-	-	-	-	
50	Inventory carrying costs	-	-	-	414	612	-	1,026	
51	Total incremental costs	1,000	-	-	414	612	-	**34,306**	

=IF(C26-C32-B35>0,C26-C32-B35,0)

=+G33*$C$15*$C$13

Summary of Costs for Alternative Aggregate Plans

Alternative	Full Costs	Marginal Costs
Pure chase	$2,894,800	$14,800
Pure level	$2,889,998	$ 9,998
Minimum workforce with subcontracting	$2,919,776	$39,776
Constant workforce with overtime	$2,941,666	$34,306

<u>Discussion</u>

MANAGING QUEUES AT MADAME TUSSAUD'S SCENERAMA, AMSTERDAM

A short holiday in Amsterdam would not be complete without a visit to Madame Tussaud's Scenerama, located on four upper floors of the city's most prominent department store in Dam Square. With 600 000 visitors each year, this is the third most popular tourist attraction in Amsterdam, after the flower market and canal trips. On busy days in the summer, the centre can just manage to handle 5000 visitors. On a wet day in January, however, there may only be 300 visitors throughout the whole day. The centre is open for admission, seven days a week, from 10 h to 17.30 h.

In the streets outside, orderly queues of expectant tourists snake along the pavement, looking in at the displays in the store windows. In this public open space, Tussaud's can do little to entertain the visitors, but entrepreneurial buskers and street artists are quick to capitalize on a captive market. On reaching the entrance lobby, individuals, families and groups purchase their admissions tickets. The lobby is in the shape of a large horseshoe, with the ticket sales booth in the centre. On winter days or at quiet spells, there will only be one sales assistant, but on busier days, visitors can pay at either side of the ticket booth, to speed up the process. Having paid, the visitors assemble in the lobby outside the two lifts. While waiting in this area, a photographer wanders around offering to take photos of the visitors standing next to life-sized wax figures of famous people. They may also be entertained by living look-alikes of famous personalities who act as guides to groups of visitors in batches of around 25 customers (the capacity of each of the two lifts which takes visitors up to the facility). The lifts arrive every four minutes and customers simultaneously disembark forming one group of about 50, customers who stay together throughout the Scenerama section.

Questions

1. Generally, what could Madame Tussaud's do to cope with its demand fluctuations?
2. What does the operation do to make queueing relatively painless? What else could it do?

Example Parks and Recreation Department

Actual Demand Requirement for Full-Time Direct Employees and Full-Time-Equivalent (FTE) Part-Time Employees

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Days	22	20	21	22	21	20	21	21	21	23	18	22	252
Full-time employees	66	28	130	90	195	290	325	92	45	32	29	60	
Full-time days*	1,452	560	2,730	1,980	4,095	5,800	6,825	1,932	945	736	522	1,320	28,897
Full-time-equivalent part-time employees	41	75	72	68	72	302	576	72	0	68	84	27	
FTE days	902	1,500	1,512	1,496	1,512	6,040	12,096	1,512	0	1,564	1,512	594	30,240

Note: Some workweeks are staggered to include weekdays, but this does not affect the number of workdays per employee.

*Full-time days are derived by multiplying the number of days in each month by the number of workers.

Three Possible Plans for the Parks and Recreation Department

Alternative 1: Maintain 116 full-time regular direct workers. Schedule work during off seasons to level workload throughout the year. Continue to use 120 full-time-equivalent (FTE) part-time employees to meet high demand periods.

Costs	Days per Year (Exhibit 13.10)	Hours (employees x days x 8 hours)	Wages (full-time, $8.90; part-time, $8.06)	Fringe Benefits (full-time, 17%; part-time, 11%)	Administrative Cost (full-time, 20%; part-time, 25%)
116 full-time regular employees	252	233,856	$2,081,318	$353,824	$416,264
120 part-time employees	252	241,920	1,949,875	214,486	487,469
Total cost = $5,503,236			$4,031,193	$568,310	$903,733

Alternative 2: Maintain 50 full-time regular direct workers and the present 120 FTE part-time employees. Subcontract jobs, releasing 66 full-time regular employees. Subcontract cost, $2,200,000.

Costs	Days per Year (Exhibit 13.10)	Hours (employees x days x 8 hours)	Wages (full-time, $8.90; part-time, $8.06)	Fringe Benefits (full-time, 17%; part-time, 11%)	Administrative Cost (full-time, 20%; part-time, 25%)	Subcontract Cost
50 full-time employees	252	100,800	$ 897,120	$152,510	$179,424	
120 FTE part-time employees	252	241,920	1,949,875	214,486	487,469	$2,200,000
Subcontracting cost						
Total cost = $6,080,884			$2,846,995	$366,996	$666,893	$2,200,000

Alternative 3: Subcontract all jobs previously performed by 116 full-time regular employees. Subcontract cost, $3,200,000. Subcontract all jobs previously performed by 120 full-time-equivalent part-time employees. Subcontract cost, $3,700,000.

Cost	Subcontract Cost
0 full-time employees	
0 part-time employees	
Subcontract full-time jobs	$3,200,000
Subcontract part-time jobs	3,700,000
Total cost	$6,900,000

Yield Management

•*Yield (Revenue) Management*

–The concept used in service operations with high-fixed costs and low-variable costs that attempts to match supply and demand (a chase strategy) to maximize capacity utilization.

•*Yield Management Requires:*

–The ability to segment the market

–High-fixed and low-variable costs where additional sales create more profits

–Product perishability (cannot be inventoried)

–Lower-priced capacity that can be presold

Comparison of Costs for All Three Alternatives

	Alternative 1: 116 Full-time Direct Labor Employees, 120 FTE Part-Time Employees	Alternative 2: 50 Full-Time Direct Labor Employees, 120 FTE Part-Time Employees, Subcontracting	Alternative 3: Subcontracting Jobs Formerly Performed by 116 Direct Labor Full-time Employees and 120 FTE Part-Time Employees
Wages	$4,031,193	$2,846,995	—
Fringe benefits	568,310	366,996	—
Administrative costs	903,733	666,893	—
Subcontracting, full-time jobs		2,200,000	$3,200,000
Subcontracting, part-time jobs			3,700,000
Total	$5,503,236	$6,080,884	$6,900,000

Discussion

Getting the message

Companies which traditionally operate in seasonal markets can demonstrate some considerable ingenuity in their attempts to develop counter-seasonal products. One of the most successful industries in this respect has been the greetings card industry. Mother's Day, Father's Day, Hallowe'en, Valentine's Day, and other occasions have all been promoted as times to send (and buy) appropriately designed cards. Now, having run out of occasions to promote, greetings card manufacturers have moved on to 'non-occasion' cards, which can be sent at any time. These have the considerable advantage of being less seasonal, thus making the companies' seasonality less marked.

Hallmark Cards, the market leader in North America, has been the pioneer in developing non-occasion cards. Their cards include those intended to be sent from parent to child with messages such as, 'Would a hug help?' or, ''Sorry I made you feel bad', and 'You're perfectly wonderful - it's your room that's a mess'. Other cards deal with more serious adult themes such as friendship ('You're more than a friend, you're just like family') or even alcoholism ('This is hard to say, but I think you're a much neater person when you're not drinking'). Whatever else these products may be, they are not seasonal!

Questions

1. What seem to be the advantages and disadvantages of the strategy adopted by Hallmark Cards?
2. What else could it do to cope with demand fluctuations?

5. MASTER PRODUCTION SCHEDULING

After the production plan is established, the next step in manufacturing planning is to prepare the master production schedule (MPS).

The master schedule (MS) is a presentation of the demand, including the forecast and the backlog (customer orders received), the master production schedule (the supply plan), the projected on hand (POH) inventory, and the available-to-promise (ATP) quantity. The master production schedule (MPS) is the primary output of the master scheduling process. The MPS specifies the end items the organization anticipates manufacturing each period. End items are either final products or the items from which final assemblies (products) are made; as described later in this section. Thus, the MPS is the plan for providing the supply to meet the demand.
The MPS will focus on scheduling end items by date and quantity. Objective is to balance the demand with available resources

Master Production Scheduling (MPS)
–It is the link between production planning and what manufacturing will actually build.
–Forms the basis for calculating the capacity and resources needed.
–Drives the material requirements plan.
–It is a priority plan for manufacturing.

- The MPS forms a link between sales and production
  - It makes possible valid order promises
  - It is a plan of what is to be produced and when
  - It is an agreed upon plan between marketing and manufacturing.

- Information needed to develop a MPS
  - The production plan
  - Forecasts for individual end items
  - Actual orders received and for stock
  - Inventory levels of end items
  - Capacity restraints

- Objectives in Developing a MPS
  - To maintain the desired level of customer service
    - Maintain finished goods inventory levels
    - Scheduling to meet customer delivery needs
  - To make the best use of resources
  - To maintain inventory investment at the required levels

Example

Demand

Week	**1**	**2**	**3**	**4**	**5**	**6**
Prod A	70	70	70	70	70	80
Prod B	40	40	40	40	95	120
Prod C	50	50	50	50	50	50
Total	160	160	160	160	215	250

Opening inventory
Product A 350
Product B 100
Product C 50
Total 500

Master Schedule

Week	**1**	**2**	**3**	**4**	**5**	**6**
Prod A						205
Prod B	205	205	205			
Prod C				205	205	
Total Planned	205	205	205	205	205	205

Inventory

Week	**1**	**2**	**3**	**4**	**5**	**6**
Prod A	280	210	140	70	0	125
Prod B	265	430	595	555	460	340
Prod C	0	-50	-100	55	210	160
Total Planned	545	640	735	680	670	625

1 Week
Prod A = 350 + 0 -70 = 280
Prod B = 100 + 205 – 40 =265
Prod C = 50 + 0 -50 = 0

2 Week
Prod A = 280 + 0 -70 = 210
Prod B = 265 + 205 – 40 =430
Prod C = 0 + 0 -50 = -50

5.1. STEPS TO PREPARE THE MPS

- Develop a preliminary MPS
- Check the preliminary MPS against capacity
    - Rough-cut capacity planning
- Resolve differences between the preliminary MPS and capacity availability

Example

Task: to create MPS

Period	**1**	**2**	**3**	**4**	**5**	**6**
Forecast	60	60	60	60	60	60
Production Planned inv. 80						
MPS						

Example MPS

The Wicked Witch Wisk Company manufacturers a line of broomsticks. The most popular is the 92 cm model, and the sales department has prepared a forecast for six weeks. The opening inventory is 30. As a master scheduler, you must prepare an MPS. The brooms are manufactured in lots of 100.

Week		1	2	3	4	5	6
Forecast Sales		10	50	25	50	10	15
Projected Available	30						
MPS							

- **Rough Cut Capacity Planning**
  - Checks whether critical resources are available to support the preliminary MPS
  - Critical resources may include:
    - Bottleneck operations
    - Labor
    - Critical materials

5.2. EVALUATING THE MPS

- Resource Use
  - Is the MPS within capacity restraints in each period?
- Customer Service
  - Will due dates be met?
  - Will delivery performance be acceptable?

- Cost
  - Is the plan economical?
  - Will excess costs be incurred?
    - OT, subcontracting, expediting, transportation, etc.
    -

Dealing With a Complex Assemble to Order System

- Possibility of many options exists

- MPS is established at the component level
  - Treated as a make to stock situation

- A final assembly schedule (FAS) may be used to deal with assemblies.
  - Schedules customer orders as they are received
  - Based on the components in the MPS

Planning Horizons

- Time span for which plans are made.

- It must cover a period at least equal to the time required to accomplish the plan.

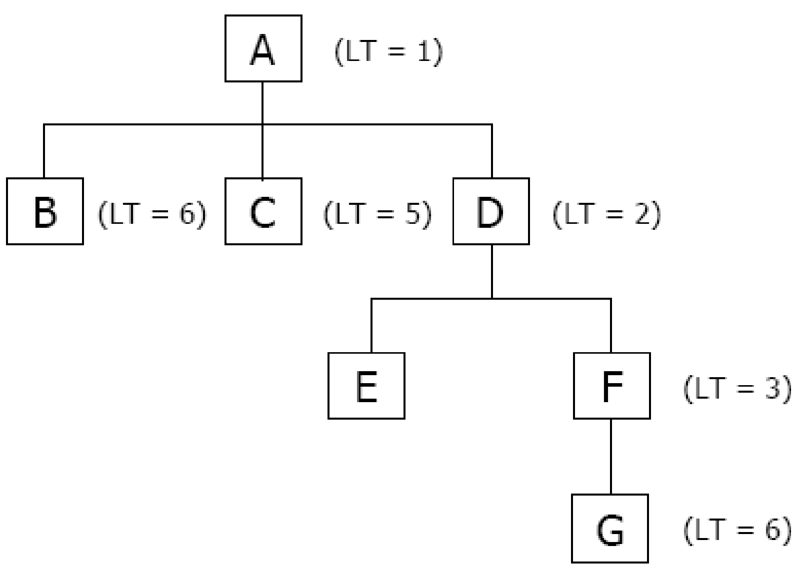
- For the MPS, the minimum planning horizon is the longest cumulative or end-to-end lead time in the product structure

- Longer horizons provide better "visibility"

- Increases ability to anticipate future events
  - Problems
  - Opportunities

- The horizon for the FAS must include time to assemble a customer's order
  - Does not include time to manufacture components

Product Structure & Lead Time



Longest cumulative lead-time = a+d+f+g=1+2+3+6=12

5.3. FORECASTS AND PLANNING

- The production plan reconciles forecast demand with available resources.

- The production plan uses information from the strategic plan and market forecasts to establish an overall plan for manufacturing.

- The production planning goal is to satisfy forecast demand within the limits of capacity.
- The MPS is derived from forecasts and actual demand for individual end items.

- The MPS is concerned with what items will actually be built, in what quantities, and when, to meet expected demand.

- While based on forecast information, the MPS is not a forecast
  - It is what production will accomplish

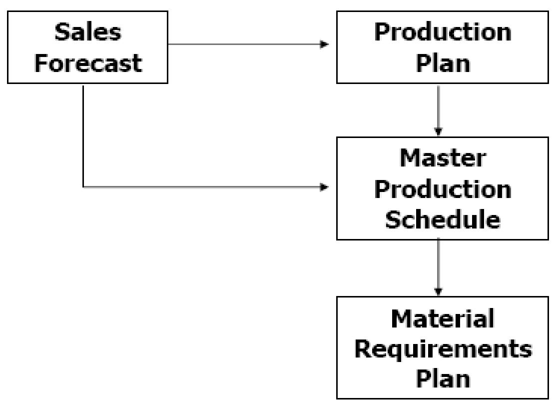
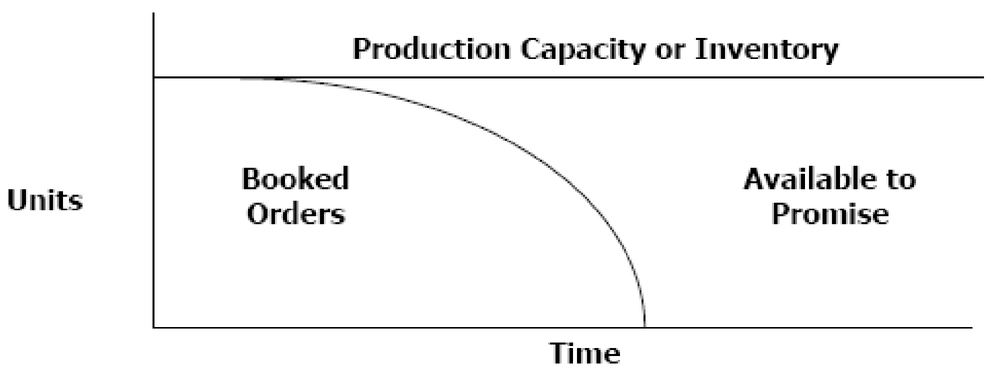


Figure. Forecast and planning

- **Orders and Capacity**
  - In general, demand may be satisfied from inventory or scheduled receipts.
  - As orders are received, they use available capacity.



- **Available to Promise (ATP)**
  - ATP is that portion of the firm's inventory and planned production that is not already committed and is available to the customer.
    - Allows delivery promises to be made
  - ATP is calculated by adding scheduled receipts to the beginning inventory and then subtracting actual orders scheduled before the next scheduled receipt.

Example: A company has 100 units on hand. Customer service has received 80 orders for the month. What is the ATP?

ATP = qty. on hand - orders =

ATP = units

Projected Available Balance (PAB)

Before demand time fence

PAB = prior period PAB or on-hand + MPS **–** Customer orders

After demand time fence

PAB = prior period PAB or on-hand + MPS **–** greater of customer orders or forecast

Example

Week	1	2	3	**4**	**5**
Forecast	40	40	40	40	40
Cust Orders	39	42	39	33	23

Week	1	2	3	**4**	**5**
PAB 40					
MPS					

PAB before the time fence consider only customer orders after the fence consider the higher number between the forecast and customer orders

1 week =

2 week =

3 week =

4 week =

5 week =

5.5. CHANGES TO THE MPS

- Customers cancel or change orders
- Machines break down or machines are added
- Suppliers have problems
- Processes create more scrap than expected

■ **Changes Result In:**
- Cost increases
- Decreased customer service
- Loss of credibility of the MPS and the overall planning process

■ **Changes and Timing**
- Changes occurring in the distant future may be accommodated with little cost or disruption.
- Near term changes become more costly to make.
- How to determine when changes may be accommodated

■ **Time Fences**
- Established by dividing the planning horizon into zones.

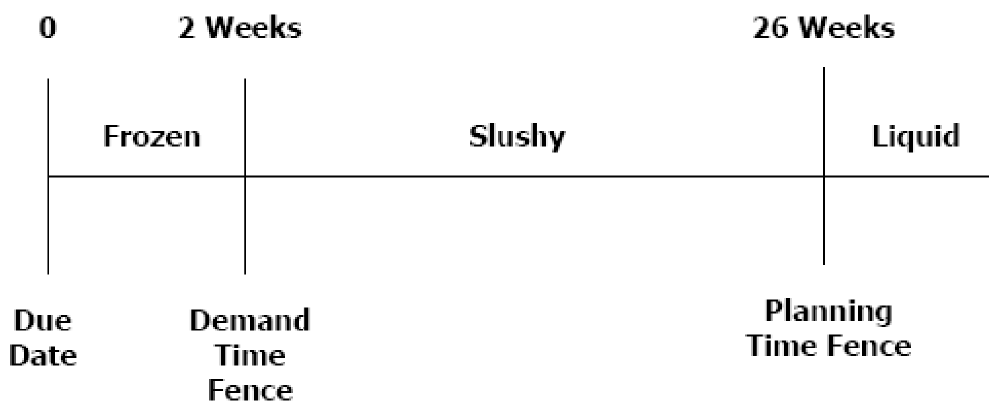


Figure. Planning zones

Questions:
1. What are major levels of planning? **2.** What are main requirements for the effective production planning? **3.** What are main differences between Hierarchical production planning and Production planning? **4.** What are main factors affecting capacity decisions? **5.** What are main production planning strategies? **6.** What are main principles preparing MPS?

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Module M09

Global Supply Chain Management and Stocks

Optimisation of transportation and allotment problems

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Learning objectives:
⇒ using a specifical method to solve the main solution of a transport problem ⇒ using an optimisaton method for transport problems ⇒ degeneration identification for transport problems ⇒ modelling as transport problem of repartition problem ⇒ using the Network Modeling module of WinQSB software

1. THE CLASSIC TRANSPORTATION PROBLEM

The economic development of a country, the world economy in general, cannot be conceived without transportations. They assure the good deployment of production in industry and agriculture, the circulation of material goods and of people.

Transports represent for most countries of the world a distinct branch of economy, assuring the movement of products and persons through space and the connections between diverse sectors of activity in the manufacture process, contributing to its good operation.

Transport or transportation, coming from the Latin “*transport*” means displacement in space (*trans* – space, *port* – to move). The transportation of merchandise represents the distribution of loads with motor vehicle from the loading point to the destination point based on the transportation contracts. Transportation is a production branch, with a commercial character, assuring the vital necessity of society in the transport of merchandise and voyagers.

The method of transportation bears this name as it is used for solving the problems of linear programming related to displacements of loads in the transport networks.

By extension, the method of transportation is applied in the problems of trans-boarding and assignment.

This problem occurs frequently in the planning of the distribution of goods and services from certain supply units to certain addresses.
In general, the quantity of goods stored at each *supply unit* (origin, supplier, manufacture centre, factories, supply) is fixed or limited.
At each *receiving unit* (or destination, beneficiary, distribution centre, demand) there is a quantity of goods specified by order or demand.
Because of the great variety of transportation routes or of different costs for these routes, the objective is to establish how many merchandise units can be transported from each origin to each destination so that all demands be satisfied, and the transportation costs be diminished

1.1. THE MATHEMATICAL MODEL OF THE TRANSPORTATION PROBLEM

The transportation problem is a particular problem of linear programming frequently encountered in economic applications enounced by the following example:

One considers a number of ***m*** suppliers (supply centres, warehouses) of a certain product as well as ***n*** consumers (stores, factories etc.) for this product. The product considered is available in the quantity a_i, $(1 \le i \le m)$, at the supplier ***i***, being demanded in the quantity b_j by the consumer ***j***, $(1 \le j \le n)$. If x_{ij}, $(1 \le i \le m,\ 1 \le j \le n)$ is the quantity of the product considered that the supplier ***i*** puts at the disposal of consumer ***j***, the unitary transportation cost from supplier ***i*** to consumer ***j*** being marked as c_{ij}. The available amount of supplier ***i*** can be distributed to all consumers, according to:

$$x_{i1} + x_{i2} + \ldots + x_{ij} + \ldots + x_{in} = a_i, \qquad 1 \le i \le n$$

whereas consumer ***j*** can receive products form all suppliers, according to the relation:

$$x_{1j} + x_{2j} + \ldots + x_{ij} + \ldots + x_{mj} = b_j, \qquad 1 \le j \le m$$

The total available quantity of the m suppliers (the supply) is given by the relation:

$$D = \sum_{i=1}^{m} a_i ,$$

and the necessary of all consumers (the demand) is equal to:

$$N = \sum_{j=1}^{n} b_j$$

The total expenditure for the transportation activity of the considered product from the ***m*** suppliers to the ***n*** mentioned consumers are given by:

$$c_{11}x_{11} + c_{12}x_{12} + \ldots + c_{1n}x_{1n} + c_{21}x_{21} + c_{22}x_{22} + \ldots c_{2n}x_{2n} + \ldots$$
$$. + c_{m1}x_{m1} + c_{m2}x_{m2} + \ldots + c_{mn}x_{mn}$$

which represents the sum of all expenditure incurred on the occasion of transporting the quantity x_{ij} from supplier ***i*** to consumer ***j***, equal to $c_{ij}x_{ij}$ $(1 \le i \le m;\quad 1 \le j \le n)$.

The transportation problem consists in determining the optimum variant (the least expensive). Mathematically, it means minimising the function::

$$[\min]f = \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij} ,$$

in the conditions:

$$\sum_{j=1}^{n} x_{ij} = a_i ; \quad 1 \le i \le m$$

$$\sum_{i=1}^{m} x_{ij} = b_j ; \quad 1 \le j \le n$$

$$x_{ij} \ge 0 .$$

If instead of transportation costs c_{ij}, in the objective function above one uses the profits earned by the transport firm by moving one merchandise unit form point i to point j, then the objective function will be a function of maximum, under the same restrictions regarding the available quantity D_i , the necessary quantity N_j and the non-negativity of variables.

The mathematical model of the balanced transportation problem is the following:

$$\begin{cases} [\min,\max]f = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij}x_{ij} \to \text{the objective function (1)} \\ \begin{cases} \sum_{j=1}^{n} x_{ij} = a_i , i = \overline{1,m} \to \text{restrictions related to sources (2)} \\ \sum_{i=1}^{m} x_{ij} = b_j , j = \overline{1,n} \to \text{restrictions related to destinations (3)} \end{cases} \\ x_{ij} \ge 0 \ , \ i = \overline{1,m} \ , \ \ j = \overline{1,n} \to \text{ conditions on non-negativity of decisional variables} \end{cases}$$

The equilibrium condition: $\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j = T$

We suppose a problem of balanced transportation type with ***m*=2, *n*=3**.
Under the form of table we have:

Table 1

	B_1	B_2	B_3	Available
A_1	c_{11} x_{11}	c_{12} x_{12}	c_{13} x_{13}	a_1
A_2	c_{21} x_{21}	c_{22} x_{22}	c_{23} x_{23}	a_2
Necessary	b_1	b_2	b_3	Total (T)

where:
A_i (A_1, A_2) - suppliers (producers)
D (a_1,a_2) – available amount (supply)

B_j (B_1,B_2,B_3) - consumers
N (b_1,b_2,b_3) – necessary amount (demand)

$$T = a_1+a_2 = b_1+b_2+b_3$$

The mathematical model results, of the form:
$[\min]f = c_{11}\, x_{11}+c_{12}\, x_{12}+c_{13}\, x_{13}+c_{21}\, x_{21}+c_{22}\, x_{22}+c_{23}\, x_{23}$

$$\begin{cases} x_{11}+x_{12}+x_{13}=a_1 \\ x_{21}+x_{22}+x_{23}=a_2 \\ x_{11}+x_{21}=b_1 \\ x_{12}+x_{22}=b_2 \\ x_{13}+x_{23}=b_3 \\ x_{ij}\geq 0; i=1,2;\ j=1,2,3 \end{cases}$$

The linear transportation problem generally contains ***m+n-1*** independent linear equations and a higher number of unknown terms, i.e. ***mn.***

Remark: One of the situations frequently occurring is that when the total supply is not equal to the total demand (total available different form total necessary):

- if the *total supply is higher than the total demand*, there is no need of any modification the model of linear programming, we interpret as unused supply or quantity of merchandise not transported from the origin

$$\sum_{i=}^{m} a_i \geq \sum_{j=1}^{n} b_j$$

The difference between total available and total necessary is absolved by a *fictitious beneficiary* introduced in the problem only to balance it, and the transportation costs associated to the routes involving this beneficiary are considered null.

- If the *total supply is lower than the total demand,*

$$\sum_{i=}^{m} a_i \leq \sum_{j=1}^{n} b_j$$

the model of linear programming will not have a practical solution, as the conditions of demand cannot be fulfilled. In this case we need to operate a modification in the model of linear programming to reach the desired solution, more precisely, we use a *fictitious supplier* to absorb the difference to the total of demand and one assigns a zero cost to the transported unit on any routs, starting from this fictitious factory.

1.2. THE ECONOMIC MODEL OF THE TRANSPORTATION PROBLEM

One transports from m supplying centres, $F_1, F_2, ..., F_m$ representing the place of merchandise loading on t transport means, a type of merchandise demanded by certain destination points, which can be n retail centres, consumption centres (beneficiaries) $B_1, B_2, ..., B_n$, where the merchandise is unloaded and thus the transportation process is completed.

We know:

- The matrix of the unitary transportation costs:

$$C = (c_{ij})_{\substack{i=\overline{1,m} \\ j=\overline{1,n}}}$$

- The quantities available at each supplier:

$$(a_i)_m, i = \overline{1,m}$$

- The quantities necessary at each beneficiary:

$$(b_j)_n, j = \overline{1,n}$$

- The matrix of the transported quantities:

$$X = (x_{ij})_{\substack{i=\overline{1,m} \\ j=\overline{1,n}}}$$

- Delivery is made by direct transportation without trans-boarding points.

We must determine the optimum transportation plan, so that the total transportation costs be minimum.

Remarks:

1. The transportation problem is a problem that can be modelled mathematically as a problem of linear programming, aiming at minimising the transportation costs and thus for the transportation problems there are also optimisation algorithms and computer software.

2. A problem of linear programming associated to a transportation problem becomes of problem of maximum if instead of transportation costs c_{ij}, in the objective function (1) one uses the profits earned by the transport firm by moving one merchandise unit from point i to point j under the same restrictions regarding the available, the necessary and the non-negativity of solutions.

1.3. DETERMINING THE INITIAL BASIC SOLUTION FOR THE TRANSPORTATION PROBLEM

As for any problem of linear programming, finding the optimum solution means passing through two main stages:
Stage 1: Generating a basic admissible solution.
Stage 2: Verifying the optimality of the solution found and if need be its improvement until the finding the finite optimum solution.

As the application of the simplex algorithm for the problem of linear programming of the transportation type leads to a very large amount of calculation, for solving this problem one elaborated specific methods , as below.

The method of the northwest corner (N-W) is based on the introduction of the element situated in the NW corner / the cell from the table, its value being subtracted from the row available and until the satisfaction of the necessary on the column for each consumption centre. The method of the NW corner does not take into account the unitary costs c_{ij}.

The method of the row minimum cost On the line one starts form the minimum cost and then gradually until the row saturation, i.e. until the exhaustion of the available amount.

The economic support of the method takes into account the fact that transportation is paid by the supplier.

The method of column minimum cost: One starts from the column minimum cost and then gradually until the saturation of the column until the covering of the necessary. One takes in account the fact that transportation is paid by beneficiary (consumer).

The method of the matrix / table minimum cost: one chooses from the table the cell containing the minimum cost and the entire available amount is distributed to satisfy the necessary, and then one chooses the next minimum cost and the procedure of covering the necessary is repeated within the limit if the available amount. If the minimum is multiple, one chooses a random cell.

The method of maximum differences. One calculates the absolute difference between the lowest row or column cost, and the next low cost. One eliminates the row or column with the highest difference, one redoes the table and the procedure is applied until the satisfaction of the last demand.

Exercise 01

Find a basic solution to the problem in the table below by applying the method of the northwest corner, the methods of row and column minimum cost and the method of matrix / overall minimum cost.

Table 2

A \ B	B_1	B_2	B_3	B_4	Available
A_1	2	3	1	4	**140**
A_2	3	1	4	3	**160**
A_3	4	2	3	2	**200**
Necessary	**115**	**135**	**130**	**120**	**500**

Solution :

We can find the optimum solution by linear programming, using the simplex algorithm.

One verifies the balancing:

$$T = a_1 + a_2 + a_3 = b_1 + b_2 + b_3 + b_4$$

$$T = 140 + 160 + 200 = 115 + 135 + 130 + 120 = 500 \text{ units}$$

The problem is balanced, as $\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j = T$ =500 units

The mathematical model is the following:

$[\min]f = 2x_{11} + 3x_{12} + x_{13} + 4x_{14} + 3x_{21} + x_{22} + 4x_{23} + 3x_{24} + 4x_{31} + 2x_{32} + 3x_{33} + 2x_{34}$

$$\begin{cases} x_{11}+x_{12}+x_{13}+x_{14}=140 \\ x_{21}+x_{22}+x_{23}+x_{24}=160 \\ x_{31}+x_{32}+x_{33}+x_{34}=200 \\ x_{11}+x_{21}+x_{31}=115 \\ x_{12}+x_{22}+x_{32}=135 \\ x_{13}+x_{23}+x_{33}=130 \\ x_{14}+x_{24}+x_{34}=120 \\ x_{ij}\ge 0 \end{cases}$$

There are 7 restrictions of which 3 + 4 – 1 = 6 are independent, and thus the solution x_{ij} has maximum 6 strictly positive components.

An initial basic solution has exactly $m + n - 1 = 3 + 4 - 1 = 6$ non-null components if it is a basic non-degenerate solution and a number below 6 of non-null components if it is a basic degenerate solution.

As the application of the simplex algorithm for the problem of transportation linear programming leads to a very large volume of calculation, in order to solve this problem one uses the following specific solving methods:

a) the method of the north-west corner
b) the method of the row minimum element (minimum row cost)
c) the method of the column minimum element (minimum column cost)
d) the method of the matrix minimum element (table overall)
e) the method of the maximum differences or Vogel's method.

As these methods do not require a special theorisation, they will be detailed along with their application.

a) The solution by the **method of the north-west corner** will be:

Table 3

B / A	B_1	B_2	B_3	B_4	
A_1	115 (2)→	25 (3)↓	–	–	140-115=25 25-25=0
A_2	–	110 (1) →	50 (4)↓	–	160-110=50 50-50=0
A_3	–	–	80 (3) →	120 (2)	200-80=120 120-120=0
Necessary	**115**	**135**	**130**	**120**	-

According to the data in the table, the solution is:

$[\min]f = 2\cdot 115 + 3\cdot 25 + 1\cdot 110 + 4\cdot 50 + 3\cdot 80 + 2\cdot 120 = 1095$ m.u.

The method of the northwest corner does not take into account the minimum unitary costs c_{ij}.

b) The method of the row minimum cost

On each row one takes into account the minimum cost.

Row 1:

$c_{13}=1 \Rightarrow x_{13} = \min\{130, 140\} = 130 \Rightarrow 130+10 = 140$ EXHAUSTED
$c_{11}=2 \Rightarrow x_{11}= \min\{140-130, 115\}= \min\{10,115\} =10$
$c_{12}=3 \Rightarrow x_{12}=0$
$c_{14}=4 \Rightarrow x_{14}=0$

Row 2:

$c_{22}=1\Rightarrow x_{22} = \min\{135, 160\} =135$
$c_{21}=c_{24}=3\Rightarrow x_{21} = \min\{160-135, 115-10\} = \min\{25, 105\} = 25$
$x_{21}= \min\{140-115, 115-10\} = \min\{25, 105\} = \min\{140-115, 105\} = 25$
$x_{21}= 25 \Rightarrow x_{23} = x_{24} = 0$

Row 3:

$c_{32}=c_{34} = 2\Rightarrow x_{34} = \min\{120, 200\} = 120$
$x_{31}=115-(10+25) = 115-35 = 80$

The solution obtained with the method of row minimum cost is shown in the table below:

Table 4

10 (2)	-	130 (1)	-	**140**
25 (3)	135 (1)	-	-	**160**
80 (4)	-	-	120 (2)	**200**
115	**135**	**130**	**120**	**500**

The total transportation cost is:

$[\min]f = 2\cdot 10 + 130\cdot 1 + 3\cdot 25 + 1\cdot 135 + 4\cdot 80 + 2\cdot 120 = 920$ m.u.

The economic support of the method takes into account the fact that transportation is paid by the supplier.
On the line one starts form the minimum cost and then gradually until the saturation of the line.

c) The method of column minimum cost

One considers the fact that transportation is paid by the consumer (beneficiary).

Column 1:

$c_{11}=2 \Rightarrow x_{11} = \min\{115, 140\} =115$

Column 2:

$c_{22}=1 \Rightarrow x_{22} = \min\{135, 160\} =135$

Column 3:

$c_{13}=1 \Rightarrow x_{13} =140-115 = 25$
$c_{33}=3 \Rightarrow x_{33} =130-25 = 105$

Column 4:

$x_{24} = 160\text{-}135 = 25$
$x_{34} = 200\text{-}105 = 95$

The solution is given by the table below:

Table 5

115 (2)	–	25 (1)	–	**140**
–	135 (1)	–	25 (3)	**160**
–	–	105(2)	95 (2)	**200**
115	**135**	**130**	**120**	**500**

The transportation value will be:

$[\min]f = 2 \cdot 115 + 1 \cdot 25 + 1 \cdot 135 + 3 \cdot 25 + 3 \cdot 105 + 2 \cdot 95 = 970$ u.m.

d) The method of matrix / overall minimum cost

The minimum cost is 1 and it corresponds to:

$c_{13}=1 \Rightarrow x_{13}=130$
$c_{22}=1 \Rightarrow x_{22}=135$

Then follows cost 2, i.e.:

$c_{11}=2 \Rightarrow x_{11}=140\text{-}130=10$
$c_{32}=2 \Rightarrow x_{21}=160\text{-}135=25$
$c_{34}=2 \Rightarrow x_{31}=115\text{-}(10+25) = 80 \Rightarrow x_{34} = 200\text{-}80=120$

The following value is 3 resulting:

$c_{12}=3 \Rightarrow x_{12} = 25\text{-}25 = 0$

The last cost is 4 leading to:

$c_{13}=4 \Rightarrow x_{13} = 80\text{-}80 = 0$

The solution of the method is given in the table below:

Table 6

(2) 10		(1) 130		**140**
(3) 25	(1) 135			**160**
(4) 80			(2) 120	**200**
115	**135**	**130**	**120**	**500**

The value of the transportation will be given by:

$[\min]f = 2 \cdot 10 + 3 \cdot 25 + 4 \cdot 80 + 1 \cdot 135 + 1 \cdot 130 + 2 \cdot 120 = 920$ u.m.

e) The method of maximum differences or Vogel’s method.

It usually determines a basic solution as close as possible to the optimum solution. It is applied as follows:

- (m+n-1) helping rows and columns are attached to the initial matrix;
- the difference is calculated between the lowest costs from each row and each column;
- the highest difference is chosen and the transported quantity is assigned to the cell with the lowest cost on the respective row or column, taking into account the following rule:

$$x_{ij} = \min\{a_i, b_j\}$$

If two or more equal maximum differences result, one chooses that corresponding to the minimum transportation cost; if they are still equal, one chooses that assuring the allotment of the maximum quantity to be transported.

Step 1 – filling in the matrix with the problem data

Table 7

B_j / **A_i**	**B_1**			**B_2**			**B_3**			**B_4**			**Differences**			**Available**
A_1	c_{11}=2			c_{12}=3			c_{13}=1			c_{14}=4						**140**
A_2	c_{21}=3			c_{22}=1			c_{23}=4			c_{24}=3						**160**
A_3	c_{31}=4			c_{32}=2			c_{33}=3			c_{34}=2						**200**
Necessary	**115**			**135**			**130**			**120**						**500**
Differences																

Step 2 – calculation of differences

Table 8

B_j / **A_i**	**B_1**			**B_2**			**B_3**			**B_4**			**Differences**			**Available**
A_1	c_{11}=2			c_{12}=3			c_{13}=1			c_{14}=4			1			**140**
A_2	c_{21}=3			c_{22}=1			c_{23}=4			c_{24}=3			2			**160**
A_3	c_{31}=4			c_{32}=2			c_{33}=3			c_{34}=2			1			**200**
Necessary	**115**			**135**			**130**			**120**						**500**
Differences	1			1			2			1						

Step 3 – analysis of differences and selection of the highest difference resulted

On the line or column where the highest difference was found one chooses the cell within the lowest cost c_{ij}.

One remarks that the highest difference is on line 2 and column 3 . One chooses line 2, as a larger quantity of merchandise can be transported.

Table 9

B_j / A_i	B_1	B_2	B_3	B_4	Differences			Available
A_1	$c_{11}=2$	$c_{12}=3$	$c_{13}=1$	$c_{14}=4$	1			**140**
A_2	$c_{21}=3$	$c_{22}=1$	$c_{23}=4$	$c_{24}=3$	2			**160**
A_3	$c_{31}=4$	$c_{32}=2$	$c_{33}=3$	$c_{34}=2$	1			**200**
Necessary	**115**	**135**	**130**	**120**				**500**
Differences	1	1	2	1				

Step 4 – Assigning a quantity to the cell where the lowest c_{ij} was found.

One will allot cell (22) the lowest value between the available a_2 and necessary b_2, i.e. 135 :

Table 10

B_j / A_i	B_1	B_2	B_3	B_4	Diferențe			Disponibil
A_1	$c_{11}=2$	$c_{12}=3$ 0	$c_{13}=1$	$c_{14}=4$	1			**140**
A_2	$c_{21}=3$	$c_{22}=1$ **135**	$c_{23}=4$	$c_{24}=3$	2			**~~160~~ 25**
A_3	$c_{31}=4$	$c_{32}=2$ 0	$c_{33}=3$	$c_{34}=2$	1			**200**
Necesar	**115**	**~~135~~ 0**	**130**	**120**				**500**
Diferențe	1	1	2	1				

Step 2 a – calculus of the new differences

Table 11

B_j / A_i	B_1			B_2			B_3			B_4			Differences			Available
A_1	$c_{11}=2$			$c_{12}=3$ 0			$c_{13}=1$			$c_{14}=4$			1	1		**140**
A_2	$c_{21}=3$			$c_{22}=1$ **135**			$c_{23}=4$			$c_{24}=3$			2	1		~~**160**~~
A_3	$c_{31}=4$			$c_{32}=2$ 0			$c_{33}=3$			$c_{34}=2$			1	1		**200**
Necessary	**115**			~~**135**~~ **0**			**130**			**120**						**500**
Differences	1	1		1			2	2		1	1					

Step 3 a – analysis of differences and choice of the highest difference resulted

The highest difference is on column 3, and the LOWEST cost on this column is $c_{13} = 1$.

Table 12

B_j / A_i	B_1			B_2			B_3			B_4			Differences			Available
A_1	$c_{11}=2$			$c_{12}=3$ 0			$c_{13}=1$			$c_{14}=4$			1	1		**140**
A_2	$c_{21}=3$			$c_{22}=1$ **135**			$c_{23}=4$			$c_{24}=3$			2	1		~~**160**~~
A_3	$c_{31}=4$			$c_{32}=2$ 0			$c_{33}=3$			$c_{34}=2$			1	1		**200**
Necessary	**115**			~~**135**~~ **0**			**130**			**120**						**500**
Differences	1	1		1			2	2		1	1					

Step 4 a – Allotting a quantity to the cell where the lowest c_{ij} was found

One will allot cell (13) the lowest value between the available a_1 and then necessary b_3, i.e. 130 units.

Table 13

B_j / A_i	B_1	B_2	B_3	B_4	Differences			Available
A_1	$c_{11}=2$	$c_{12}=3$ 0	$c_{13}=1$ **130**	$c_{14}=4$	1	1		**~~140~~**
A_2	$c_{21}=3$	$c_{22}=1$ **135**	$c_{23}=4$ 0	$c_{24}=3$	2	1		**~~160~~**
A_3	$c_{31}=4$	$c_{32}=2$ 0	$c_{33}=3$ 0	$c_{34}=2$	1	1		**200**
Necessary	**115**	**~~135~~** **0**	**130**	**120**				**500**
Differences	1 1	1	2 2	1 1				

Steps 2 a + 3 a + 4 a

Row 1 and row 3 gave the highest differences. One chooses the lowest cost, i.e. c_{11} and c_{34} . One chooses cell (34) .

Table 14

B_j / A_i	B_1	B_2	B_3	B_4	Differences			Available
A_1	$c_{11}=2$ 10	$c_{12}=3$ 0	$c_{13}=1$ 130	$c_{14}=4$ 0	1	1	2	**~~140~~**
A_2	$c_{21}=3$ 25	$c_{22}=1$ 135	$c_{23}=4$ 0	$c_{24}=3$ 0	2	1	0	**~~160~~**
A_3	$c_{31}=4$ 80	$c_{32}=2$ 0	$c_{33}=3$ 0	$c_{34}=2$ 120	1	1	2	**~~200~~**
Necessary	**~~115~~** **~~35~~** **~~25~~** **0**	**~~135~~** **0**	**~~130~~** **0**	**~~120~~** **0**				**500**
Differences	1 1 1	1	2 2	1 1 1				

The basic solution determined supposes a total transportation cost of:

[min]f = 10x2 + 130x1 + 25x3 + 135x1 + 80x4 + 120x2 = 920 m.u.

1.4. DETERMINING THE OPTIMUM SOLUTION

This represents the second stage in the optimisation of a transportation problem and is made of the following steps:

Step 1. Testing optimality.
Is the initial solution X_1 optimum ?

If YES→ STOP. One interprets results economically.
If NOT→ Step 2.

Step 2. Improving the solution.
Solution X_1 is improved by passing to a new admissible basic solution, X_2, with $f(X_2) \leq f(X_1)$. One returns then to step 1, replacing X_1 by X_2. After a finite number of successive improvements, the optimum solution is obtained.

The testing and the improvement of the solution may be done by:

- method of potentials;
- the modified distributive method;
- the Stepping-Stone method, etc.

The Stepping – Stone method

It is an iterative method starting from a feasible initial solution which, in successive steps, identifies an optimum solution. On order to reach this requirement, one evaluates the value of the efficiency of the transportation of product on a route with the destination a cell which is not comprised in the analysed solution.

The method is performed in the following stages:

1. One identifies cells A_iB_j where no distribution was done through the initial solution or an intermediary solution, and call them void cells.

Table 15

B_j / A_i	B_1	B_2	B_3	B_4	Available
A_1	$c_{11}=2$ **115**	$c_{12}=3$ **25**	$c_{13}=1$ 0	$c_{14}=4$ 0	**140**
A_2	$c_{21}=3$ 0	$c_{22}=1$ **110**	$c_{23}=4$ **50**	$c_{24}=3$ 0	**160**
A_3	$c_{31}=4$ 0	$c_{32}=2$ 0	$c_{33}=3$ **80**	$c_{34}=2$ **120**	**200**
Necessary	**115**	**135**	**130**	**120**	**500**

2. Starting from each void cell nominated in the previous stage, one establishes a track on the horizontal and the vertical containing cells with allotments and between which products may be permuted towards the void cell, without affecting the horizontal and vertical balance of the analysed solution. This movement may be done among 4 or 6 cells.

3. One allots for the transportation expenditure c_{ij} o the void cell the sign +, placing alternatively minus and plus for each transport expenditure specific to the successive cell on the set track until if becomes a closed circuit.

4. One calculates for each void cell the loss on the product unit registered if one does not effect permutations in a closed circuit, allotting a product unit to the respective cell.

As initial solution, very likely optimisible, we choose the solution obtained through the N–W method. This is considered as first iteration.

Iteration 2

On the first horizontal we have two void cells A_1B_3 and A_1B_4, cells in which in the initial solution no products were allotted.

Table 16

	B_2	**B_3**
A_1	$c_{12}=3$ -	$c_{13}=1$ +
A_2	$c_{22}=1$ +	$c_{23}=4$ -

The track to allot product in cell **A_1B_3** is the following:

$A_1B_3 \rightarrow A_2B_3 \rightarrow A_2B_2 \rightarrow A_1B_2$

The gain obtained by the transfer of one product to cell A_1B_3 on he respective route is:

$P_{13} = +1 \; -4 \; +1 \; -3 \; = \; -5$

For cell **A_1B_4**, one has the following track:

$A_1B_4 \rightarrow A_3B_4 \rightarrow A_3B_3 \rightarrow A_2B_3 \rightarrow A_2B_2 \rightarrow A_1B_2$, and

$P_{14} = +4 - 2 + 3 - 4 + 1 - 3 = -1$

Foe cell **A_2B_1**, one has the following track:

$A_2B_1 \rightarrow A_2B_2 \rightarrow A_1B_2 \rightarrow A_1B_1$, and

$P_{21} = +3 - 1 + 3 - 2 = +3$

Due to the fact that the value $P_{21}>0$, it means that transfer is inefficient. Instead of gaining by allotting one product unit to the respective cell, the distribution leads to a transportation effort higher that in the initial solution.

For cell **A_2B_4**, one has the following track:

$A_2B_4 \rightarrow A_3B_4 \rightarrow A_3B_3 \rightarrow A_2B_3$, and

$P_{24} = +3 - 2 + 3 - 4 = 0$

The new distribution does not bring any gain and thus it is useless.

The track by which products are allotted to cell $\mathbf{A_3B_1}$ is the following:

$A_3B_1 \rightarrow A_3B_3 \rightarrow A_2B_3 \rightarrow A_2B_2 \rightarrow A_1B_2 \rightarrow A_1B_1 = + 4 - 3 + 4 - 1 + 3 - 2 = + 5$

For cell A_3B_2 we have:

$A_3B_2 \rightarrow A_3B_3 \rightarrow A_2B_3 \rightarrow A_2B_2 = + 2 - 3 + 4 - 1 = + 2$

The last two distributions are not helping, on the contrary they would bring losses.

By centralising the data obtained for each void cell in the N-W solution, the allotments that might be taken into consideration are those whose value is negative and thus losses should be registered if the permutations were not done. One chooses the highest negative value, i.e.:

$P_{13} = - 5$ and $P_{14} = - 1$

In the cells where $P_{ij} < 0$ it means that at a transfer of a product unit to the respective cell one gains the value resulted from the calculation. If there are several cells with negative value one will choose the transfer to the cell with the highest absolute value which leads to the highest gain.

The highest gain is obtained by transferring to cell A_1B_3 the minimum of quantity found in the cell of the initial distribution on the set transfer route, in our case 25 products.
The new distribution is shown in the table below:

Table 17

$\mathbf{B_j}$ / $\mathbf{A_i}$	$\mathbf{B_1}$	$\mathbf{B_2}$	$\mathbf{B_3}$	$\mathbf{B_4}$	**Available**
$\mathbf{A_1}$	$c_{11}=2$ **115**	$c_{12}=3$ 0	$c_{13}=1$ **25**	$c_{14}=4$ 0	**140**
$\mathbf{A_2}$	$c_{21}=3$ 0	$c_{22}=1$ **135**	$c_{23}=4$ **25**	$c_{24}=3$ 0	**160**
$\mathbf{A_3}$	$c_{31}=4$ 0	$c_{32}=2$ 0	$c_{33}=3$ **80**	$c_{34}=2$ **120**	**200**
Necessary	**115**	**135**	**130**	**120**	**500**

The objective function for the new distribution is:

$[\min]f = 115x2 + 25x1 + 135x1 + 25x4 + 80x3 + 120x2 = 970$ m.u.

By comparison to the basic initial solution obtained through the method of the N-W corner we have a total transportation cost lower by 125 m.u.

The method is iterative. One resumes the calculations having as initial data those obtained from the new solution:

Iteration 3

For cell $\mathbf{A_1B_2}$:

$A_1B_2 \rightarrow A_1B_3 \rightarrow A_2B_3 \rightarrow A_2B_2$

$P_{12} = + 3 – 1 + 4 – 1 = 5$

For cell $\mathbf{A_1B4}$:

$A_1B_4 \rightarrow A_3B_4 \rightarrow A_3B_3 \rightarrow A_1B_3$

$P_{14} = + 4 – 2 + 3 – 1 = 4$

For cell $\mathbf{A_2B_1}$:

$A_2B_1 \rightarrow A_2B_3 \rightarrow A_1B_3 \rightarrow A_1B_1$

$P_{21} = + 3 – 4 + 1 – 2 = - 2$

For cells A_2B_4, A_3B_1 and A_3B_2 there is no gain as $P_{ij} > 0$.

There is only one cell where $P_{ij} < 0$ more precisely $\mathbf{A_2B_1}$**.**

The new distribution is presented in the table below:

Table 18

B_j / A_i	B_1	B_2	B_3	B_4	Available
A_1	$c_{11}=2$ **90**	$c_{12}=3$ 0	$c_{13}=1$ **50**	$c_{14}=4$ 0	**140**
A_2	$c_{21}=3$ **25**	$c_{22}=1$ **135**	$c_{23}=4$ 0	$c_{24}=3$ 0	**160**
A_3	$c_{31}=4$ 0	$c_{32}=2$ 0	$c_{33}=3$ **80**	$c_{34}=2$ **120**	**200**
Necessary	**115**	**135**	**130**	**120**	**500**

The objective function for the new distribution is:

[min]f = 90x2 + 50x1 + 25x3 + 135x1 + 25x4 + 80x3 + 120x2 = 920 m.u.

Iteration 4

One resumes the calculations having as initial data those obtained from the new solution.

Cell A_1B_2 $\quad A_1B_2 \rightarrow A_2B_2 \rightarrow A_2B_1 \rightarrow A_1B_1$

$P_{12} = + 3 – 1 + 3 – 2 = 3$

Cell A_1B_4 $\quad A_1B_4 \rightarrow A_3B_4 \rightarrow A_3B_3 \rightarrow A_1B_3$

$P_{14} = + 4 – 2 + 3 – 1 = 4$

Cell A_2B_3 $A_2B_3 \rightarrow A_1B_3 \rightarrow A_1B_1 \rightarrow A_2B_1$

$P_{23} = +4 - 1 + 2 - 3 = 2$

Cell A_2B_4 $A_2B_4 \rightarrow A_3B_4 \rightarrow A_3B_3 \rightarrow A_1B_3 \rightarrow A_1B_1 \rightarrow A_2B_1$

$P_{24} = +3 - 2 + 3 - 1 + 2 - 3 = 2$

Cell A_3B_1 $A_3B_1 \rightarrow A_3B_3 \rightarrow A_1B_3 \rightarrow A_1B_1$

$P_{31} = +4 - 3 + 1 - 2 = 0$

Cell A_3B_2 $A_3B_2 \rightarrow A_3B_3 \rightarrow A_1B_3 \rightarrow A_1B_1 \rightarrow A_2B_1$

$P_{32} = +2 - 3 + 1 - 2 + 3 - 1 = 0$

As no other permutation toward void cells is negative, it follows that there is no other distribution able to bring about a reduction of the objective function (of the transportation effort).

It results that the solution found in iteration 3 is the optimum one.

Remark : Through the method of the row minimum element and the matrix minimum element, as well as through the Vogel method, one obtained another distribution, but with the same transportation effort as in the Stepping – Stone method. Thus both distributions are optimum and in order to verify if the solution obtained through the methods of the row and matrix minimum elements and through Vogel's method can or cannot be optimised anymore, one considers this distribution as initial solution and attempts to improve it through the Stepping – Stone method.

The initial solution is given in the table below:

Table 19

B_j / A_i	B_1	B_2	B_3	B_4	**Available**
A_1	$c_{11}=2$ **10**	$c_{12}=3$ 0	$c_{13}=1$ **130**	$c_{14}=4$ 0	**140**
A_2	$c_{21}=3$ **25**	$c_{22}=1$ **135**	$c_{23}=4$ 0	$c_{24}=3$ 0	**160**
A_3	$c_{31}=4$ **80**	$c_{32}=2$ 0	$c_{33}=3$ 0	$c_{34}=2$ **120**	**200**
Necessary	**115**	**135**	**130**	**120**	**500**

One calculates with the same method (Stepping – Stone) the gains or losses by the transfer of one product unit to the void cells.

Cell A_1B_2 $A_1B_2 \rightarrow A_2B_2 \rightarrow A_2B_1 \rightarrow A_1B_1$

$P_{12} = +3 - 1 + 3 - 2 = 3$

Cell A_1B_4 $A_1B_4 \rightarrow A_3B_4 \rightarrow A_3B_1 \rightarrow A_1B_1$

$P_{14} = +4 - 2 + 4 - 2 = 4$

Cell A_2B_3 $\quad A_2B_3 \rightarrow A_1B_3 \rightarrow A_1B_1 \rightarrow A_2B_1$

$P_{23} = +4 - 1 + 2 - 3 = 2$

Cell A_2B_4 $\quad A_2B_4 \rightarrow A_3B_4 \rightarrow A_3B_1 \rightarrow A_2B_1$

$P_{24} = +3 - 2 + 4 - 3 = 2$

Cell A_3B_2 $\quad A_3B_2 \rightarrow A_3B_1 \rightarrow A_2B_1 \rightarrow A_2B_2$

$P_{32} = +2 - 4 + 3 - 1 = 0$

Cell A_3B_3 $\quad A_3B_3 \rightarrow A_3B_1 \rightarrow A_1B_1 \rightarrow A_1B_3$

$P_{33} = +3 - 4 + 2 - 1 = 0$

As all the P_{ij} values are positive, it results that both distributions are optimum.

1.5. SOLVING THE TRANSPORT PROBLEM WITH THE WINQSB SOFTWARE

In order to solve this type of problems, we use the ***Network Modelling*** module, presented below. The launching in execution of the ***Network Modelling*** module opens the main window below, which contains in its upper side:

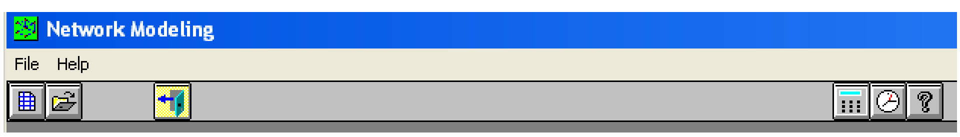


Fig. 1. Main window of the *Network Modelling* module

To load an existing file, click on the button marked in the figure below:

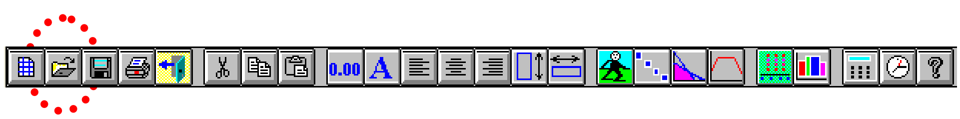


Fig. 2.

The specification of the type of problem, the type of the objective function, the form of input data presentation as well as the title of the problem, the number of sources and a destinations is done by completing the box in the figure below:

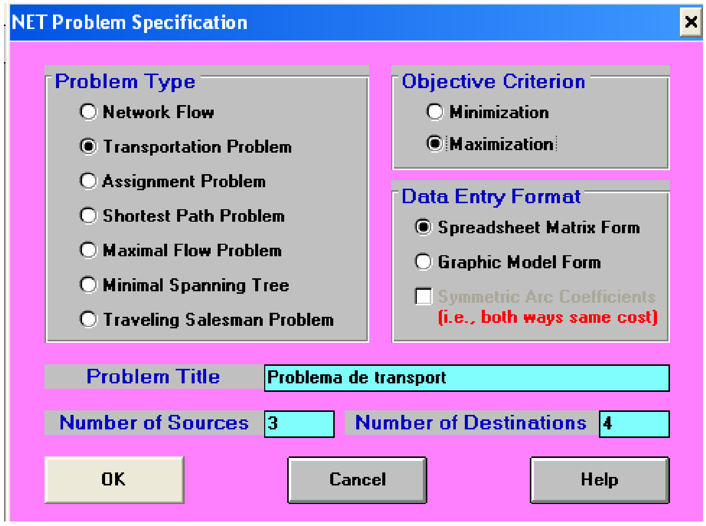


Fig. 3. NET Problem Specification Box

After the introduction of data in the figure above, click OK, which leads to the change of the window menu and the opening of a "working area" (fig.4).

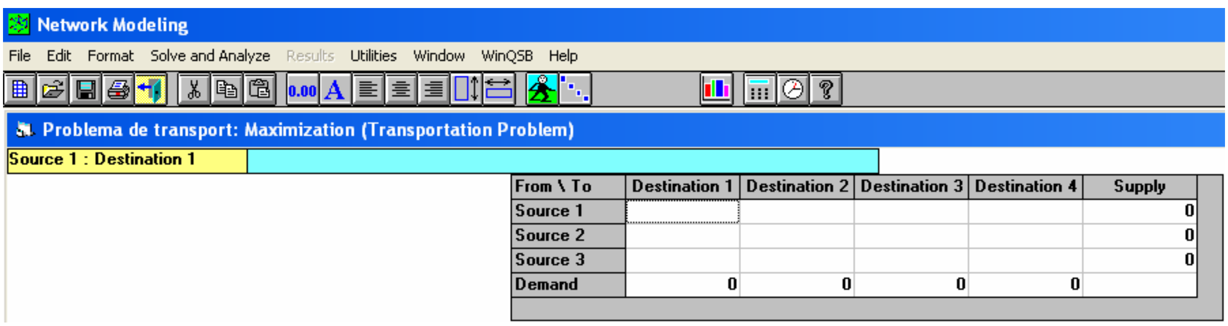


Fig. 4. Area of input data introduction under the matrix form

If you want to change the title of the problem, click on the ***Edit*** menu, which contains the option ***Problem Name***. When this command is activated, a box appears at the right side of figure 5, where you can make the change.

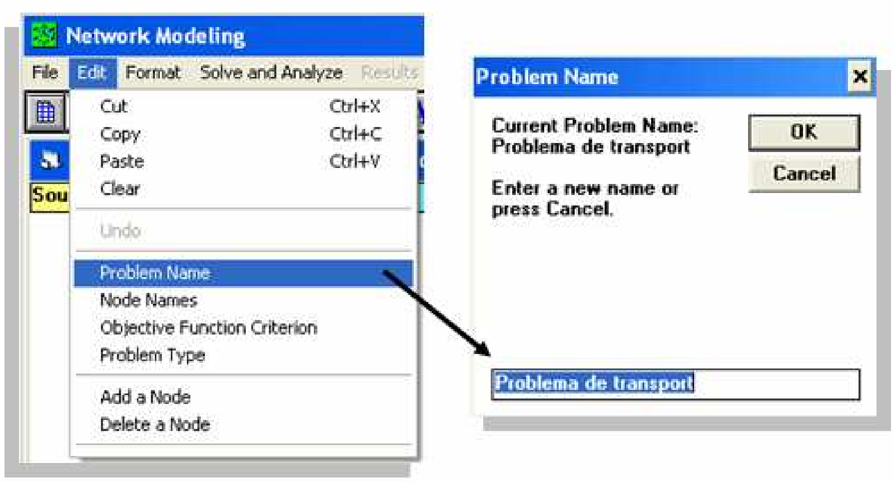


Fig. 5. Manner of changing the title of the problem

Still from the ***Edit*** menu one may introduce the name of each source and each destination separately, by activating ***Node Name*** command (fig.6).

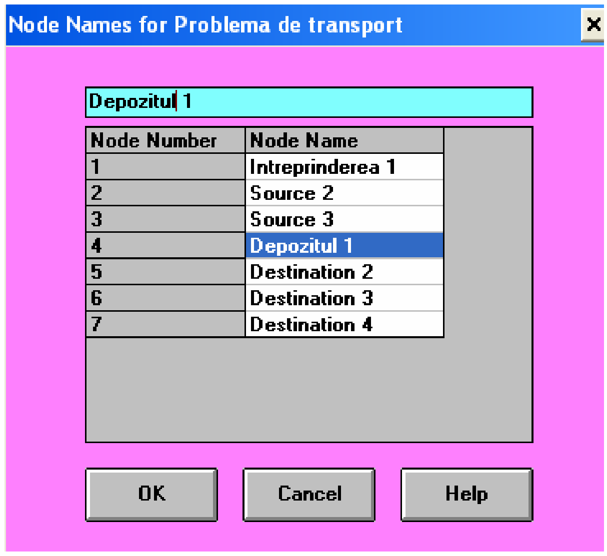


Fig. 6. Manner of changing the name of each node

Another option in the ***Edit*** menu is to modify the type of objective function (fig.7).

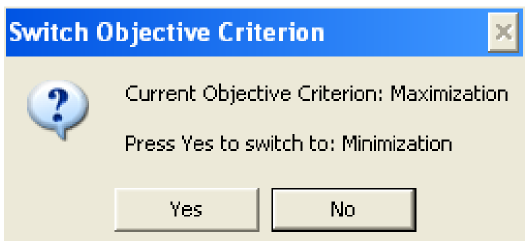


Fig. 7. Manner of changing the type of objective function

At the same time one may change the type of problem from the ***Edit→Problem Type*** menu (fig.8).

The command ***Add a Node*** form the ***Edit*** menu (fig.9) offers the possibility to introduce new sources or destination, if necessary, and the command ***Delete a Node***, to delete the nodes that are useless (fig.10).

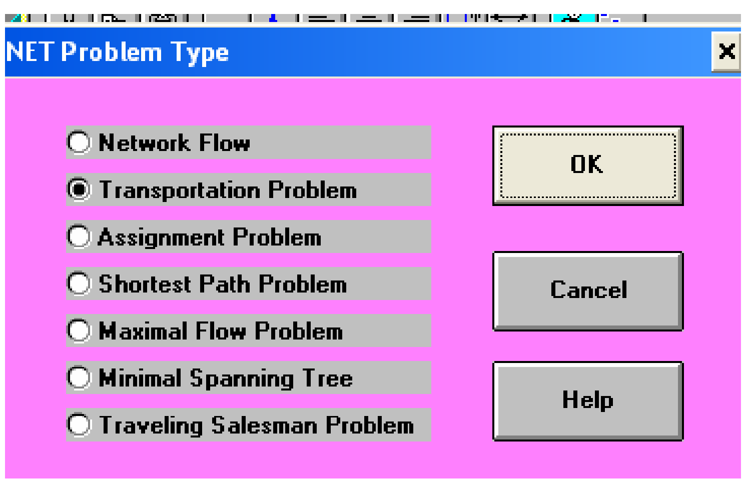


Fig. 8. Manner of changing the type of problem

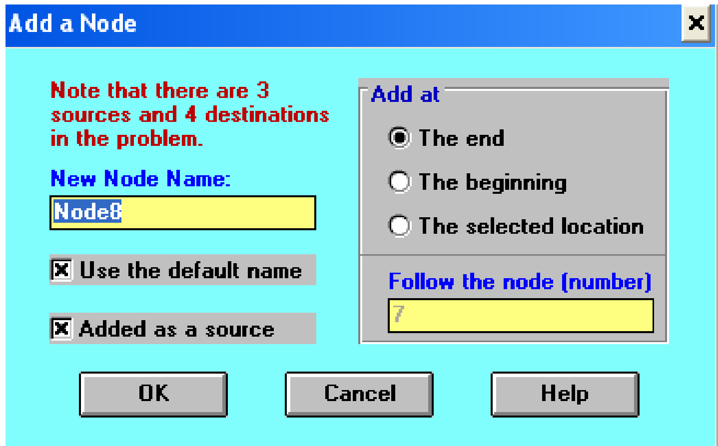


Fig. 9. Manner of introducing new nodes

Fig. 10. Manner of deleting nodes

The problems of this module may be introduced in two manners:

- Under the form of a matrix ; or
- By graph plotting.

The options are found in the ***Format*** menu.

Matrix form

Implicitly, the module supposes the introduction of the problem under the matrix form., each cell in the afferent matrix represents the coefficient of the arc from one node to the next, coefficient that may have different significations: transport unitary cost, profit, distance or capacity of the respective arc. The source nodes are arranged on the rows, whereas the destination nodes are on the columns.

Plotting

1. Nodes editing - option *Node* from the *Edit* menu.

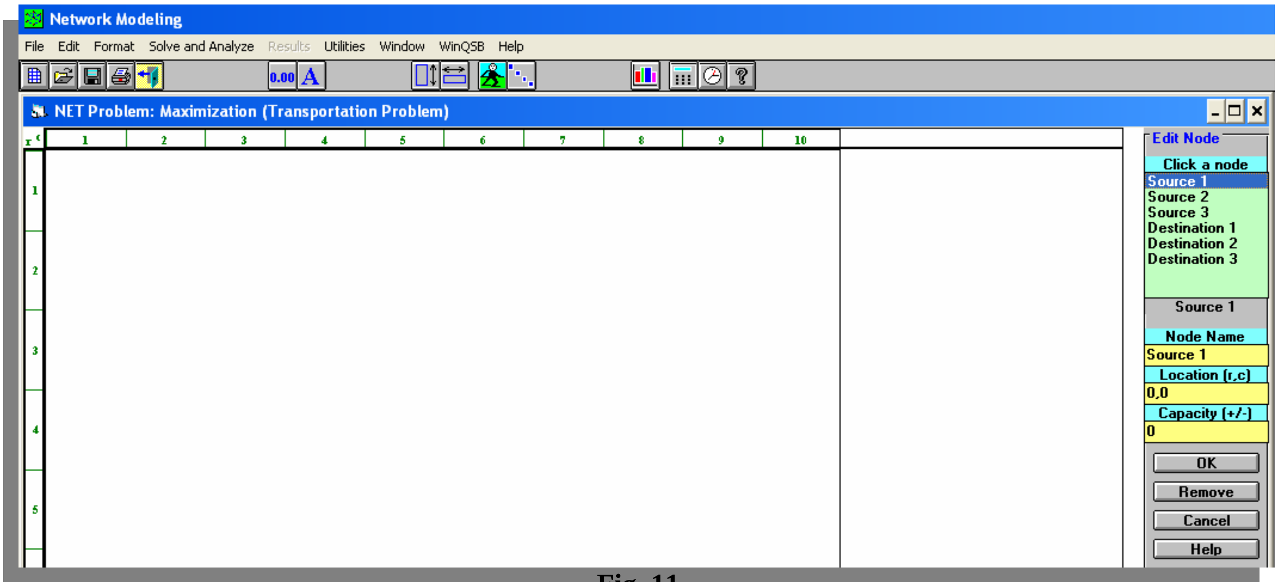


Fig. 11.

In the afferent window we may specify: node name, node location, node capacity, with (+) for demand and (-) supply (fig. 11).
To delete a node select *Remove*.

2. Arcs editing– option *Arc/Connection/Link* from the *Edit* menu.
Arcs are edited by selecting the names of the involved nodes from the list. Then one may introduce or modify costs, distances, profit, capacity or coefficient, as appropriate.
In the end click OK. An arc may be deleted by selecting the *Remove* button.

3. The graphic model is represented on a sheet with vertical and horizontal lines. The sheet configuration is done by selection the option *Configuration*: *Row*, *Column, and Width* from the *Format* menu.

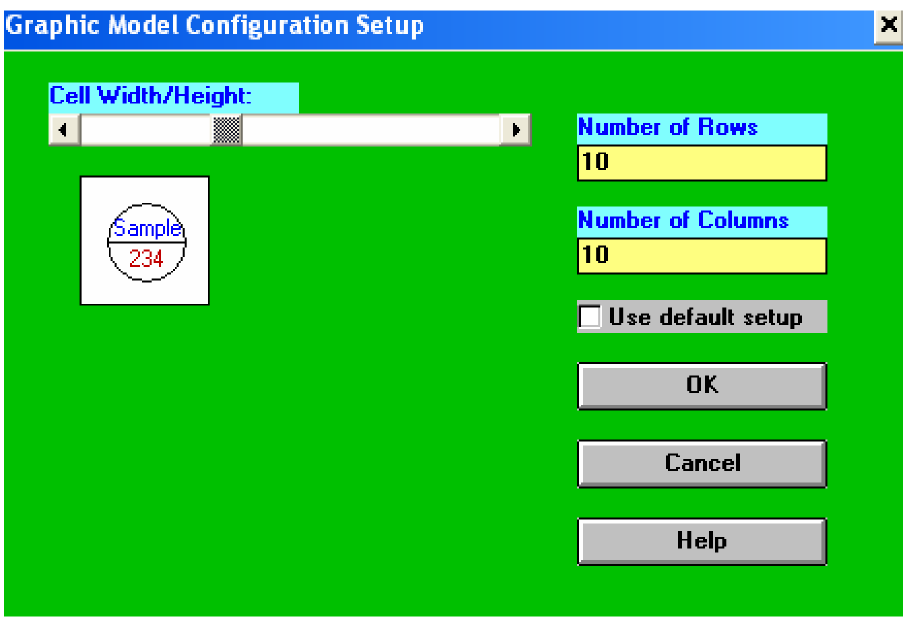


Fig. 12. Sheet configuration

4. The use of the mouse

- Left double click in an empty cell for the drawing of a new node
- For drawing an arc, left click on an existing node and draw toward the desired node

2. Exercises – resolved

2.1. Balanced transportation problems

Exercise 02

We start form the problem presented in example 01.

We introduce the data of the problem under the matrix form and we have:

From \ To	B 1	B 2	B 3	B 4	Supply
A 1	2	3	1	4	140
A 2	3	1	4	3	160
A3	4	2	3	2	200
Demand	115	135	130	120	

Fig.13. Input data

The transportation problem is balanced as $\sum_{i=1}^{3} a_i = \sum_{j=1}^{4} b_j = 500$.

1. The basic initial solution

a) In order to obtain the basic initial solution we shall use the method of the N-W corner

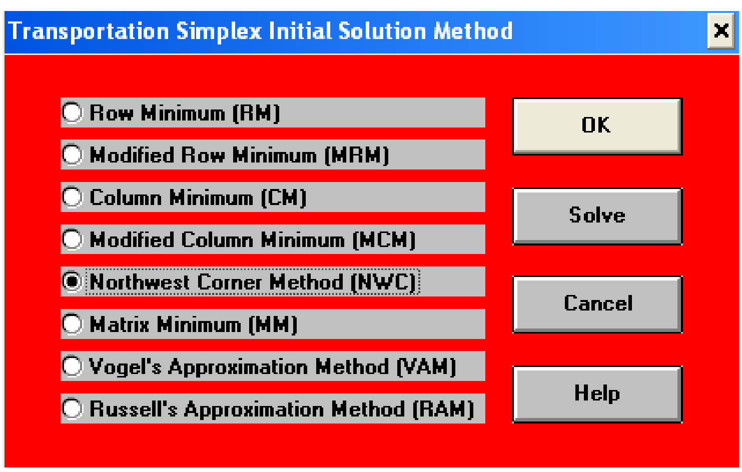


Fig. 14. Methods of solving the transportation problems provided by the software

By using the method of the N-W corner we obtain the following results:

From \ To	B 1	B 2	B 3	B 4	Supply	Dual P(i)
A 1	2 115	3 25*	1 Cij=-5 **	4	140	0
A 2	3	1 110	4 50	3	160	-2
A3	4	2	3 80	2 120	200	-3
Demand	115	135	130	120		
Dual P(j)	2	3	6	5		
	Objective Value = 1095 (Minimization)					

Fig. 15. Solution of the problem under the matrix form – Method of the N-W corner

According to the data in the table of fig.13. it results the solution:

$[\min]f = 2 \cdot 115 + 3 \cdot 25 + 1 \cdot 110 + 4 \cdot 50 + 3 \cdot 80 + 2 \cdot 120 = 1095$ m.u.

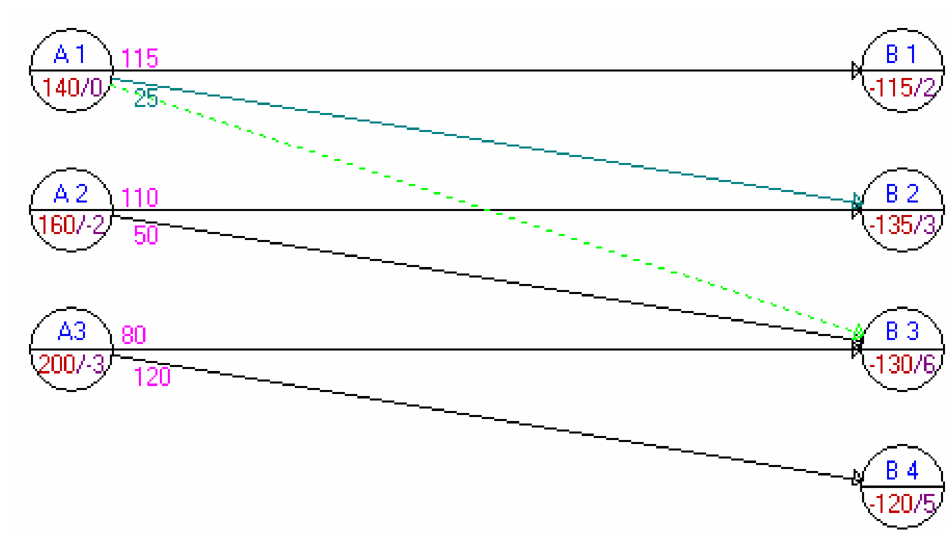


Fig. 16. The solution of the problem in the graphic form – the method of the N-W corner

b) The method of the row minimum cost

The total transportation cost is:

$[\min]f = 2 \cdot 10 + 130 \cdot 1 + 3 \cdot 25 + 1 \cdot 135 + 4 \cdot 80 + 2 \cdot 120 = 920$ m.u.,

according to fig.17.

From \ To	B 1	B 2	B 3	B 4	Supply	Dual P(i)
A 1	2 10	3	1 130	4	140	0
A 2	3 25	1 135	4	3	160	1
A3	4 80	2	3	2 120	200	2
Demand	115	135	130	120		
Dual P(j)	2	0	1	0		
	Objective Value = 920 (Minimization)					

Fig.17. The solution of the problem in matrix form – method of the row minimum element

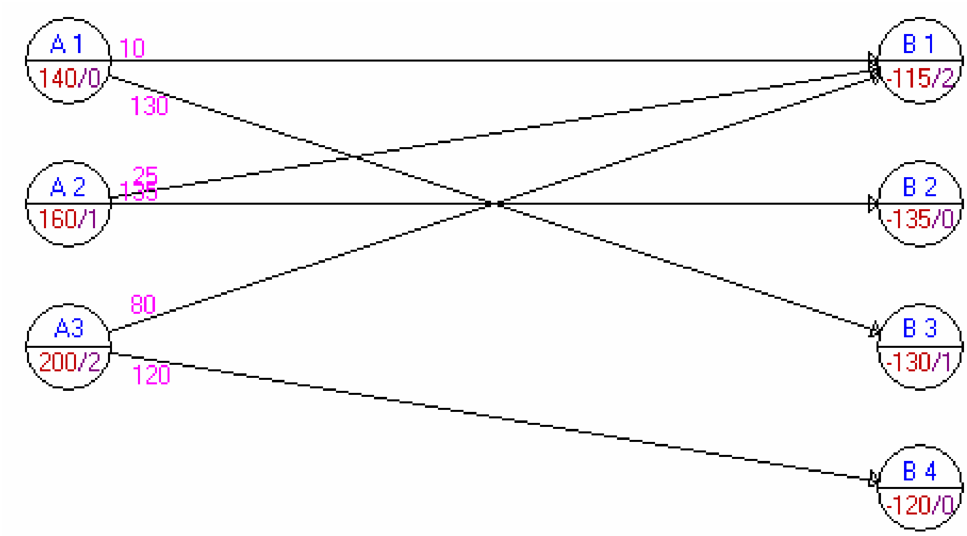


Fig.18. Solution of the problem in graphic form – method of the row minimum element

c) The method of the column minimum cost

The objective function is:

$$[\min]f = 2 \cdot 115 + 1 \cdot 25 + 1 \cdot 135 + 3 \cdot 25 + 3 \cdot 105 + 2 \cdot 95 = 970 \text{ m.u.},$$

as we can see in figure 19.

From \ To	B 1	B 2	B 3	B 4	Supply	Dual P(i)
A 1	2 115	3	1 25	4	140	0
A 2	3 Cij=-2 **	1 135	4	3 25*	160	3
A3	4	2	3 105	2 95	200	2
Demand	115	135	130	120		
Dual P(j)	2	-2	1	0		
	Objective Value = 970 (Minimization)					

Fig. 19. The solution of the problem in matrix form – method of the column minimum element

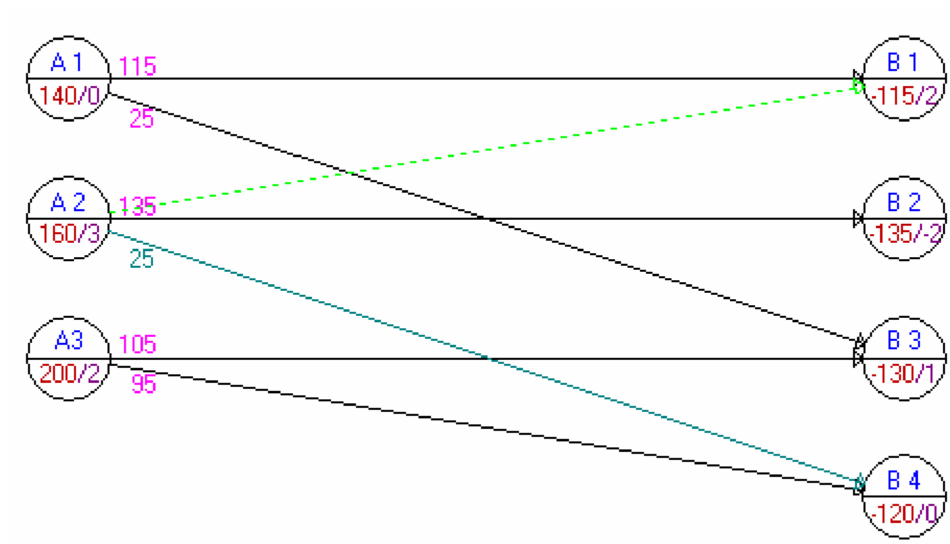


Fig. 20. Solution of the problem in graphic form – method of the column minimum element

d) Method of the minimum cost on the whole

The value of transportation will be given by:

$$[\min]f = 2 \cdot 10 + 3 \cdot 25 + 4 \cdot 80 + 1 \cdot 135 + 1 \cdot 130 + 2 \cdot 120 = 920 \text{ m.u.},$$

which may be remarked in the figure below:

From \ To	B 1	B 2	B 3	B 4	Supply	Dual P(i)
A 1	2 10	3	1 130	4	140	0
A 2	3 25	1 135	4	3	160	1
A3	4 80	2	3	2 120	200	2
Demand	115	135	130	120		
Dual P(j)	2	0	1	0		
	Objective Value = 920 (Minimization)					

Fig. 21. Solution of the problem in matrix form – method of the matrix minimum element

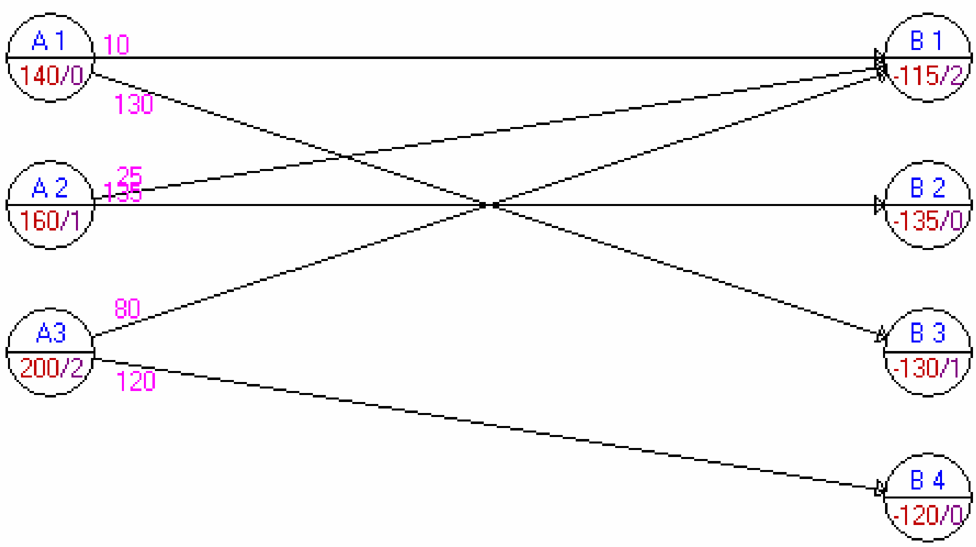


Fig. 22. Solution of the problem in graphic form – method of the matrix minimum element

e) Method of maximum differences or Vogel's method.

The determined basic solution supposes a total transportation cost of:

[min]f = 10x2 + 130x1 + 25x3 + 135x1 + 80x4 + 120x2 = 920 m.u.,

represented in the figure below:

From \ To	B 1	B 2	B 3	B 4	Supply	Dual P(i)
A 1	2 10	3	1 130	4	140	0
A 2	3 25	1 135	4	3	160	1
A3	4 80	2	3	2 120	200	2
Demand	115	135	130	120		
Dual P(j)	2	0	1	0		
	Objective Value = 920 (Minimization)					

Fig. 23. Solution of the problem in matrix form – Vogel's method

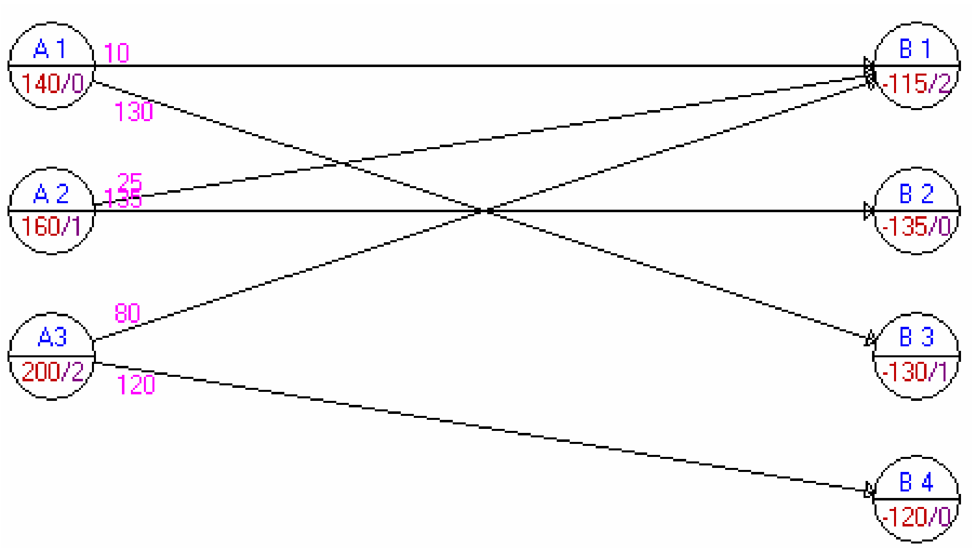


Fig. 24. Solution of the problem in graphic form – Vogel's method

2. The optimum solution

The Stepping – Stone method

We start from the basic initial solution obtained by applying the method of the N-W corner (fig.15.), which is considered iteration 1 and we have:

From \ To	B 1	B 2	B 3	B 4	Supply	Dual P(i)
A 1	2 115	3	1 25	4	140	0
A 2	3 Cij=-2 **	1 135	4 25*	3	160	3
A3	4	2	3 80	2 120	200	2
Demand	115	135	130	120		
Dual P(j)	2	-2	1	0		
	Objective Value = 970 (Minimization)					

Fig. 25. Iteration 2

Transportation Tableau for Curs intensiv - Iteration 3 (Final)

From \ To	B 1	B 2	B 3	B 4	Supply	Dual P(i)
A 1	2 90	3	1 50	4	140	0
A 2	3 25	1 135	4	3	160	1
A3	4	2	3 80	2 120	200	2
Demand	115	135	130	120		
Dual P(j)	2	0	1	0		
	Objective Value = 920 (Minimization)					

Fig. 26. Iteration 3

There is no other distribution able to realise a reduction of the objective function and thus the solution found in iteration 3 is the optimum one.

05-25-2011	From	To	Shipment	Unit Cost	Total Cost	Reduced Cost
1	A 1	B 1	90	2	180	0
2	A 1	B 3	50	1	50	0
3	A 2	B 1	25	3	75	0
4	A 2	B 2	135	1	135	0
5	A3	B 3	80	3	240	0
6	A3	B 4	120	2	240	0
	Total	Objective	Function	Value =	920	

Fig. 27. The optimum solution in table form. The basic initial solution obtained as a result of applying the method of the N-W corner

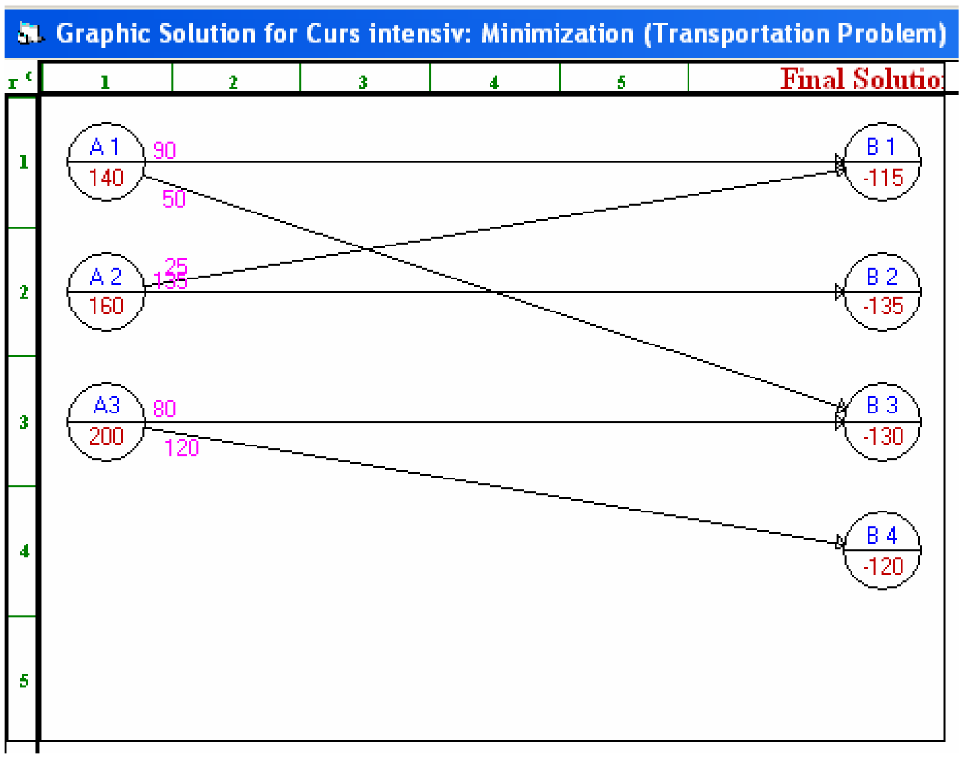


Fig. 28. The optimum solution in graphic form. The basic initial solution obtained after the application of the method of the N-W corner

The minimum total transportation cost is of 920 m.u., if:

- A1 supplies B1 with 90 units and B3 with 50 units.
- A2 supplies B1 with 25 units and B2 with 135 units.
- A3 supplies B3 with 80 units and B4 with 120 units.

Remark: By the method of the line and matrix minimum element and by Vogel's method we obtained another distribution, with the same transportation effort as by the Stepping – Stone method. Consequently, as we mentioned in the previous chapter, both distributions are optimum and in order to verify if the solution obtained by the methods of the row and matrix minimum element and Vogel's method cannot be optimised any more, we consider this distribution as an initial solution and attempt to improve it by the Stepping – Stone method.
So we start from the distribution presented in figures 17, 21 and 23 and attempt to optimise it, which is no longer possible. Thus the following distribution is also optimum:

From	To	Shipment	Unit Cost	Total Cost	Reduced Cost
A 1	B 1	10	2	20	0
A 1	B 3	130	1	130	0
A 2	B 1	25	3	75	0
A 2	B 2	135	1	135	0
A3	B 1	80	4	320	0
A3	B 4	120	2	240	0
Total	Objective	Function	Value =	920	

Fig. 29. The optimum solution in matrix form

The objective function has the same value as in the previous case, when we started with the solution obtained by the N–W method as basic initial solution.

2.2. Non-balanced transportation problems

Exercise 03

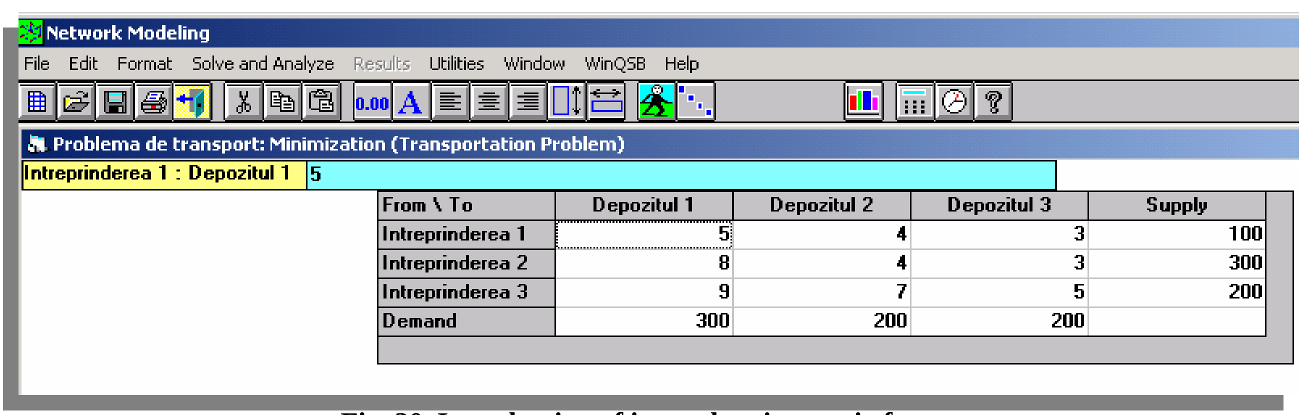
A company produces the same product in 3 different facilities and distributes it through 3 regional warehouses. The manufacture capacitates of the facilities and the necessary of the warehouses are given in table 1. The manufacture costs for this product are identical in all three facilities, the only relevant costs being those of transportation between facilities and warehouses found in table 20, expressed in EUR.

Table 20

To / From	Warehouse 1	Warehouse 2	Warehouse 3	Capacity (pcs) - b_j
Facility 1	5	4	3	100
Facility 2	8	4	3	300
Facility 3	9	7	5	200
Necessary (pcs) - a_i	300	200	200	

We aim at determining the manner of delivering the products from facilities to warehouses in order to minimise the total transportation cost, with the observance of the constraints related to the manufacture capacity of the facilities and the necessary of the warehouses.

Solution



From \ To	Depozitul 1	Depozitul 2	Depozitul 3	Supply
Intreprinderea 1	5	4	3	100
Intreprinderea 2	8	4	3	300
Intreprinderea 3	9	7	5	200
Demand	300	200	200	

Fig. 30. Introduction of input data in matrix form

We remark that the given problem is not balanced , because:

$$\sum_{i=1}^{3} a_i = 600 < \sum_{j=1}^{3} b_j = 400$$

In order to satisfy the balance condition we must introduce a fictional facility, with a capacity equal to 700 – 600 = 100 pcs and with null unitary transportation costs, which is automatically done by WinQSB.

After the introduction of the data, the problem solving is done choosing one of the available options from the *Solve and Analyze* menu, i.e.:

- *Solve the Problem* – opens a new window with the final results in matrix form.
- *Solve and Display Steps-Network* – viewing the stages in the problem solving in graphic form.
- *Solve and Display Steps-Tableau* – viewing the stages in the problem solving in matrix form.
- *Select Initial Solution Method* – offers the possibility to choose a method of the initial solution, form among the following available ones (fig. 31).

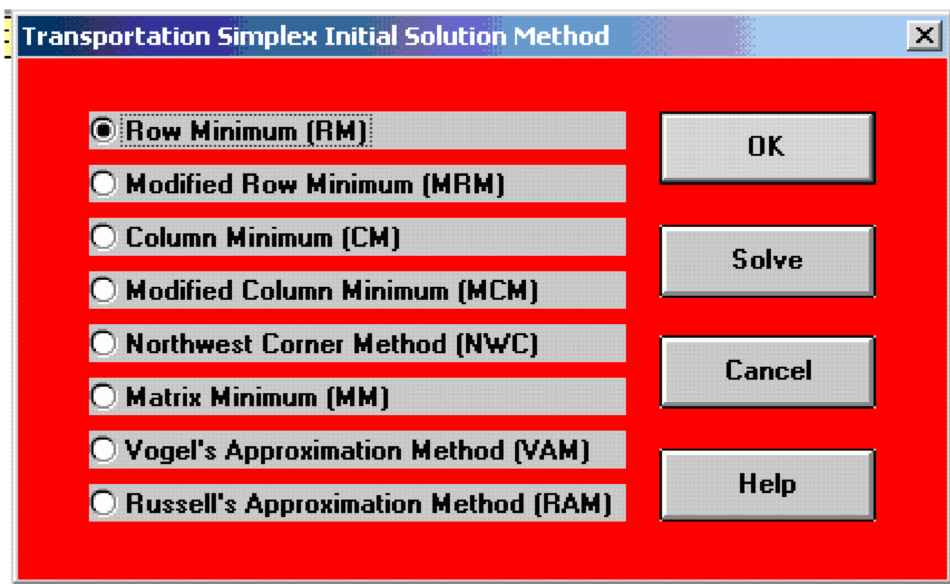


Fig. 31. Choosing the "Row minimum" method

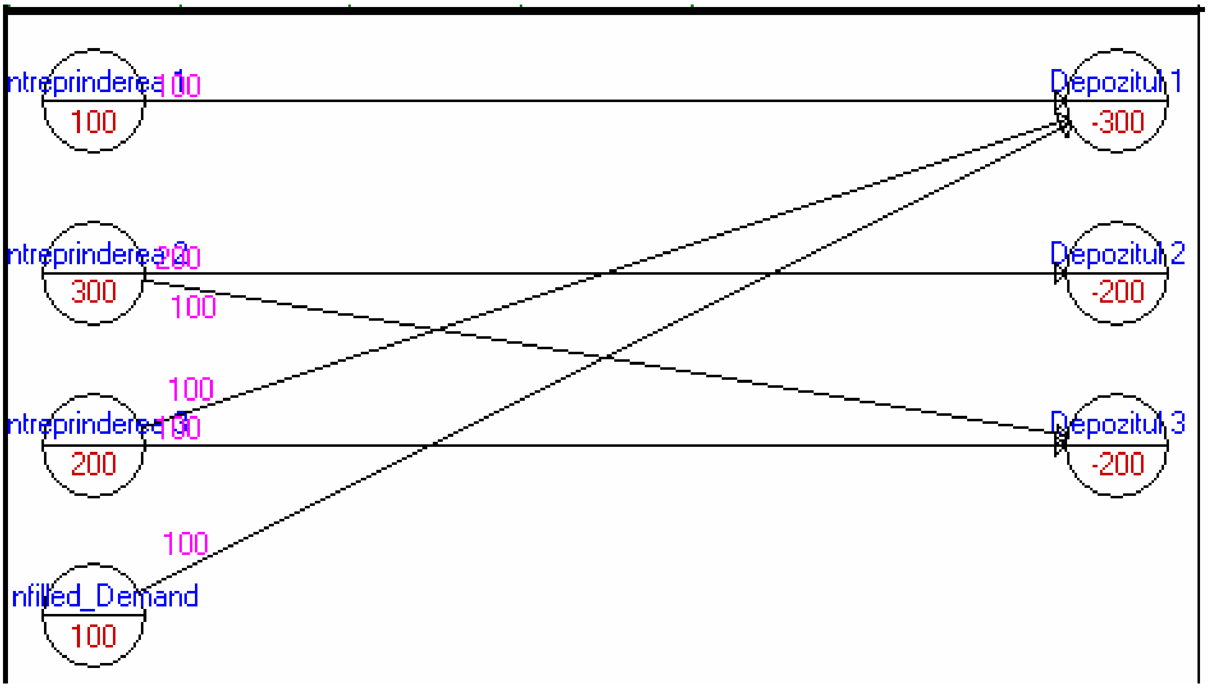
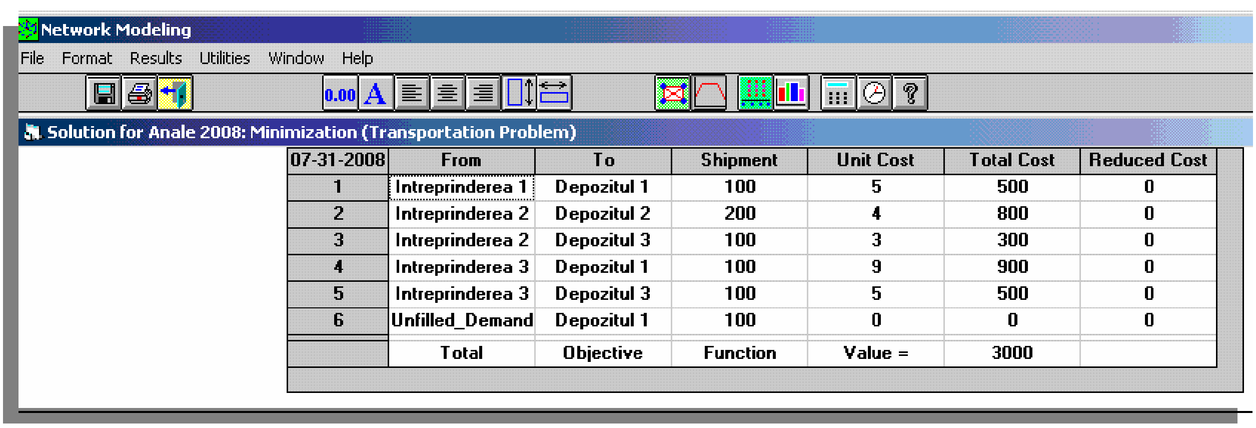


Fig. 32. The graph afferent to the problem provided by the WinQSB software

As a result of the selection of the *Solve the Problem* option we obtained the following results showing the quantities to be transported among warehouses, so that the total transportation cost be minimum.



07-31-2008	From	To	Shipment	Unit Cost	Total Cost	Reduced Cost
1	Intreprinderea 1	Depozitul 1	100	5	500	0
2	Intreprinderea 2	Depozitul 2	200	4	800	0
3	Intreprinderea 2	Depozitul 3	100	3	300	0
4	Intreprinderea 3	Depozitul 1	100	9	900	0
5	Intreprinderea 3	Depozitul 3	100	5	500	0
6	Unfilled_Demand	Depozitul 1	100	0	0	0
	Total	Objective	Function	Value =	3000	

Fig. 33. Solution presentation

The total transportation cost is minimum 3000 EUR if:

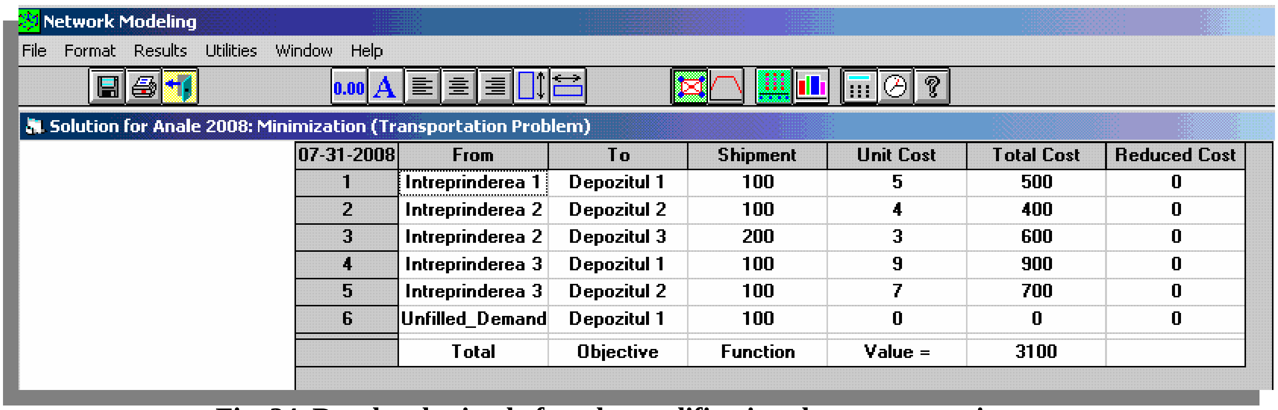
- Facility 1 supplies only Warehouse 1 with 100 product pcs.
- Facility 2 supplies Warehouse 2 with 200 pieces and Warehouse 3 with 100 pcs.
- Facility 3 supplies Warehouse 1 with 100 pieces and Warehouse 3 with 100 pcs.
- The fictitious Facility covers the rest of the necessary, i.e. 100 pcs for Warehouse 1.

Analyses performed with the help of the WinQSB software

The *Network Modelling* module offers the possibility to perform certain “What-If” or parametrical analyses, by making appeal to the options *Perform What If Analysis* or *Perform Parametric Analysis* from the *Solve and Analyze* menu.

For instance, if the transportation cost between Facility 3 and Warehouse 3 increases, it becomes 7 EUR.

The selection of the *Perform What-If Analysis* option results in the opening of a dialogue window in which we shall specify the elements that change.



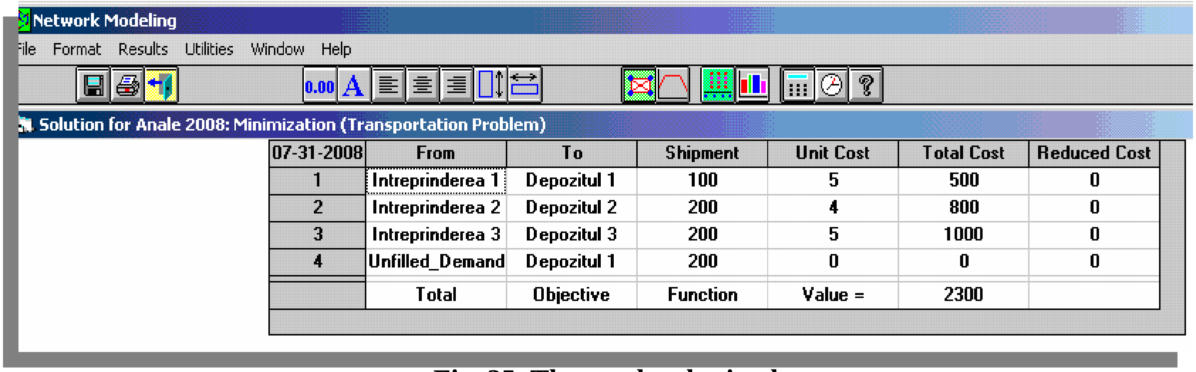
07-31-2008	From	To	Shipment	Unit Cost	Total Cost	Reduced Cost
1	Intreprinderea 1	Depozitul 1	100	5	500	0
2	Intreprinderea 2	Depozitul 2	100	4	400	0
3	Intreprinderea 2	Depozitul 3	200	3	600	0
4	Intreprinderea 3	Depozitul 1	100	9	900	0
5	Intreprinderea 3	Depozitul 2	100	7	700	0
6	Unfilled_Demand	Depozitul 1	100	0	0	0
	Total	Objective	Function	Value =	3100	

Fig. 34. Results obtained after the modification the transportation cost

Following the increase of the transportation cost from Facility 3 to Warehouse 3, the total transportation cost will increase by 100 EUR, becoming thus 3100 EUR, and at the same time the quantities to be transported change. (fig. 34) as follows:

- Facility 1 continues to supply only Warehouse 1 with 100 product pieces.
- Facility 2 supplies Warehouse 2 with 100 pieces and Warehouse 3 with 200 pieces.
- Facility 3 no longer supplies Warehouse 3, but provides 200 pcs. for Warehouse 1 and 100 pcs. for Warehouse 2.
- The fictitious Facility also supplies Warehouse 1 with 100 pieces.

But if Facility 2 has a manufacture capacity of only 200 pieces, the results obtained following the modification of the manufacture capacity of Facility 2 are those shown in figure 35.



Network Modeling

File Format Results Utilities Window Help

Solution for Anale 2008: Minimization (Transportation Problem)

07-31-2008	From	To	Shipment	Unit Cost	Total Cost	Reduced Cost
1	Intreprinderea 1	Depozitul 1	100	5	500	0
2	Intreprinderea 2	Depozitul 2	200	4	800	0
3	Intreprinderea 3	Depozitul 3	200	5	1000	0
4	Unfilled_Demand	Depozitul 1	200	0	0	0
	Total	Objective	Function	Value =	2300	

Fig. 35. The results obtained

The total transportation cost drops to 2300 EUR, but Warehouse 1 can be supplied with only 100 pieces by Facility 1 and with 200 pieces by the fictitious Facility. At the same time, 2 supplies only Warehouse 2, with 200 pieces, and the necessary of Warehouse 3 being covered by Facility 3.

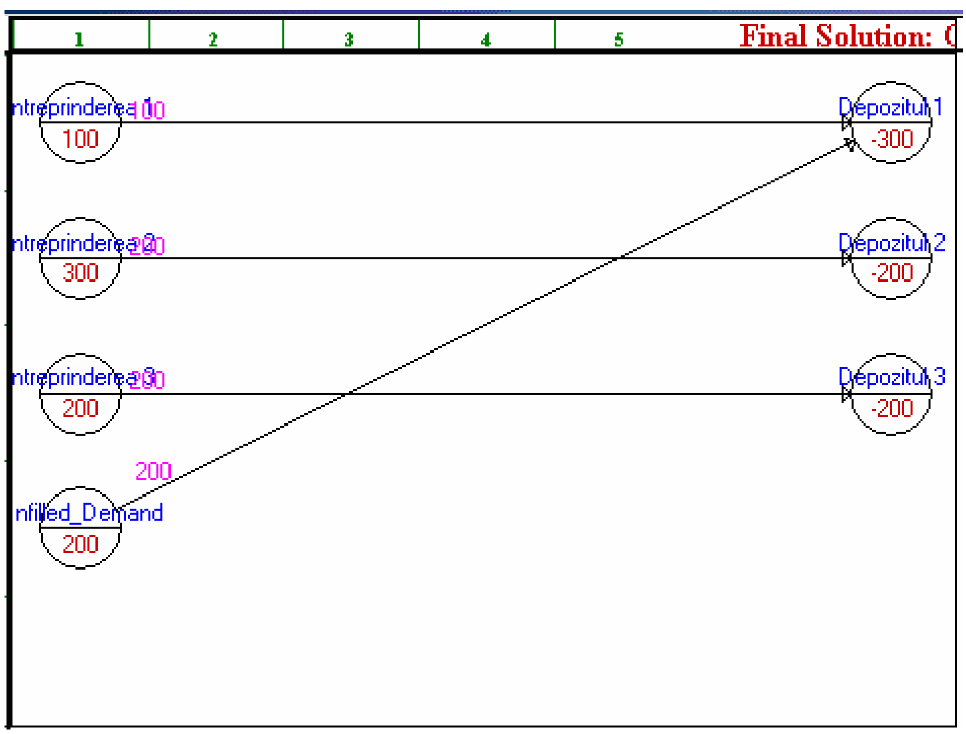


Fig.36. The afferent graph

Exercise 04

A company manufactures the same product in four different facilities and distributed through four regional warehouses. The manufacture capacities of the facilities and the necessary of the warehouses are given in table 21. The manufacture costs for this product are identical in all four facilities, the only relevant costs being those of transportation between facilities and warehouses and are shown in table 21, expressed in monetary units.

Table 21.

Destinations Sources	D 1	D 2	D 3	D 4	Available (pcs/month)
S 1	5	4	3	2	55.000
S 2	8	2	3	6	40.000
S 3	2	7	5	9	25.000
S 4	4	3	2	5	50.000
Demand (pcs/month)	20.000	30.000	50.000	40.000	170.000 140.000

We intent to determine the delivery manner of products from facilities to warehouses, in order to achieve the minimisation of total transportation cost, with the observance of the constraints related to the manufacture capacities of facilities and the necessary of the warehouses.

Between the total demand and total available (total supply) is a difference of o 30,000 pieces, which imposes the balancing of the problem, introducing a fictitious consumer, which takes over the necessary difference.

We introduce the problem input data in matrix form (fig.37).

From \ To	Destination 1	Destination 2	Destination 3	Destination 4	Supply
Source 1	5	4	3	2	55000
Source 2	8	2	3	6	40000
Source 3	2	7	5	9	25000
Source 4	4	3	2	5	50000
Demand	20000	30000	50000	40000	

Fig. 37. Main window of the Network Modelling module

After the data introduction, the problem solving is done by choosing one of the available options from the *Solve and Analyze→Select Initial Solution Method* menu.

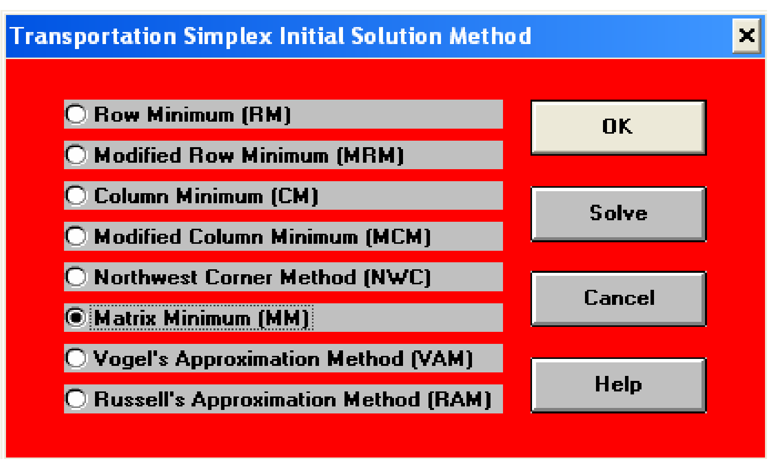


Fig. 38. Selecting the Initial Solution Method

By selecting the “matrix minimum” method we get the following:

05-26-2011	From	To	Shipment	Unit Cost	Total Cost	Reduced Cost
1	Source 1	Destination 4	40000	2	80000	0
2	Source 1	Unused_Supply	15000	0	0	0
3	Source 2	Destination 2	30000	2	60000	0
4	Source 2	Unused_Supply	10000	0	0	0
5	Source 3	Destination 1	20000	2	40000	0
6	Source 3	Unused_Supply	5000	0	0	0
7	Source 4	Destination 3	50000	2	100000	0
	Total	Objective	Function	Value =	280000	

Fig. 39. The optimum solution obtained with the “matrix minimum” method

The total transportation cost is of minimum 280,000 m.u. if:

- Facility 1 supplies Warehouse 4 with 40,000 pcs.
- Facility 2 supplies Warehouse 2 with 30,000 pcs.
- Facility 3 supplies Warehouse 1 with 20,000 pcs.
- Facility 4 supplies Warehouse 3 with 50,000 pcs.
- The fictitious consumer covers the rest of the demand, i.e. 30,000 pcs. as follows: 15,000 pcs. received from Facility 1, 10,000 pcs. from Facility 2, and the rest of 5,000 pcs. from Facility 3.

The graph associated to the studies problem is plotted in figure 39.

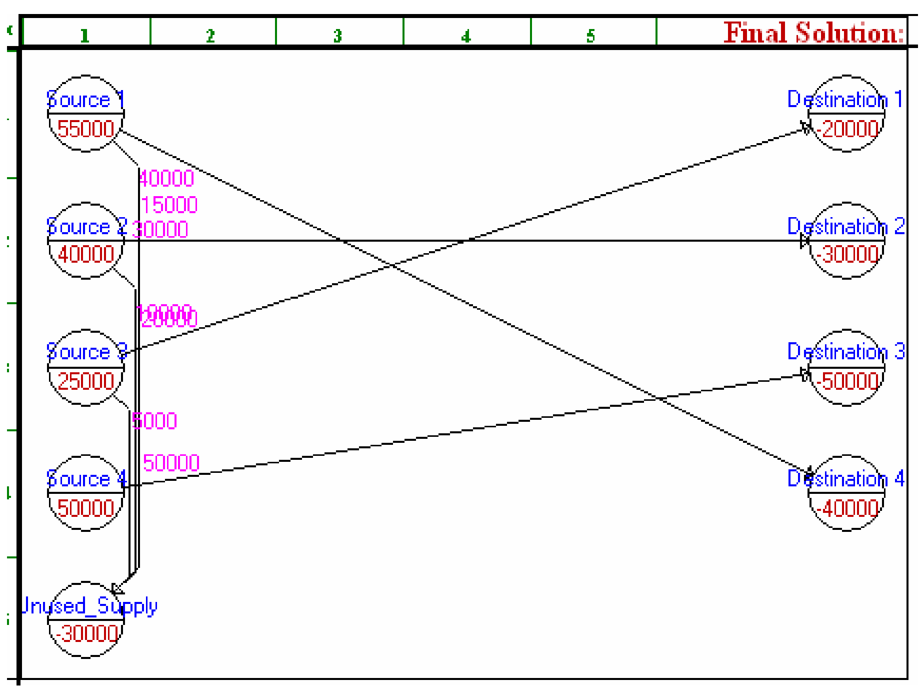


Fig. 40. The graph afferent to the problem provided by the WinQSB software

For the following month one foresees a reduction of the output, because of a series of strikes. Consequently, one estimates that the total output will drop by 30%, being distributed as follows: 35,000 pcs. at Facility 1 and 2, 19,000 pcs. at Facility 3, and the rest of 30,000 pcs. at Enterprise 4.

1.) The first manner of approaching this problem will be that of minimising the transportation costs.

We remark a difference between the total demand and total supply (140,000>119,000), which imposes a rebalancing of the problem by the introduction of a fictitious source, whose monthly output should be equal to the quantity by which the current output was reduced, i.e. 51,000 pieces .

We remark that only the demand of Warehouse 2 is entirely covered, the demand of Warehouse 1 is covered in the proportion of 95% , whereas warehouses 3 and 4 receive only 70%, and 87.5% respectively.

From	To	Shipment	Unit Cost	Total Cost	Reduced Cost
Source 1	Destination 4	35000	2	70000	0
Source 2	Destination 2	30000	2	60000	0
Source 2	Destination 3	5000	3	15000	0
Source 3	Destination 1	19000	2	38000	0
Source 4	Destination 3	30000	2	60000	0
Unfilled_Demand	Destination 1	1000	0	0	0
Unfilled_Demand	Destination 3	15000	0	0	0
Unfilled_Demand	Destination 4	5000	0	0	0
Total	Objective	Function	Value =	243000	

Fig. 41. The solution obtained in the case of minimising the transportation costs

2.) We may attempt at a distribution of the reduced output proportionally with the normal demands.

If the diminished output represents 70% of the normal one, we get:

05-26-2011	From	To	Shipment	Unit Cost	Total Cost	Reduced Cost
1	Source 1	Destination 3	5000	3	15000	0
2	Source 1	Destination 4	28000	2	56000	0
3	Source 1	Unused_Supply	2000	0	0	0
4	Source 2	Destination 2	21000	2	42000	0
5	Source 2	Unused_Supply	14000	0	0	0
6	Source 3	Destination 1	14000	2	28000	0
7	Source 3	Unused_Supply	5000	0	0	0
8	Source 4	Destination 3	30000	2	60000	0
	Total	Objective	Function	Value =	201000	

Fig. 42. The solution obtained in the case of the reduction of output proportionally with the normal demands

We remark that in this case a reduction of the total transportation cost compared to the previous case, from 243,000 m.u. to 201,000 m.u.

3.) We study a new variant of the initial transportation problem.

Until now we admitted that any route between the source and the destination may be used at a lower or higher transportation cost. We start from the hypothesis that the transportation routes are not all available any longer. Supposing that route (S2, D2) is temporarily blocked because of some modernising works, Facility 2 can no longer distribute the merchandise directly to Warehouse 2, and thus there will be modifications of the current optimum programme of transportation. In order to block this route, we will introduce a very high transportation cost (fig. 44.)

From \ To	Destination 1	Destination 2	Destination 3	Destination 4	Supply
Source 1	5	4	3	2	55000
Source 2	8	M	3	6	40000
Source 3	2	7	5	9	25000
Source 4	4	3	2	5	50000
Demand	20000	30000	50000	40000	

Fig. 43. Blocking route (S2, D2)

We may remark a major modification of the transportation programme. The current solution is no longer optimum. The blocked route (S2, D2) is no longer used in the new transportation programme, presented in the figure below.

05-26-2011	From	To	Shipment	Unit Cost	Total Cost	Reduced Cost
1	Source 1	Destination 4	40000	2	80000	0
2	Source 1	Unused_Supply	15000	0	0	0
3	Source 2	Destination 3	30000	3	90000	0
4	Source 2	Unused_Supply	10000	0	0	0
5	Source 3	Destination 1	20000	2	40000	0
6	Source 3	Unused_Supply	5000	0	0	0
7	Source 4	Destination 2	30000	3	90000	0
8	Source 4	Destination 3	20000	2	40000	0
	Total	Objective	Function	Value =	340000	

Fig. 44. The current solution

4.) We attempt to study the effect of the variation of a certain unitary transportation cost on the optimum transportation programme and the afferent total cost.

We start from the initial problem and we suppose that in order to perform transportation from Facility 2 to Warehouse 2 there are several routes that may be used in one month or another, according to the programme of routes repair and refurbishment. The possible changes of route have a direct effect on the unitary transportation cost taken into consideration (c_{22}).

Starting from the cost of route (S1, D4), i.e. : c_{22} =2, one takes into consideration the optimum solution previously determined and recalculate it.

From the *Solve and Analyze* menu, we select the *Perform What-If Analysis* option, which results in the opening of a dialogue window (fig.45), in which one will specify the elements that change.

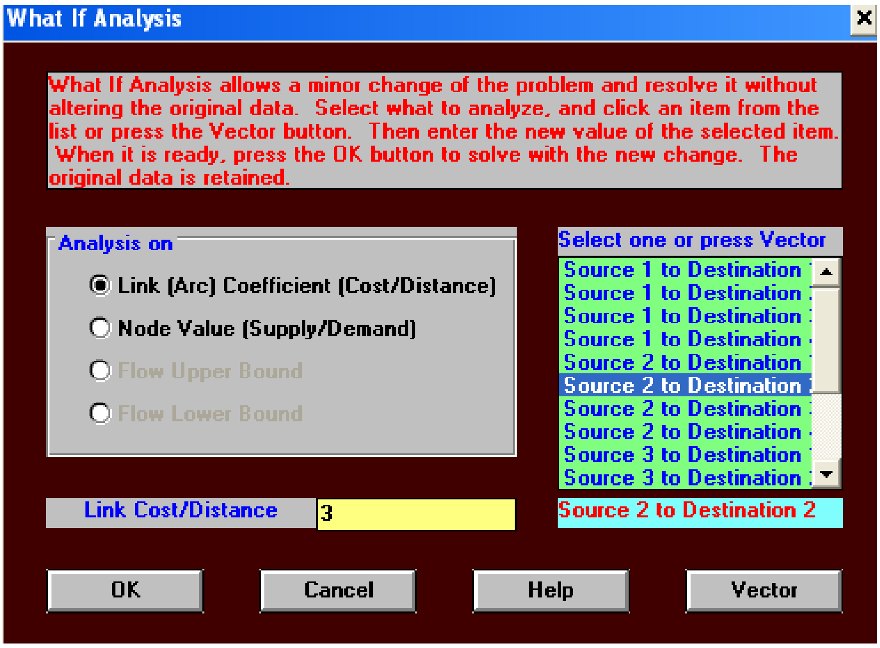


Fig. 45. The dialogue window *What-If Analysis*

If the unitary transportation cost from Facility 2 and Warehouse 2 increase by a monetary unit, we get the same optimum transportation programme, but with a different total cost of 310.000 m.u. (fig.46).

From	To	Shipment	Unit Cost	Total Cost	Reduced Cost
Source 1	Destination 4	40000	2	80000	0
Source 1	Unused_Supply	15000	0	0	0
Source 2	Destination 2	30000	3	90000	0
Source 2	Unused_Supply	10000	0	0	0
Source 3	Destination 1	20000	2	40000	0
Source 3	Unused_Supply	5000	0	0	0
Source 4	Destination 3	50000	2	100000	0
Total	Objective	Function	Value =	310000	

Fig. 46.

The unitary transportation cost from Facility 2 to Warehouse 2 increases by 2 m.u.
As a result of the doubling of the transportation cost from Facility 2 to Warehouse 2, the total transportation cost will rise by 60,000 m.u., becoming 340,000 m.u., and the quantities to be transported also change (fig.47) as follows:

- Facility 1 continues to supply only Warehouse 4 by 40,000 product pieces.
- Facility 2 now supplies Warehouse 3 with 30,000 pcs.
- Facility 3 also supplies Warehouse 1, with 20,000 pcs.
- Facility 4 continues to supply Warehouse 3, with 20,000 pcs., but also provide 30,000 pcs. for Warehouse 2.
- The fictitious warehouse covers the rest of the demand, i.e. 30,000 pcs. as follows: 15,000 pcs. received from Facility 1, 10,000 pcs. from Facility 2, and the rest of 5,000 pcs. from Facility 3.

From	To	Shipment	Unit Cost	Total Cost	Reduced Cost
Source 1	Destination 4	40000	2	80000	0
Source 1	Unused_Supply	15000	0	0	0
Source 2	Destination 3	30000	3	90000	0
Source 2	Unused_Supply	10000	0	0	0
Source 3	Destination 1	20000	2	40000	0
Source 3	Unused_Supply	5000	0	0	0
Source 4	Destination 2	30000	3	90000	0
Source 4	Destination 3	20000	2	40000	0
Total	Objective	Function	Value =	340000	

Fig. 47. The optimum transportation programme

Questions:

1. Which are the specific methods to solve the main solution?
2. Which is the difference between these methods?
3. Which are the calculation methods to achieve the main solution?
4. What represents degeneration in the case of transport problems?
5. How is possible to eliminate degeneration from the a transport problem?
6. What is the procedure in the case of an unbalanced asignation problem?
7. Which module of the WinQSB software has to be used in order to solve a transport problem? But in the case of an asignation problem?

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Module M10

Proactive Maintenance and Continuous Improvement

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Learning objectives:
⇒ Learn what Proactive Maintenance is all about ⇒ Understand preventive and predictive maintenance ⇒ Understand maintenance, repair and operations ⇒ Learn the FRACAS model ⇒ Understand Reliability centered Maintenance (RCM) ⇒ Understand continuous improvement ⇒ Learn the tools of continuous improvement

1.1. What is Proactive Maintenance?

The four terms reactive, preventive, predictive, and proactive are possibly the most widely used words in maintenance today. What do these terms mean? How do they relate to each other?

From a basic point of view there are two maintenance approaches. One approach is reactive and the other is proactive. In practice there are combinations of the basic approaches.
The reactive system responds to a work request or identified need, usually production identified, and depends on rapid response measures if effective. The goals of this approach are to reduce response time to a minimum (with computer aid) and to reduce equipment down time to an acceptable level. This is the approach used by most operations today. It may well incorporate what is termed as a preventive maintenance program and may use proactive technologies.
The proactive approach responds primarily to equipment assessment and predictive procedures. The overwhelming majority of corrective, preventive, and modification work is generated internally in the maintenance function as a result of inspections and predictive procedures. The goals of this method are continuous equipment performance to established specifications, maintenance of productive capacity, and continuous improvement.

Predictive and preventive methods are out: proactive maintenance are in. Why? Because proactive maintenance methods are currently saving industries of all sizes thousands, even millions, of dollars on machine maintenance every year. According to some specialists, “maintenance is the largest single controllable expenditure in a plant.” In many companies it often exceeds annual net profit.

The problem of costly maintenance has truly reached a serious level, but as some companies have found out, and more come to realize every day, their maintenance costs can be cut drastically by establishing a “proactive” line of defense.

Getting to the Root of the Problem
When it comes to the life of any machine, cleanliness counts. Laboratory and field tests show that more than any other factor, fluid contamination is the number one culprit of equipment failure - even the most microscopic particles can eventually grind a machine to a halt. Yet, the accepted methods currently being used to combat machine damage are based on either detecting the warning signs of failure once they’ve already begun (predictive) or regular maintenance according to a schedule rather than the machine’s true condition (preventive). No discipline has previously taken a micro view on machine damage - concentrating on the causes instead of the symptoms of wear. Proactive maintenance is that discipline, and it is quickly being recognized worldwide as the single most important means of achieving savings unsurpassed by conventional maintenance techniques.

Maintenance Strategy	**Technique Needed**	**Human Body Parallel**
Proactive Maintenance	Monitoring and correction of failing root causes, e.g., contamination	Cholesterol and blood pressure monitoring with diet control
Predictive Maintenance	Monitoring of vibration, heat, alignment, wear dibris	Detection of heart disease using EKG or ultrasonics
Preventive Maintenance	Periodic component replacement	By-pass or transplant surgery
Breakdown Maintenance	Large maintenance budget	Heart attack or stroke

Fig.1.1. Proactive, predictive, preventive and breakdown maintenance

Proactive vs. Preventive/Predictive
Proactive maintenance commissions corrective actions aimed at he sources of failure. It is designed to extend the life of mechanical machinery as opposed to 1) making repairs when often nothing is broken, 2) accommodating failure as routine and normal, and 3) preempting crisis failure maintenance - all of which are characteristics of the predictive/preventive disciplines.
Proactive maintenance is a maintenance strategy for stabilizing the reliability of machines or equipment. Its central theme involves directing corrective actions aimed at failure root causes, not active failure symptoms, faults, or machine wear conditions.
A typical proactive maintenance regimen involves three steps:

- (1) setting a quantifiable target or standard relating to a root cause of concern (e.g., a target fluid cleanliness level for a lubricant),
- (2) implementing a maintenance program to control the root cause property to within the target level (e.g., routine exclusion or removal of contaminants),
- (3) routine monitoring of the root cause property using a measurement technique (e.g., particle counting) to verify the current level is within the target.

1.2. Preventive maintenance

Preventive maintenance (PM) has the following meanings:

1. The care and servicing by personnel for the purpose of maintaining equipment and facilities in satisfactory operating condition by providing for systematic inspection, detection, and

correction of incipient failures either before they occur or before they develop into major defects.
2. Maintenance, including tests, measurements, adjustments, and parts replacement, performed specifically to prevent faults from occurring.

Preventive maintenance can be described as maintenance of equipment or systems before fault occurs. It can be divided into two **subgroups**:

- Planned maintenance
- and condition-based maintenance.

The main difference of subgroups is determination of maintenance time, or determination of moment when maintenance should be performed.

While preventive maintenance is generally considered to be worthwhile, there are risks such as equipment failure or human error involved when performing preventive maintenance, just as in any maintenance operation. Preventive maintenance as scheduled overhaul or scheduled replacement provides two of the three proactive failure management policies available to the maintenance engineer. Common methods of determining what Preventive (or other) failure management policies should be applied are: OEM recommendations, requirements of codes and legislation within a jurisdiction, what an "expert" thinks ought to be done, or the maintenance that's already done to similar equipment, and most important measured values and performance indications.

In other words:

- Preventive maintenance is conducted to keep equipment working and/or extend the life of the equipment.
- Corrective maintenance, sometimes called "repair," is conducted to get equipment working again.

The primary goal of maintenance is to avoid or mitigate the consequences of failure of equipment. This may be by preventing the failure before it actually occurs which Planned Maintenance and Condition Based Maintenance help to achieve. It is designed to preserve and restore equipment reliability by replacing worn components before they actually fail. Preventive maintenance activities include partial or complete overhauls at specified periods, oil changes, lubrication and so on. In addition, workers can record equipment deterioration so they know to replace or repair worn parts before they cause system failure. The ideal preventive maintenance program would prevent all equipment failure before it occurs.

1.3. Predictive maintenance

Predictive maintenance (**PdM**) techniques help determine the condition of in-service equipment in order to predict when maintenance should be performed. This approach offers cost savings over routine or time-based preventive maintenance, because tasks are performed only when warranted.

The main value of Predicted Maintenance is to allow convenient scheduling of corrective maintenance, and to prevent unexpected equipment failures. By knowing which equipment that needs maintenance, the maintenance work can be better planned (spare parts, people etc.) and what would had been "unplanned stops" are transformed to shorter and less "planned stops" thus increasing plant availability. Other values are increased equipment life time, increased plant safety, less accidents with negative impact on environment, an optimised spare parts handling, etc.

PdM attempts to evaluate the condition of equipment by performing periodic or continuous equipment condition monitoring. The ultimate goal of PdM is to perform maintenance at a scheduled point in time when the maintenance activity is most cost-effective and before the equipment loses performance within a threshold. This is in contrast to time- and/or operation count-based maintenance, where a piece of equipment gets maintained whether it needs it or not. Time-based maintenance is labor intensive, ineffective in identifying problems that develop between scheduled inspections, and is not cost-effective.

The "predictive" component of predictive maintenance stems from the goal of predicting the future trend of the equipment's condition. This approach uses principles of statistical process control to determine at what point in the future maintenance activities will be appropriate.

Most PdM inspections are performed while equipment is in service, thereby minimizing disruption of normal system operations. Adoption of PdM can result in substantial cost savings and higher system reliability.

Reliability-centered maintenance, or RCM, emphasizes the use of predictive maintenance (PdM) techniques in addition to traditional preventive measures. When properly implemented, RCM provides companies with a tool for achieving lowest asset Net Present Costs (NPC) for a given level of performance and risk.

One area that many times is overlooked is how to, in an efficient way, transfer the PdM data to a Computerized Maintenance Management System (CMMS) system so that the equipment condition data is sent to the right equipment object in the CMMS system in order to trigger maintenace planning, execution and reporting. Unless this is achieved, the PdM solution is of limited value, at least if the PdM solution is implemented on a medium to large size plant with tens of thousands pieces of equipment.

1.4. Maintenance, repair, and operations

Maintenance, repair, and operations (**MRO**) or **Maintenance, Repair and Overhaul** involves fixing any sort of device when it become out of order or broken (known as repair, unscheduled or casualty maintenance). MRO may be defined as all actions which have the objective of retaining or restoring an item in or to a state in which it can perform its required function. The actions include the combination of all technical and corresponding administrative, managerial, and supervision actions.

MRO operations can be categorised by whether the product remains the property of the customer, i.e. a service is being offered, or whether the product is bought by the reprocessing organisation and sold to any customer wishing to make the purchase.

The former of these represents a closed loop supply chain and usually has the scope of maintenance, repair or overhaul of the product. The latter of the categorisations is an open loop supply chain and is typified by refurbishment and remanufacture. The main characteristic of the closed loop system is that the demand for a product is matched with the supply of a used product. Neglecting asset write-offs and exceptional activities the total population of the product between the customer and the service provider remains constant

In engineering in general, the term maintenance has the following meanings:

1. Any activity – such as tests, measurements, replacements, adjustments and repairs — intended to retain or restore a functional unit in or to a specified state in which the unit can perform its required functions.
2. For material — all action taken to retain material in a serviceable condition or to restore it to serviceability. It includes inspection, testing, servicing, classification as to serviceability, repair, rebuilding, and reclamation.
3. For material — all supply and repair action taken to keep a force in condition to carry out its mission.
4. For material — the routine recurring work required to keep a facility (plant, building, structure, ground facility, utility system, or other real property) in such condition that it may be continuously used, at its original or designed capacity and efficiency for its intended purpose.

Manufacturers and Industrial Supply Companies often refer to MRO as opposed/aside to Original Equipment Manufacture (OEM). OEM includes any activity related to the direct manufacture of goods, where MRO refers to any maintenance and repair activity to keep a manufacturing plant running.

MRO software

In many organizations, especially because of the number of devices or products that need to be maintained or the complexity of systems, there is a need to manage the information with software packages. This is a must in case of aerospace (e.g. airline fleets), military installations, large plants (e.g. manufacturing, power generation, petrochemical) and ships.

These software tools help engineers and technicians in increasing the system availability and reducing costs and repair times as well as reducing material supply time and increasing material availability by improving supply chain communication.

As MRO involves working with an organization's products, resources, suppliers and customers, MRO packages have to interface with many enterprise business software systems (ERP, SCM, CRM etc.).

One of the functions of such software is the configuration of bills of materials or BOMs, taking the component parts list from engineering (eBOM) and manufacturing (mBOM) and updating it from "as delivered" through "as maintained" to "as used".

Another function is project planning logistics, for example identifying the critical path on the list of tasks to be carried out (inspection, diagnosis, locate/order parts and service) to calculate turnaround times (TAT).

Other tasks that software can perform:

- Planning operations,
- Managing execution of events,
- Management of assets (parts, tools and equipment inventories),
- Knowledge-base data on:
    - Maintenance service history,
    - Serial numbered parts,
    - Reliability data: MTBF (Mean Time Between Failures), MTTB (Mean Time To Breakdown), MTBR (Mean Time Between Repairs),
    - Maintenance and repair documentation and best practices,
    - Warranty/guarantee documents.

As maintenance evolves from "breakdown" fixes to proactive strategies, managers are beginning to rethink maintenance in an enterprise – even entrepreneurial – manner. In addition to internally converting to proactive maintenance strategies, manufacturers are leveraging their intellectual property assets to deliver maintenance services to customers.

1.5. FRACAS Model

How good is your organization at identifying failures? Of course you see failures when they occur, but can you identify when recurring failures are creating serious equipment reliability issues?

Failure Reporting Analysis and Corrective Action System (FRACAS) is an excellent process that can be used to control or eliminate failures. This is a process in which you identify any reports from your CMMS or a specialized Reliability Software that can help you to eliminate, mitigate or control failures. These reports could include cost variance, MTBF, MTBR, dominant failure patterns in your operation, common threads between failures.

Many times, the cost of unreliability remains unknown because the causes of unreliability are so many. Whether you want to point the finger at maintenance, production (operations) or engineering, each functional area plays a role in unreliability. Here are a few examples of those losses:

1. Equipment Breakdown (total functional failure)
   Causes of Equipment Breakdown:

1. No Repeatable Effective Repair, Preventive Maintenance, Lubrication, or Predictive Maintenance Procedure
2. No one following effective procedures

2 Equipment not running to rate (partial functional failure)

Causes of Equipment not Running to Rate:

1. Operator not having an effective procedure to follow
2. Operator not trained to operate or troubleshoot equipment
3. Management thinking this is the best rate at which the equipment can operate because of age or condition

3. Off-Quality Product that is identified as "first pass quality" (could be a partial or total functional failure)

Causes of Quality Issues:

1. Acceptance by management that "first pass quality" is not a loss because the product can be recycled

4. Premature Equipment Breakdown

Ineffective or no commissioning procedures. We are talking about maintenance replacement of parts or equipment and engineering/contractor that fails prematurely because no one has identified if a defect is present after the equipment has been installed, repaired, serviced, etc.

The Proactive Workflow Model

Eliminating unreliability is a continuous improvement process much like the Proactive Work Flow Model in Figure 1.2. The Proactive Workflow Model illustrates the steps required in order to move from a reactive to a proactive maintenance program.

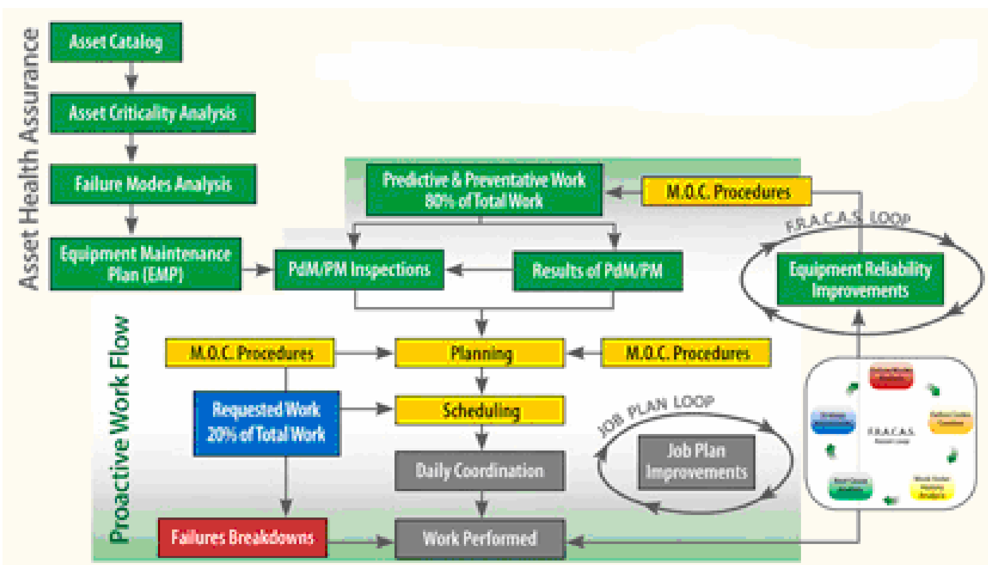

Fig. 1.2. The Proactive Workflow Model

The built-in continuous improvement processes of Job Plan Improvement and the Failure Reporting, Analysis, and Corrective Action System (FRACAS) help ensure that maintainability and reliability are always improving. All of the steps and processes have to be implemented in a well managed and controlled fashion to get full value out of the model.

You cannot have continuous improvement until you have a repeatable, disciplined process. The objective of the Proactive Work Flow Model is to provide discipline and repeatability to maintenance process. The inclusion of the FRACAS provides **continuous improvement** for maintenance strategies.

As you have failures, you use your CMMS failure codes to record the part-defect-cause of each failure. Analyzing part-defect-cause on critical assets helps you begin to make serious improvement in your operation's reliability. Looking at the FRACAS Model in figure 1.3, it begin with Work Order History Analysis, and from this analysis we decide whether we need to apply Root Cause Analysis (RCA), Reliability Centered Maintenance, or Failure Modes and Effect Analysis to eliminate or reduce the failures we discover. From the RCA, we can determine maintenance strategy adjustments needed to predict or prevent failures. Even the most thorough analysis doesn't uncover every failure mode. Performance monitoring after we make the strategy adjustments may find that new failure modes not covered by your strategy occur. You can now make a new failure code to track the new failure mode so additional failures can be tracked and managed when you review work order history. You can see this is a continuous improvement loop which never ends.

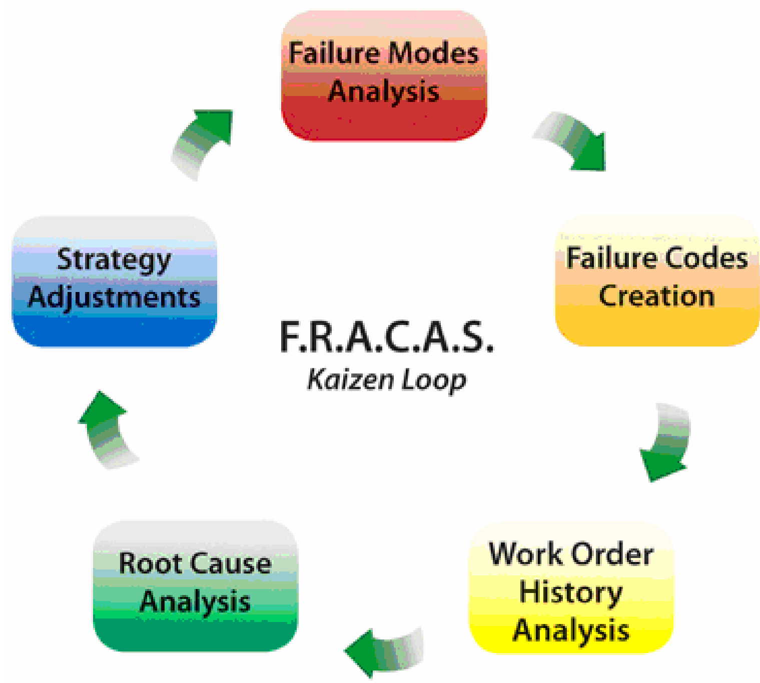

Fig. 1.3. FRACAS model

The foundational elements of an effective FRACAS are an effective validated equipment hierarchy, criticality analysis, failure modes analysis, and equipment maintenance plans.

FRACAS Checklist:

- ⇒ Equipment Hierarchy should be built and validated so that similar failures on like equipment can be identified across an organization.
- ⇒ Criticality Analysis is developed and validated so that equipment criticality is ranked based on Production Throughput, Asset Utilization, Cost, Environment, and Safety.
- ⇒ Failure Modes Analysis is completed on all critical equipment using FMA, FMEA, or RCM.
- ⇒ Equipment Maintenance Plans are developed on all critical equipment to prevent or predict a failure.

1.6. Reliability Centered Maintenance (RCM)

To effectively manage and optimize the preventive maintenance program, a streamlined RCM approach should be taken. The goal is to develop a process that reduces the need for technical involvement in maintaining and improving the implemented maintenance program.

RCM looks at a failure mode and prevention strategy at an equipment type level and applies different factors based on the functional location where the equipment is installed. For instance, a motor might have ten different failure modes and six different predictive/preventive maintenance tasks intended to monitor or prevent those failures from occurring. However, some functional locations where the motor might be installed will have no effect on the plant operations if a failure occurs. In these instances, it is more cost effective to run the motor until a failure occurs and not invest in its prevention. In a different functional location, the failure might constitute a single point of failure vulnerability for plant operation. In this case, almost any preventive/predictive maintenance that can be performed to prevent a functional failure is cost effective.

To develop the RCM process, the following **steps** were taken:

1. Prioritize the plant components by functional location. Criticality is normally broken down into three categories (five in a nuclear environment). In other words, by the impact the failure of the equipment would have on the plant:

- The first and highest is "critical" meaning that a failure at the functional location involves a single point of failure that could bring the unit off-line.
- The second is "important" meaning that the functional location is critical to the operation of the unit but a backup or other strategy exists such that a functional failure does not immediately bring the unit offline but significantly reduces the safety margin leading to the unit coming off-line.
- The third is typically "run to failure" meaning that a failure does not affect plant operation and can be dealt with in a scheduled fashion.

2. For each piece of equipment identified as Critical or Important, develop a list of significant failure mechanisms. Both manufacturer and industry information will be useful in the development of this list. For each vendor recommended PM activity, a failure mechanism should be clearly delineated. Once all of the maintenance strategies have been developed and applied to functional locations, all PMs should be tied to a maintenance strategy. Any PMs that are left over at that point should be evaluated as to why they should be kept.

3. For each Critical component, a time-based PM is designed to prevent each identified failure mechanism. The initial frequency will be based on manufacturer recommendations or regulatory requirements. After a period of operation, age-exploration will be used to optimize the PM frequencies.

The implementation of a Reliability Centered Maintenance program begins with a solid and practical Preventive Maintenance (PM) program. To adopt a RCM approach, the PM program needs to be dynamic, not remain static. In other words, as more knowledge of the individual equipment is obtained, change the frequency of performance (or change to a condition based initiation) to optimize the benefits of performing the PM. During the testing for the development of the RCM philosophy, it was determined that performing PMs too often contributed to failures. When the frequency was decreased, random failures decreased also.

4. For each Important component, Condition Monitoring is used to determine when PM activities are needed to be performed. The Condition Monitoring uses metrics designed to determine degradation that could lead to the significant failure mechanisms for the Location.

5. No PM program is used for the Run-to-Failure components. Since these components have no discernible impact to the facility if failure occurs, the maintenance strategy is to wait until failure to perform maintenance. Even if there are signs of degradation, do not perturb the schedule of maintenance on more significant items, allow the component to fail prior to performing work.

6. Mechanisms are implemented in the Work Order process to allow the technicians to be aware of the design function of the components and the justification for the PMs and frequencies. Their feedbacks on the Work Orders are solicited to allow changes to the program based on the personnel most familiar the equipment.

Toolpouch Maintenance

To support the Maintenance program, a reduced Total Productive Maintenance process has been combined with the RCM process. Plant operators are authorized and trained to perform "tool-

pouch" maintenance activities as they are identified. Toolpouch Maintenance is the process for performing work that does not require pre-planning. It is important to capture the cost (material and labor hours) and fact the work was completed. Toolpouch maintenance is simple in nature, within the basic understanding and training of the personnel.
The purpose of the Toolpouch Maintenance process is to:

- Allow maintenance on items that have little or no impact on plant operations or personnel safety without detailed work packages.
- Document work performed, after the completion, for certain qualifying types of maintenance.
- Minimize the backlog of low significance work awaiting implementation.
- Allows the trending of impact on costs for simple issues.

RCM components
There are four major components of the Reliability Centered Maintenance program: Reactive Maintenance (Corrective Maintenance), Preventive Maintenance, Predictive Maintenance (Condition Monitoring), and Proactive Maintenance (see figure 1.4).

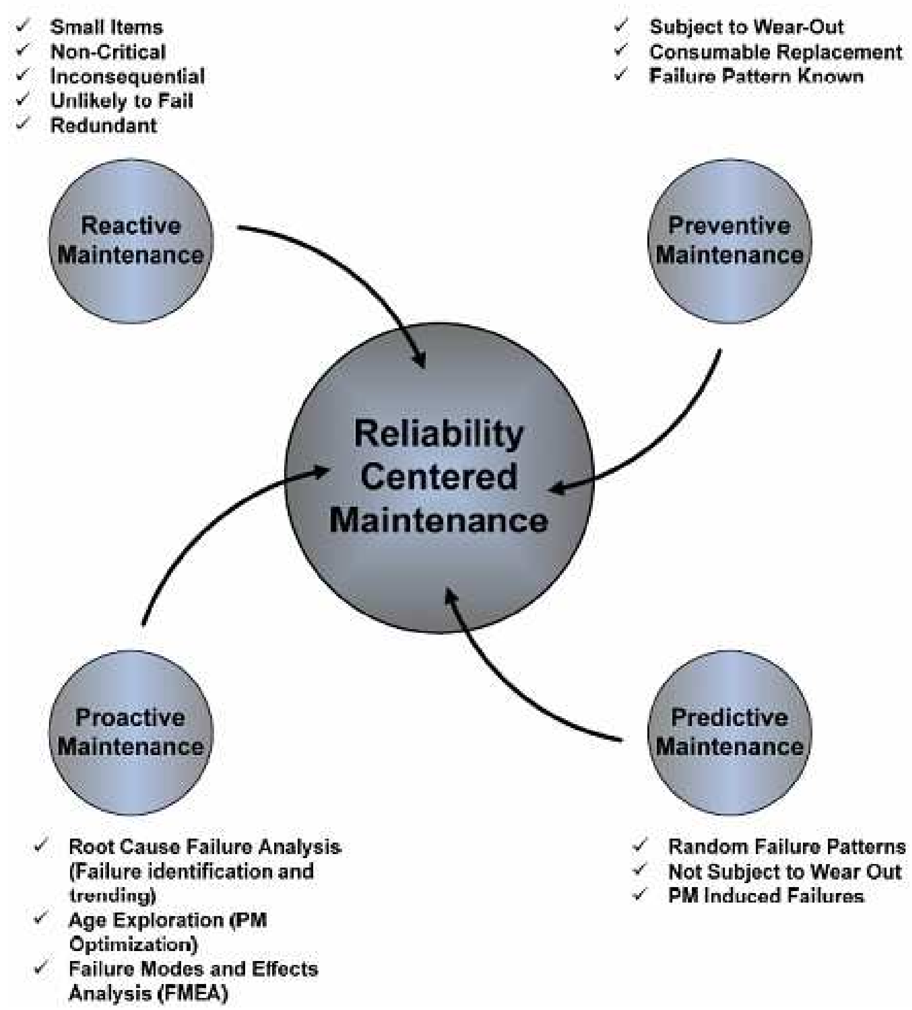

Fig.1.4. RCM components

Reactive Maintenance will occasionally have to be implemented on a piece of equipment that is not inconsequential, but overall the goal is to detect degradation before it occurs and implementing preventive maintenance to prevent the unexpected failure. When the program is implemented well, it is common for reactive maintenance to only account for 10 to 20 percent of the total maintenance performed. When combined with reduced numbers of Preventive Maintenance activities, these results in a more efficient, effective, and cost saving maintenance program.

1.7. The Barriers

Let’s look at a few barriers which prevent a plant from obtaining a higher level of reliability of their assets

1. Most maintenance departments and production only understand that a failure means the equipment is broken. A true failure of an asset is when it is no one longer meets the function required of it at some known rate of standard.

Example: Conveyor is supposed to operate at 200 meters per minute so when the conveyor’s speed is no longer meeting this requirement it has functionally failed thus causing an immediate loss of revenue for the company.

2. Maintenance does not get involved when quality or production rate issues arise in the plant. In most cases when an asset has functionally failed in a plant no one in maintenance seems to understand the equipment has failed.

3. Most maintenance departments do not know the performance targets of the plant equipment and do not understand why it is important that they understand them. This not a failure of the maintenance department but a breakdown of how a total is not aligned to meet the goals of it.

Overcoming of these barriers is essential to rapid performance in reliability. If an understanding and focus on functional failure is applied by all plant personnel rapid results will follow resulting in higher asset reliability. The focus must be on the alignment of the total plant on meeting performance targets of each asset. These performance targets and current performance rates need to be posted so everyone is aware if a gap occurs in asset performance. Production and maintenance know that when an asset has functionally failed (no longer meeting the performance target) and is probably resulting in lost revenue. We must understand this is a production and management problem and both organizations must accept responsibilities for actions to mitigate the performance losses.

One requirement a company must meet in order to have a rapid breakthrough in performance is they must define what a failure is truly:

Old definition of failure (typically reactive): The equipment is broken or stopped. A good example is the conveyor stopped because of mechanical problem

New definition of failure (typically proactive): The equipment is no longer performing the function required of its user.

Examples would be:

Partial Functional Failure Example: A conveyor is supposed to operate at 200 meters per minute however because of a problem it can only run 160 meters per minute.

Total Functional Failure Example: A conveyor has stopped based on a mechanical problem.

The function of the example conveyor is:

1. To transfer a product from point A to point B;
2. To transport product at a speed of 200 meters per minute.

The Bottom Line

A company must take a step back and review the way it manages equipment performance. If equipment continues to fail after performing preventive maintenance or overhauls, then clearly a change is needed. The focus must be on ensuring the reliability of plant assets. As a starting point, everyone in a plant should understand the definition of reliability and what it means to the success of the company.

2. Continuous Improvement

2.1. Introduction

Continuous improvement in a management context means a never-ending effort to expose and eliminate root causes of problems. Usually, it involves many incremental or small-step improvements rather than one overwhelming innovation. From a Japanese perspective continuous improvement is the basis for their business culture. Continuous improvement is a philosophy, permeating the Japanese culture, which seeks to improve all factors related to the transformation process (converting inputs into outputs) on an ongoing basis. It involves everyone, management and labor, in finding and eliminating waste in machinery, labor, materials and production methods.
The Japanese word for continuous improvement, *kaizen,* is often used interchangeably with the term *continuous improvement.* From the Japanese character *kai,* meaning change, and the character *zen*, meaning good, taken literally, it means *improvement.*
Although kaizen is a Japanese concept, many firms have adopted it with considerable success by combining the best of traditional Japanese practices with the strengths of their business practice, in other words, by merging the benefits of teamwork with the creativity of the individual. Some refer to its implementation as lean manufacturing since, when combined with the principles of just-in-time (JIT), kaizen or continuous improvement forms the foundation for the concept of lean manufacturing.

2.2. History of continuous improvement

Following the defeat of Japan in World War II, America wanted to encourage the nation to rebuild. As with the Marshall Plan in Europe, General MacArthur asked a number of leading experts from the U.S. to visit Japan and advise them on how to proceed with the rebuilding process. As history would have it, one of these experts was Dr. W. Edwards Deming. Deming was a statistician with experience in census work, so he came to Japan to set up a census. While in Japan, he noticed some of the difficulties being experienced by some of the newly emerging industries. Many Japanese manufacturers were faced with huge difficulties stemming from a lack of investment funds, raw materials, and components, and from the low morale of the nation and the workforce. Based on his recent experience in reducing waste in U.S. war manufacture, he began to offer his advice.
By the mid-1950s, he was a regular visitor to Japan. He taught Japanese businesses to concentrate their attention on processes rather than results; concentrate the efforts of everyone in the organization on continually improving imperfection at every stage of the process. By the 1970s many Japanese organizations had embraced Deming's advice and were very quickly enjoying the benefits of their actions. Most notable is the Toyota Production System, which spawned several business improvement practices utilized heavily in Japan, including JIT and Total Quality Management (TQM).
Despite the fact that much of the foundation of continuous management and other Japanese concepts originated in the U.S., the firms showed little interest until the late 1970s and early 1980s. By then the success of Japanese companies caused other firms to begin to reexamine their own approaches. Hence, kaizen or continuous management began to emerge in the U.S. concurrent along with the increasing popularity and use of Japanese techniques such as JIT and TQM. In fact, continuous improvement is a major principle of and a goal of JIT, while it is one of the two elements of TQM (the other is customer satisfaction). In some organizations, quality circles have evolved into continuous improvement teams with considerably more authority and empowerment than is typically given to quality circles. In fact, management consultants have tended to use the term *kaizen* to embrace a wide range of management practices primarily regarded as Japanese and

responsible for making Japanese companies strong in the areas of continual improvement rather than innovation.

2.3. Kaizen needs necessary for implementation

Most Japanese people are, by nature or by training, very attentive to detail and feel obligated to make sure everything runs as smoothly as possible, whether at work or at home. This attitude enhances the functionality of kaizen. Thus, to encourage the kaizen attitude, organizations require a major change in corporate culture; one that admits problems, encourages a collaborative attitude to solving these problems, delegates responsibility and promotes continuous training in skills and development attitudes.

The driving force behind kaizen is dissatisfaction with the *status quo,* no matter how good the firm is perceived to be. Standing still will allow the competition to overtake and pass any complacent firm. The founder of Honda has been quoted as saying, "In a race competing for a split second, one time length on the finish line will decide whether you are a winner or a loser. If you understand that, you cannot disregard even the smallest improvement." Although continuous improvement involves making incremental changes that may not be highly visible in the short term, they can lead to significant contributions in the long term.

Organizational performance can improve from knowledge gained through experience. Lessons learned from mistakes mean those mistakes are less likely to be repeated, while successes encourage workers to try the same thing again or continue to try new things. While this learning process occurs throughout the system it is particularly important for accomplishing the long-term improvement associated with continuous improvement. In order for continuous improvement to be successful, the organization must learn from past experience and translate this learning into improved performance.

Part of the learning process is trying new approaches, exploring new methods and testing new ideas for improving the various processes. So experimentation can be an important part of this organizational learning. Naturally, many of these worker-led experiments will fail, so it is important to recognize that there is some risk associated with this experimentation. If management is uncomfortable with risk, it may be reluctant to allow any real degree of experimentation. Obviously, management cannot risk disabling the production process itself or endanger the well-being of the workforce, but the complete absence of risk can reduce the vision of those involved in the continuous improvement process. Improvements will generally come in modest increments of progress. Therefore, management must recognize that some experiments will fail as part of the learning process, and avoid the temptation to harshly judge the perpetrator as having new but unsuccessful ideas. Some even feel that it is critical to establish an environment that reinforces the notion that risk is good. Again, this involves consistency in management's attitude toward change and the empowerment of employees.

The achievement of continuous improvement requires a long-term view and the support of top management. But it is also important that all levels of management actively support and become involved in the process. Proper support structures of training, management, resource allocation, measurement, and reward and incentive systems must be in place for successful adoption. This includes a willingness to provide financial support and to recognize achievements. It is desirable to formulate goals with the workers' help, publicize the goals, and document the accomplishments. These goals give the workers something tangible to strive for, with the recognition helping to maintain worker interest and morale.

Kaizen also requires that all employees in the organization be involved in the process. Every employee must be motivated to accept kaizen as a means by which the firm can achieve a competitive advantage in the marketplace. All involved must push continuously at the margins of their expertise, trying to be better than before in every area. Japanese companies have been very successful with the use of teams composed of workers and managers. These teams routinely work

together on problem solving. Moreover, the workers are encouraged to report problems and potential problems to the teams; their input is as important as that of management. In order to establish a problem-solving orientation, workers should receive extensive training in statistical process control, quality improvement, and problem solving.
Problem solving is the driving force behind continuous improvement. Workers can be trained to spot problems that interrupt, or have the potential to interrupt, the smooth flow of work through the system. When such problems do occur, it is important to resolve them quickly. Also, workers are trained to seek improvements in the areas of inventory reduction, set-up time and cost reduction, increasing output rate, and generally decreasing waste and inefficiency.

2.4. Benefits of Kaizen

The benefits of continuous improvement manifest themselves in numerous ways.
Exanple: in an August 2004 article, Perry Flint examined how American Airlines' Tulsa MRO base has seen dramatic improvements after implementing continuous improvement initiatives. The base is the largest such facility in the world with some 8,000 employees and 3 million square feet of docks and shops across 300 acres. Continuous Improvement teams in their components and avionics shop have helped reduce $1.5 million in inventory requirements while freeing 11,600 sq. ft. of shop space; repairing broken cargo door torque tubes in lieu of purchasing a new replacement has resulted in a savings of $250,000 per year; turnaround times for overhauls have improved more than 38 percent, and replacing parts only as needed has resulted in a savings of $100,000.
These improvements have been made possible through employee and union buy-in, the creation of employee-led work teams, and the realized benefits, after implementation, of employee-recommended improvements and streamlined procedures. The employee-driven improvements are integral to the success of the Continuous Improvement process. The changes are not force-fed by management, thus the employees are less resistant to the changes and recognize the necessity and value in implementing these alternative methods.
Through kaizen or continuous improvement, firms are able to produce better products and services at lower prices, thus providing greater customer satisfaction. In the long term, the final product will be more reliable, of better quality, more advanced, cheaper and more attractive to customers.

2.5. Implementation of Kaizen Strategy

Seven Conditions for Successful Implementation of Kaizen Strategy

1. Top management commitment
2. Top management commitment
3. Top management commitment
4. Setting up an organization dedicated to promote Kaizen
5. Appointing the best available personnel to manage the Kaizen process
6. Conducting training and education
7. Establishing a step-by-step process for Kaizen introduction.

All conditions are important. Without top management supporting every move, however, the trial will be short-lived regardless of other preconditions.
Top management may express commitment in many different ways, and it must take every opportunity to preach the message, become personally involved in following up the progress of Kaizen, and allocate resources for successful implementation.
One of the most difficult aspects of introducing and implementing Kaizen strategy is assuring its continuity.
When a company introduces something new, such as quality circles, or total quality management (TQM), it experiences some initial success, but soon such success disappear like fireworks on

summer night and after a while nothing is left, and management keeps looking for a new flavor of the month.
This if because the company lacks the first three most important conditions for the successful introduction and implementation of Kaizen strategy.

Quick and Easy Kaizen
Quick and Easy Kaizen (or Mini-Kaizen) is aimed at increasing productivity, quality, and worker satisfaction, all from a very grassroots level. Every company employee is encouraged to come up with ideas – however small – that could improve his/her particular job activity, job environment or any company process for that matter. The employees are also encouraged to implement their ideas as small changes can be done by the worker him or herself with very little investment of time.
Quick and easy Kaizen helps eliminate or reduce wastes, promotes personal growth of employees and the company, provides guidance for employees, and serves as a barometer of leadership. Each kaizen may be small, but the cumulative effect can be tremendous.

2.6. Continuous Improvement Tools

Within the business environment, Japan has contributed greatly to the language of business with numerous concepts that represent continuous improvement tools (*kaizen tools*) and with production philosophies such as *just-in-time*.
Here it is important to remark first about a contribution from Henry Ford. In 1926, Henry Ford wrote: To standardize a method is to choose out of the many methods the best one, and use it. Standardization means nothing unless it means standardizing upward.
Today's standardization, instead of being a barricade against improvement, is the necessary foundation on which tomorrow's improvement will be based.
You must think of ''standardization'' as the best that you know today, but which is to be improved tomorrow—you get somewhere. If you think of standards as confining, then progress stops.
Creating a usable and meaningful standard is key to the success of any enterprise. It is not the solution but is the target on which change can be focused. Using this standard, businesses usually use two different kinds of improvements: those that suppose a revolution in the way of working and those that suppose smaller benefits with less investment that are also very important.
In production systems, evolutionary as well as revolutionary change is supported through product and process innovations, as is shown in figure 2.1.

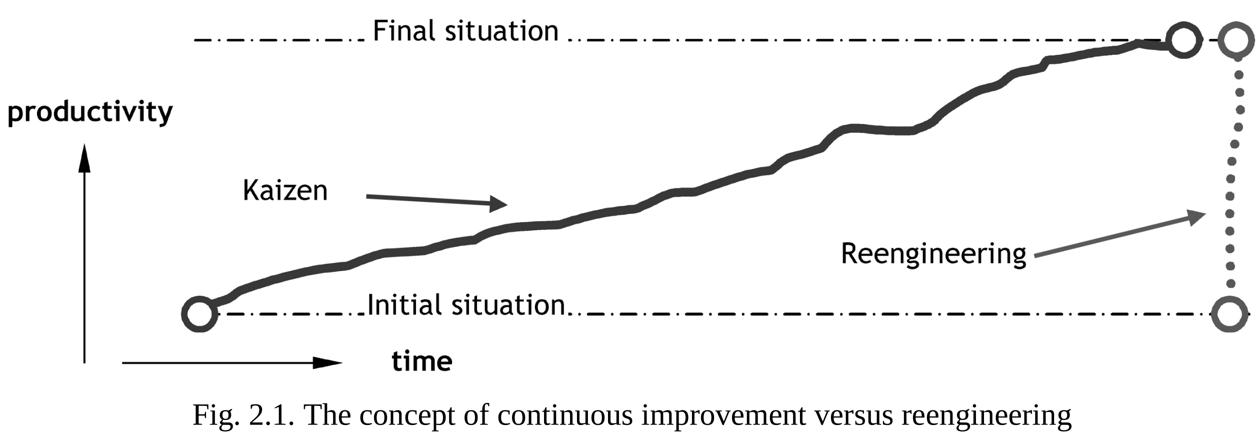

Fig. 2.1. The concept of continuous improvement versus reengineering

The evolution consists of continuous improvements being made in both the product and the process. A rapid and radical change process is sometimes used as a precursor to *kaizen* activities. This radical change is referred to as *kaikaku* in Japanese. These revolutions are carried out by the use of methodologies such as process reengineering and a major product redesign. These kinds of

innovations require large investments and are based, in many cases, on process automation. These radical activities frequently are called *kaizen blitzes*.
If the process is being improved constantly, as shown in figure 2.2 (continuous line), the innovation effort required to make a major change can be reduced, and this is what *kaizen* does (dotted line on the left).

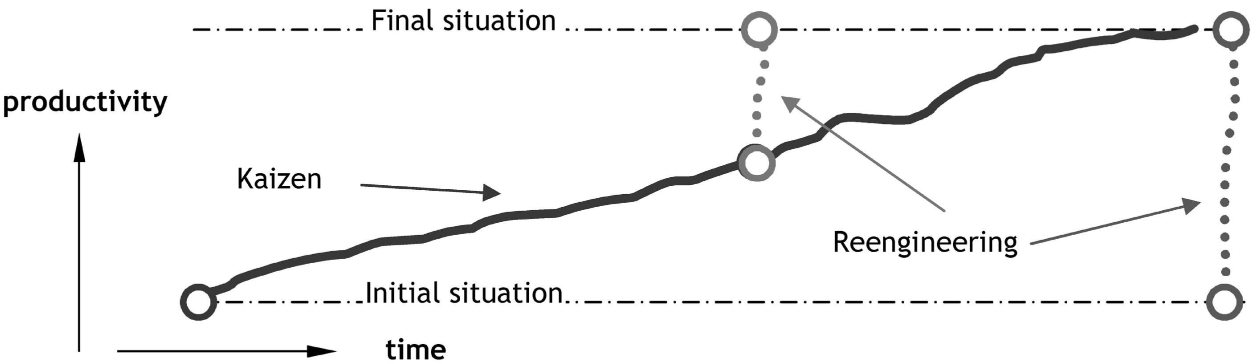

Fig. 2.2. Continuous change can offset the expense and time required for radical changes.

While some companies focus on meeting standards, small improvements still can be made in order to reduce these expensive innovation processes. Hence innovation processes and *kaizen* are extremely important. Otherwise, the process of reengineering to reach the final situation can become very expensive (dotted line on the right).

Improvement philosophies and methodologies
In order to improve (quality, cost, and time) production activities, it is necessary to know the source of a factory's problem(s). However, in order to find the factory's problem, it is important to define and understand the source and core of the problem. Here it is critical to note that variability in both quality and productivity are considered major problems.
Any deviation from the standard value of a variable (quality and production rate) presents a problem. It is necessary to know what the variable objective is (desired standard) and what the starting situation (present situation) is in order to propose a realistic objective. There are three main factors that production managers fear most: (1) poor quality, (2) an increase in production cost, and (3) an increase in lead time.
These three factors are signs of poor production management. Production improvements should be based on improvements to processes and operations. In a production area, problems can appear in any of the basic elements that constitute the area.
Some problems, just to list a few examples, are defects, obsolete work methods, energy waste, poorly coached workers, and low rates of performance in machines and materials. By analyzing the production management history, several improvement approaches can be identified.
Two known improvement approaches will be presented briefly here: *just-in-time* and the *20 keys to workplace improvement*.

JUST-IN-TIME (JIT)
In accordance with this philosophical principle, nothing is manufactured until it is demanded, fulfilling customer requirements: ''I need it today, not yesterday, not tomorrow.''
The plant flexibility required to respond to this kind of demand is total and is never fully obtained. Today, it is critical that inventory is minimized. This is especially critical because product obsolescence can make in-process and finished goods inventories worthless.
In 1949, Toyota was on the brink of bankruptcy, whereas in the United States (thanks to Henry Ford's invention), Ford's car production was at least eight times more efficient than Toyota's. The president of Toyota, Kiichiro Toyoda, presented a challenge to the members of his executive team: ''To achieve the same rate of production as the United States in three years.''

Taiichi Ohno, vice president of Toyota, accepted his challenge and, inspired by the way that an American supermarket works, ‘‘invented’’ the JIT method.
The goal: ‘‘Deliver the right material, in the exact quantity, with perfect quality, in the right place just before it is needed.’’ To achieve this goal, they developed different methodologies that improved the production of the business. The main methodologies are illustrated in figure 2.3.

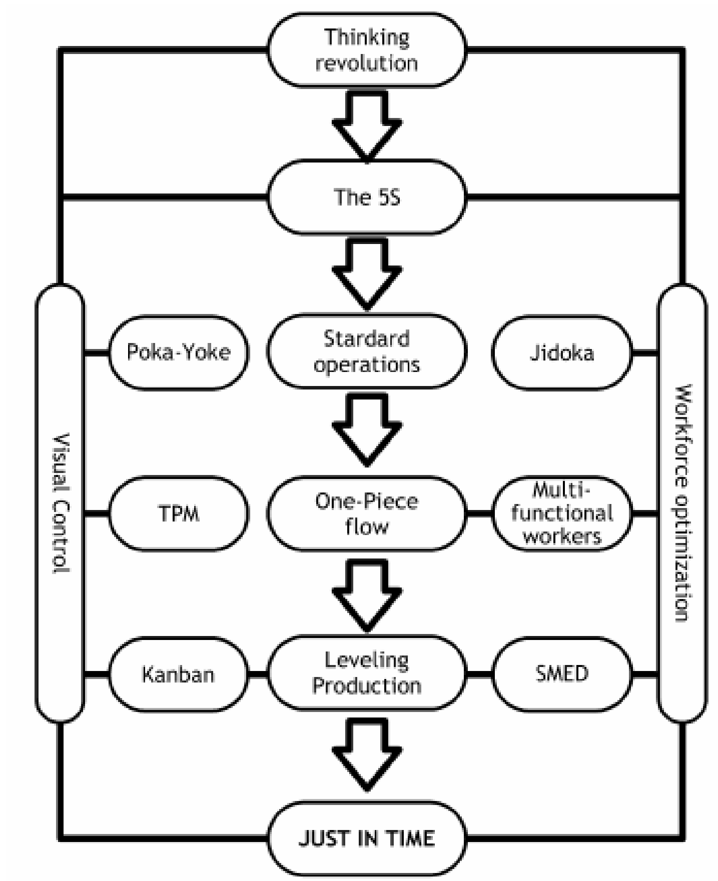

Fig. 2.3. Just-in-time thinking principles.

It is important to point out that, in the figure, JIT appears as a result of several methodologies being applied, not as the beginning of a different production philosophy.
The systematic application of all the methodologies that JIT gathered created a new management philosophy. The real value that JIT brings into the business is the knowledge acquired during its implementation.
However, all these principles are not always applicable, and in several firms, some methodologies are unnecessary or even impossible to implement.
The philosophy developed at Toyota was not accepted until the end of the 1960s. Japan in 1973 benefited from the petroleum crisis and started to export fuel-efficient cars to the United States. The automobile industry in the United States decreased the cost of production and vehicle quality, but it was already too late to recover much of the automobile market.

Thinking Revolution
In the years when the JIT philosophy was being developed, the Western world employed the following formula to obtain the price of a product: Price = cost + profit
In this formula, if the cost increases, the best way to maintain the same profit is by raising the price while maintaining the same added value in the product.
Japan, mainly at Toyota, employed the following expression: Profit = price – cost.

In this case, if the market fixes the price of a car, the only way to obtain profit is by reducing the cost. Today, this formula is used worldwide, but many years ago it was a revolutionary way of managing a company.
In order to make sure that Toyota would work like a supermarket filled with perishable goods that cannot be held too long, a new philosophy was adopted. When a product is withdrawn, the system must be able to replace it in a short period of time so that the system will not ‘‘starve.’’ To accomplish this, it was necessary to identify and eliminate in a systematic way all business and production wastes.

Seven Types of Waste

Hiroyuki Hirano defined *waste* as ‘‘everything that is not absolutely essential.’’ This definition supposes that few operations are safe from elimination, and this is essentially what has happened. He also defined *work* as ‘‘any task that adds value to the product.’’ Toyota’s factories outside Japan required between 5 to 10 times more operations to produce the same car as its Japanese factories. The elimination of waste and the decrease in production inefficiencies rapidly convinced managers that this philosophy was going to be successful. In conclusion, it was possible to realize the goal by changing work methods instead of attempting to do the operations at a faster speed.
Shigeo Shingo identified seven main wastes common to factories:

• *Overproduction.* Producing unnecessary products when they are not needed and in a greater quantities than required.

• *Inventory.* Material stored as raw material, work-in-process, and final products.

• *Transportation.* Material handling between internal sections.

• *Defects.* Irregular products that interfere with productivity, stopping the flow of high-quality products.

• *Processes.* Tasks accepted as necessary.

• *Operations.* Not all operations add value to the product.

• *Inactivities.* Machines with idle time or operators with idle time.

Of all these types of waste, inventory waste is considered to have the greatest impact. Inventory is a sign of an ill factory because it hides the problems instead of resolving them.
For example, in a factory, in order to cope with the problem of poor process quality, the size of production lots typically is increased. As a consequence, products that probably will never be used get stored. If the problem that produces the low quality is solved, inventory could be reduced without affecting service.
Sometimes, because of resistance to change, the inventory level does not decrease after the improvement. In such cases it will be necessary to force a decrease in inventory.
In addition, holding cost (the cost to carry a product in inventory) frequently is underestimated. The maintenance and repair costs of the inventory equipment or material handling elements are not usually considered.

Lean Manufacturing

Basically, *lean manufacturing* is the systematic elimination of waste.
As the name implies, *lean* is focused on cutting ‘‘fat’’ from production activities. *Lean* also has been applied successfully to administrative and engineering activities.
Lean manufacturing is one way to define Toyota’s production system. Another definition that describes lean manufacturing is *waste-free production*. *Muda* is the term chosen to refer to lean manufacturing. In Japanese, *muda* means waste. Lean manufacturing is supported by three philosophies, JIT, *kaizen* (continuous improvements), and *jidoka*. *Jidoka* is a Japanese word that translates as ‘‘autonomation’’, a form of automation in which machinery automatically inspects each item after producing it, ceasing production and notifying humans if a defect is detected.
Toyota expands the meaning of *jidoka* to include the responsibility of all workers to function similarly, i.e., to check every item produced and to make no more if a defect is detected until the cause of the defect has been identified and corrected.

According to the lean philosophy, the traditional approximations to improve the lead time are based on reducing waste in the activities that add value (AV) to the products, as is shown in figure 2.4.

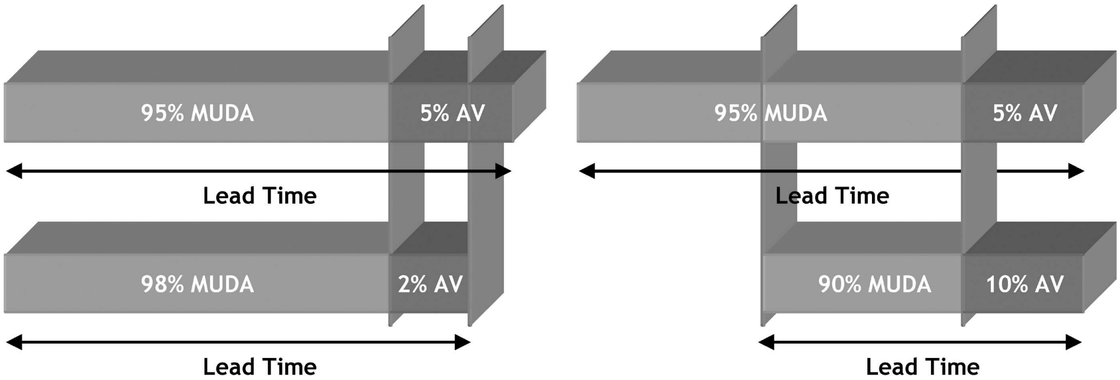

Fig. 2.4. Saving time means eliminating waste.

Lean manufacturing, however, reduces the lead time by eliminating operations that do not add value to the product (*muda*). According to lean manufacturing, lead time should not be 10 times greater than the added-value time (time that adds value to the product), as is shown on the right. When the *lean team* is established, and if the team operates effectively, the most important wastes are detected and eliminated.

20 Keys to Workplace Improvement

Iwao Kobayashi, in 1988 published a book explaining 20 keys to workplace improvement. They all must be considered in order to achieve continuous improvement.

These 20 keys are arranged in a circle (figure 2.6) that shows the relations between the keys and their influence on the three main factors: quality, cost, and lead time. The arrangement in the circle is not categorical, and some keys offer benefits in more than one factor.

There are four keys outside the circle. Three of them (keys 1, 2, and 3) must be implemented before the rest, and key 20 is the result of implementing the other 19 keys.

Kobayashi divided each key into five levels and set some criteria to rise from one level to the next. The first step in the methodology consists of specifying the actual company's current level and then the required level. After figuring out the current level of the company, he offers the steps the company must use to reach the final level gradually rather than attempting to reach the top directly.

On the other hand, to show the evolution of the factory, Kobayashi presents a radar graphic (figure 2.5) in which the scoring of each key is represented.

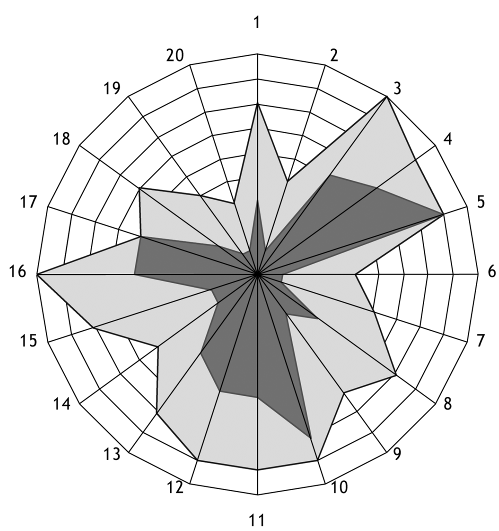

Fig. 2.5. Radar graphic for each factor.

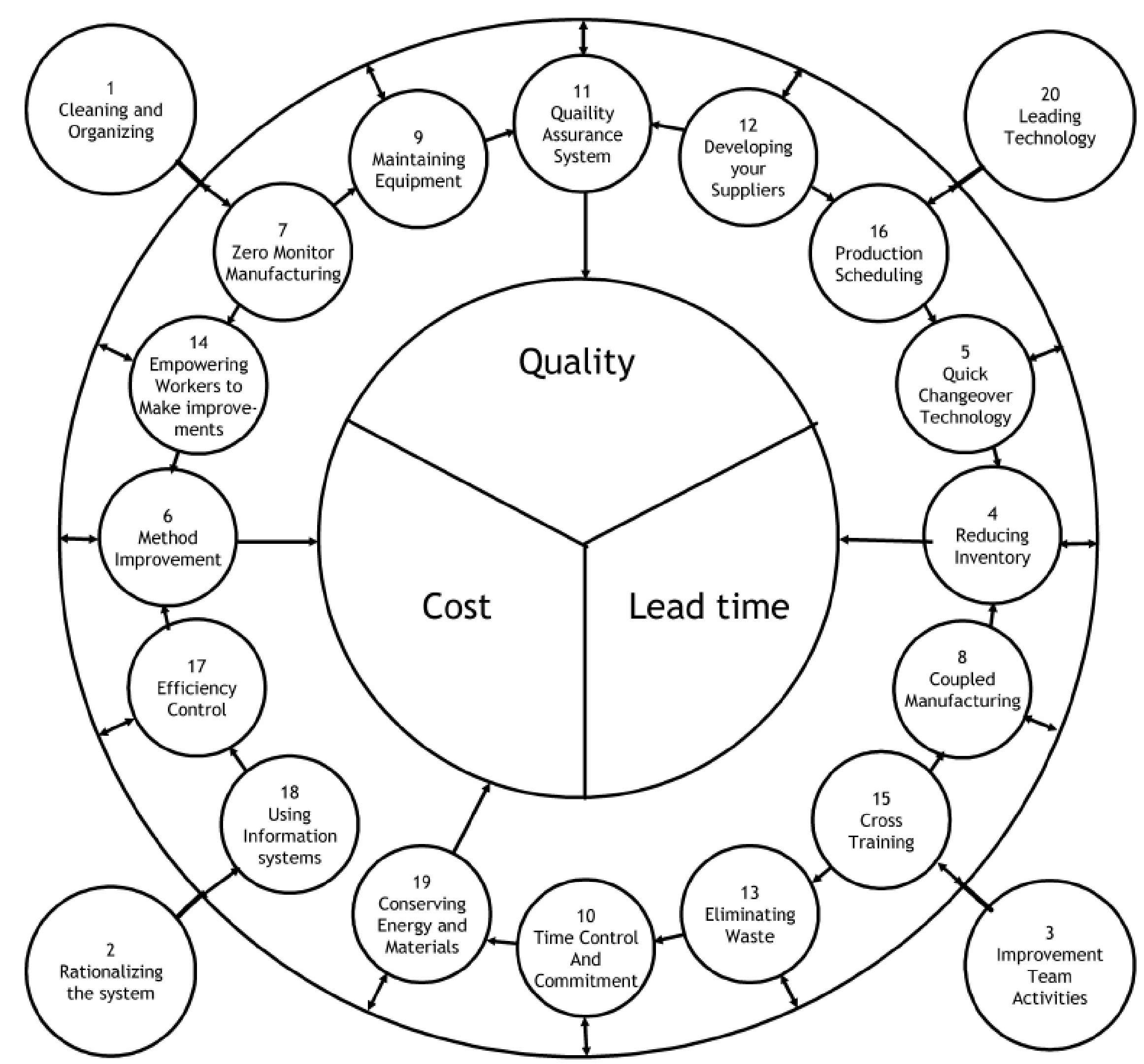

Fig. 2.6. The 20 keys to workplace improvement.

Kobayashi recommends improving all the keys equally. Because of this recommendation, in the radar graphic, the factory's scoring will grow concentrically.

2.7. Six steps to continuous improvement of student learning

According to Dr. Stephane Booth**,** associate provost for AQIP (Academic Quality Improvement Project), there are six steps to continuous improvement. These steps are (see also figure 2.7):

- Identify goals,
- Identify objectives,
- Specify approaches,
- Specify measures,
- Evaluate and share results, and
- Make Changes.

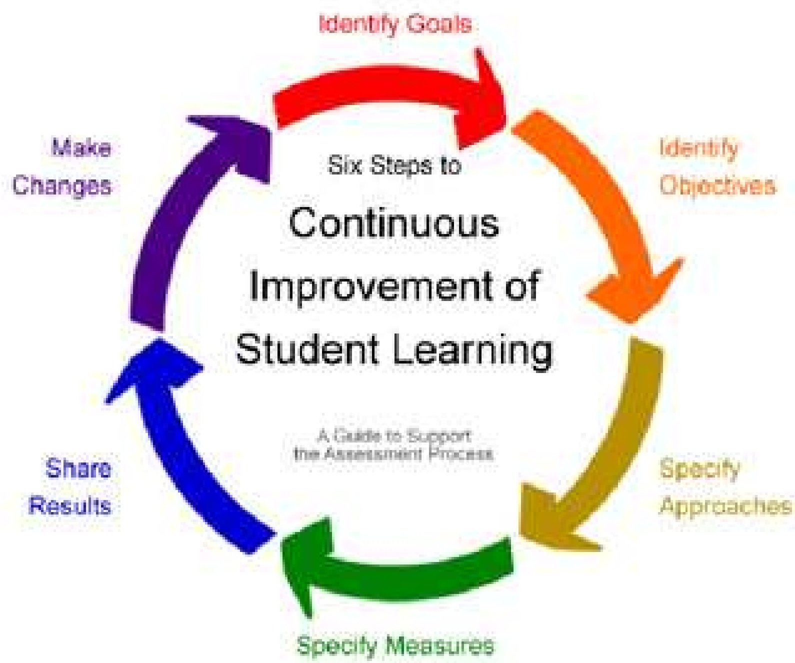

Fig.2.7. AQIP Six steps to continuous improvement of student learning

Thus the six steps to guide an assessment process

1. Identify in broad terms what educational goals are valued
2. Articulate multiple measurable objectives for each goal
3. Select appropriate approaches to assess how well students are meeting the articulated objectives
4. Select appropriate measures that can be administered, analyzed, and interpreted for evidence of student learning outcomes
5. Communicate assessment findings to those involved in the process of assessment
6. Use feedback to make changes and inform curricular decisions and reevaluate the assessment process with the intent to continuously improve the quality of student learning.

These six steps can be applied to different levels or areas of student learning such as that of a program, a major field of study or a course. The steps are useful for programs in academic units that are degree granting as well as for the wide range of programs and processes that influence learning, such as distance learning, library resources or liberal education courses.

Assessment of student learning is important because of three main factors. These are improvement, accountability and accreditation. In regards to (continuous) improvement, AQIP seeks to:

- Engage faculty and staff in self-reflection on learning goals,
- Determine degree to which goals correspond to student and societal needs,
- Evaluate degree to which students' activities, products or performances coincide with expectations set in learning goals,
- Inform students about the knowledge, skills and other attributes they can expect to possess after successfully completing an academic program or co-curricular activity and
- Help academic and student support units understand the dimensions of student learning when seeking to improve student achievement and the educational process.

3. Total Productive Maintenance in the Dynamic Change of Enterprises. The Case of Romanian Enterprises

3.1. Introduction

At this moment, it is very important in certain sectors of Romanian economy to change the organizational structure and to operate according to the complexity of European integrated economy. In the paper, we try to develop a new methodology for practical problems in the electrical power sector and railway transportation. We present the results of our studies for a regional enterprise in electric power maintenance and the change in the organizational and operational projects. Also, for a national railway transportation enterprise, we show the results of implementation of this methodology. The originality value of the paper comes from the changes that have to be done in design, in the development of the project, in management and leadership, to obtain the full efficiency of the system.

The aim here is to demonstrate the importance and the role of Total Productive Maintenance (TPM) in the dynamic change of the Romanian enterprises. This problem is very important in some sectors that have to change in the Romanian global economy when the complexity of work increases, for example in the energetic and electric power systems, railroad stock and transportation.

The authors try to present in what way it is possible to translate the theory and philosophy of TPM into practical strategies that can be applied in any domain of industrial activities.

In the paper, we try to develop a new methodology for practical problems in the sectors and domains of the Romanian enterprises which have to change the operational and functional structure. The example of the two domains (electrical power and transportation), is very important in the new vision of the integration of the Romanian economy in the European economy, where the complexity and performance are very high.

3.2. The approach of maintenance as a management strategic system

The starting point of this paper consists in the classical approach of maintenance as a group of activities which enables the subsystems functioning as long as possible, and, if feasible, not to ever stop production or any service carried out. According to the authors, the systemic approach is essential both in the field of railroad stock in the railway transportation, and mostly in the field of energetic equipment (electric energy production, transportation, and distribution) (refer to figure 3.1).

The system will be approached strategically, first of all with the aim of obtaining performance, and then with the aim of enabling the big system be governed in a collaboration interaction of its sub-systems, so that the strategic and performance indicators aimed at by the MANDANT may be finally recorded in the MANDATE. Thus, the MANDATARIES will be coordinated to obtain a global optimum in interaction (refer to figure 3.2).

Total Productive Maintenance takes into account the premise that an economic-engineering system is both optimum and notable in interaction, when each sub-system which makes it up is, in its turn, optimum notable in interaction. TPM takes into account both the preventive maintenance, and the repair one, either planned or fortuitous, which practically takes place in the energetic field and in that of railroad transportation (refer to figure 3.3). It is essential that the approach of the inspection and intervention time be made in such a way as to obtain that operational and functional optimum in interaction.

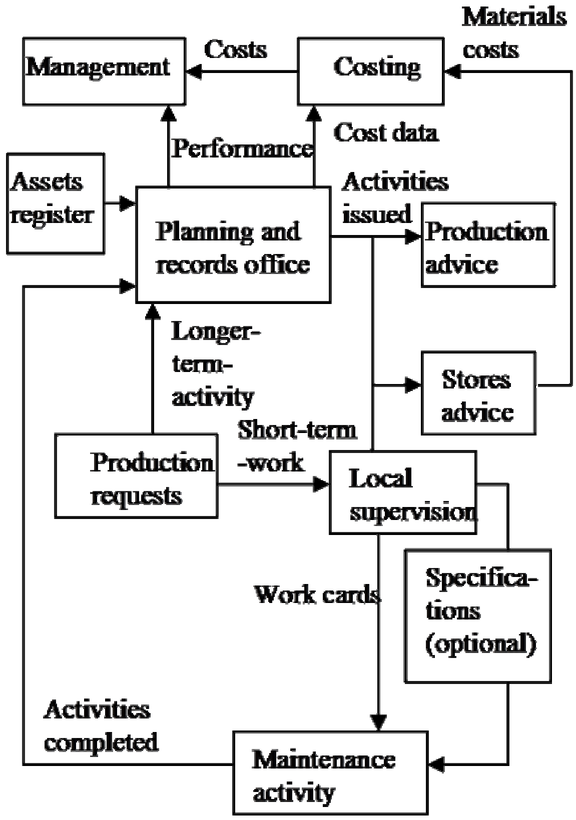

Fig. 3.1: Maintenance management system

Fig. 3.2: Performance, governance and mandatory of maintenance

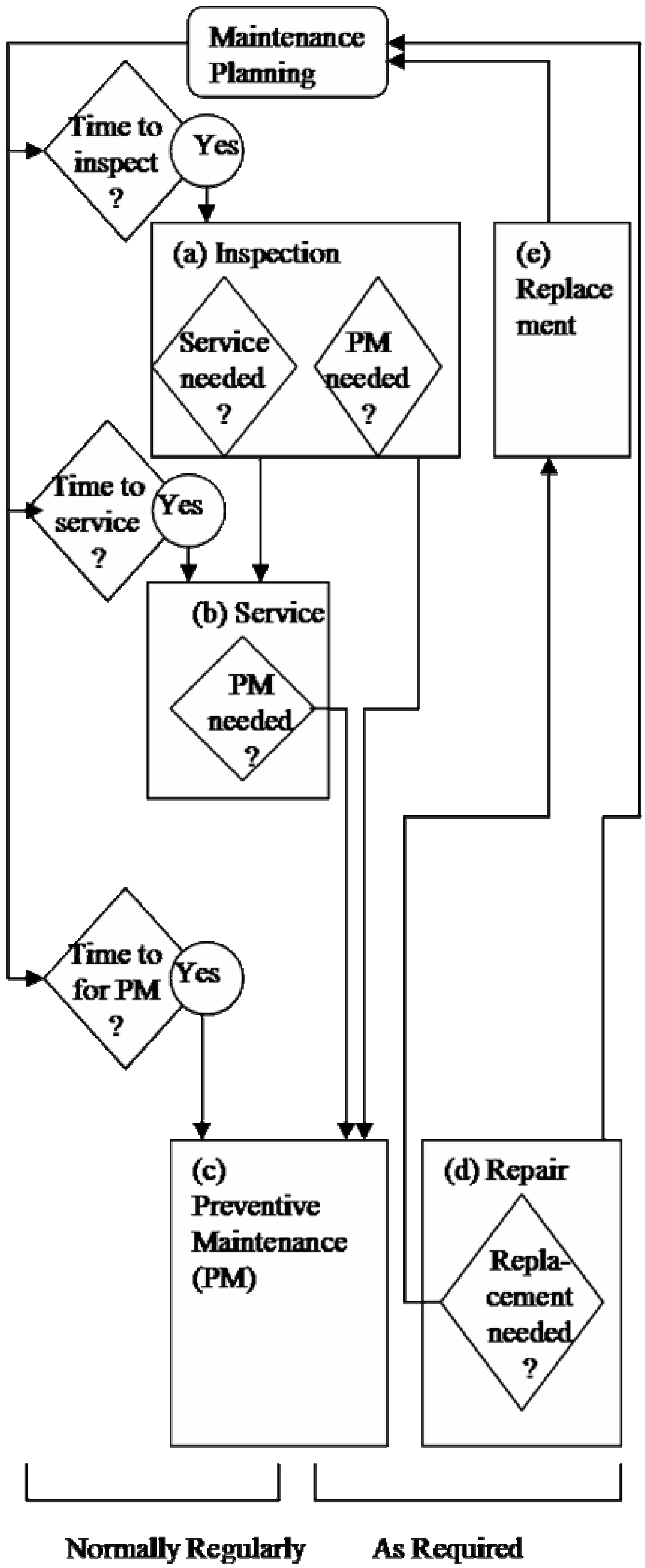

Fig. 3.3: Operational maintenance system

3.3. The methodology of Total Productive Maintenance approach

The methodology provides the drawing up and the design of the maintenance management system within an approach that is logical, coherent, sequential in time and space, so that it may serve in an optimum way the systems in which it operates (the system of electric energy production, transport, and distribution, namely the railroad stock of the railroad transportation).

The integration in the European Union, i.e. the operating standards required by it within the given activity fields, asks for the establishing of an entity responsible with maintenance which will stipulate the way of the maintenance system drawing up and operation. The collaboration and cooperation with the EU will be carried out in agreement, since the maintenance responsible entity (MRE) has no legal power, it proposing certifications and amendments to the directives of railroad safety within the field of electric energy, water, oil, natural gases, etc. production and distribution. We also proposes that this maintenance industry be organized according to documents which define the processes as well as the elements of this industrial structure. Each country will establish the way these MREs fulfill their responsibilities and assume their obligations regarding railroad system maintenance, i.e. the electric systems in our case. First, there have been identified the required processes, as well as their sequence and the interaction between them, and a logigram establishing the maintenance management system operation has been drawn up. The dynamics of the events and activities changing and development within the interactive processes will be a challenge for each organization, firm, enterprise from the maintenance field (refer to figure 3.4).

This logical diagram can be used by any organization which wants to restructure its maintenance management system. Following the identification and the defining of the processes, there will be elaborated the operational procedures needed for the functioning, monitoring, and keeping under control the maintenance system activities. Thus, activities are clearly distributed according to responsibilities, identified regarding the resources, and well defined in time and space. The actual assurance of the maintenance processes development is illustrated in the logogram presented in figure 3.5.

The next stage is represented by the monitoring and the control of the maintenance activities development with a view to identify, in due time, the nonconforming work, and to take the required steps according to the monitoring and control records (refer to figure 3.6).

Practically, the interactive processes within the maintenance system will never stop. They follow up the processes which define continuous improvement (refer to figure 3.7).

Finally, the objectives established for the maintenance system will be measured through the performance indicators of each process. In order to comply with the objectives specificity, reality, opportunity, and tangibility (SMART), the performance indicators shall be defined and chosen as function of each process separately, by accurately following up the achievements, or failures of the process specific activities.

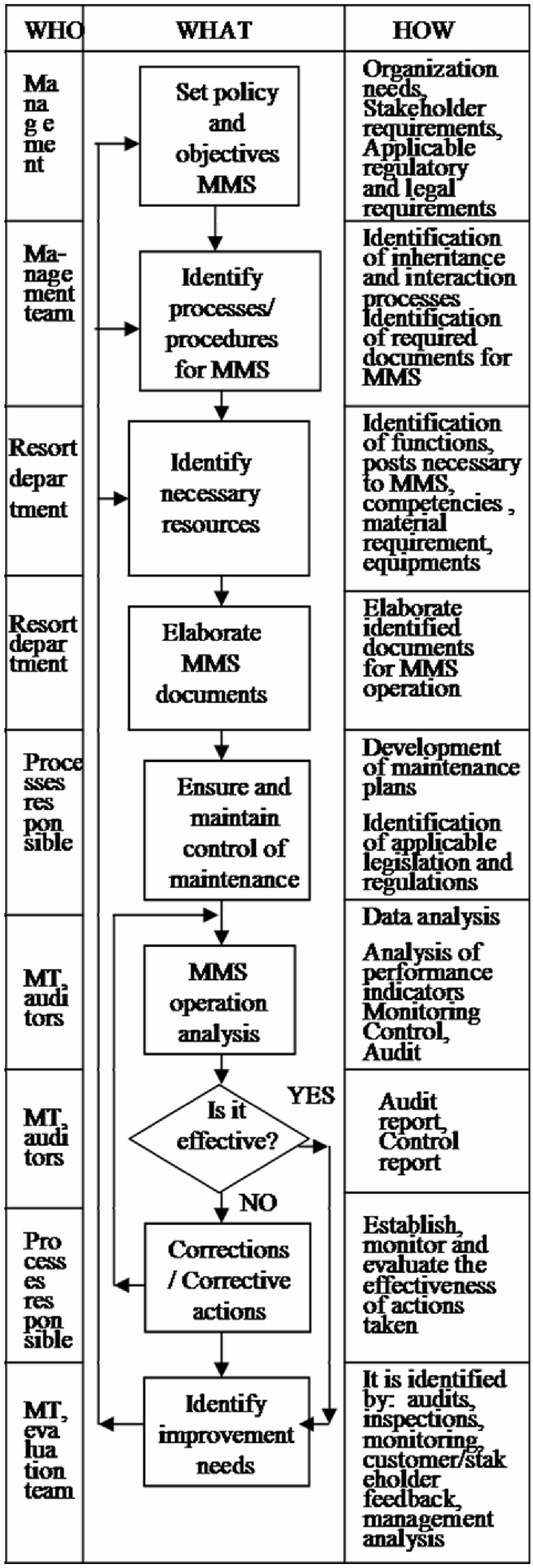

Fig. 3.4: Logical flow charts of maintenance

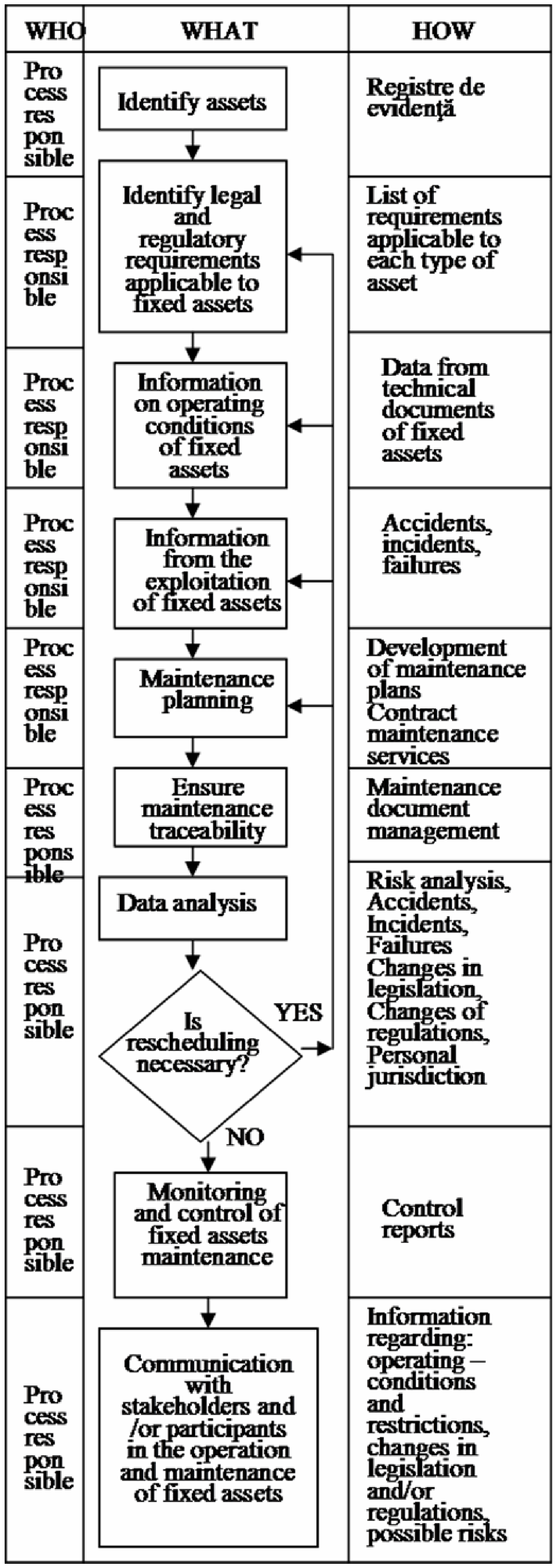

Fig. 3.5: Logical flow charts of maintenance assurance

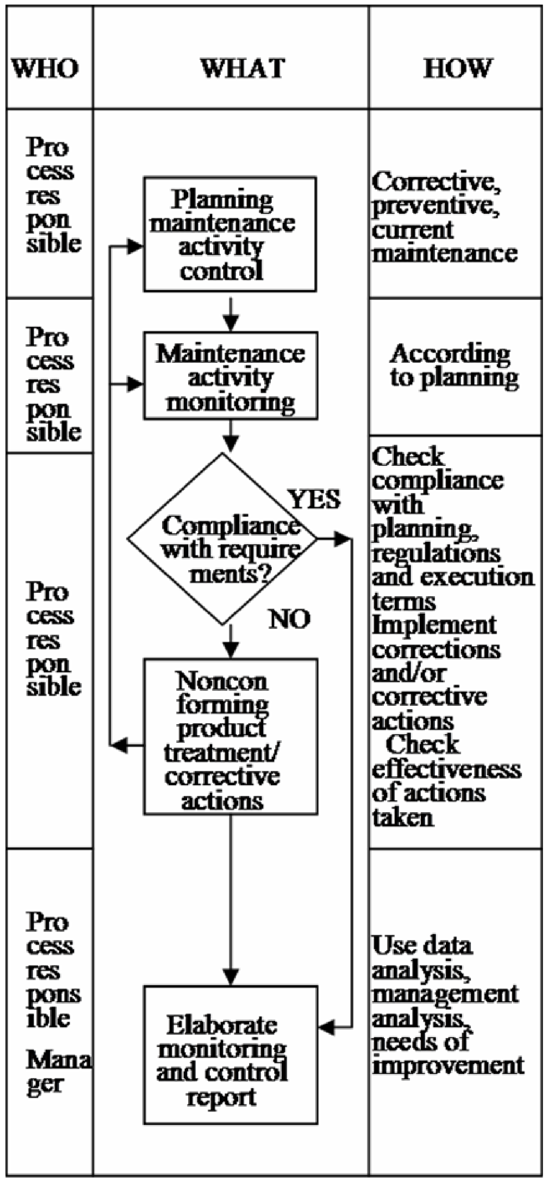

Fig. 3.6: Logical flow charts of monitoring

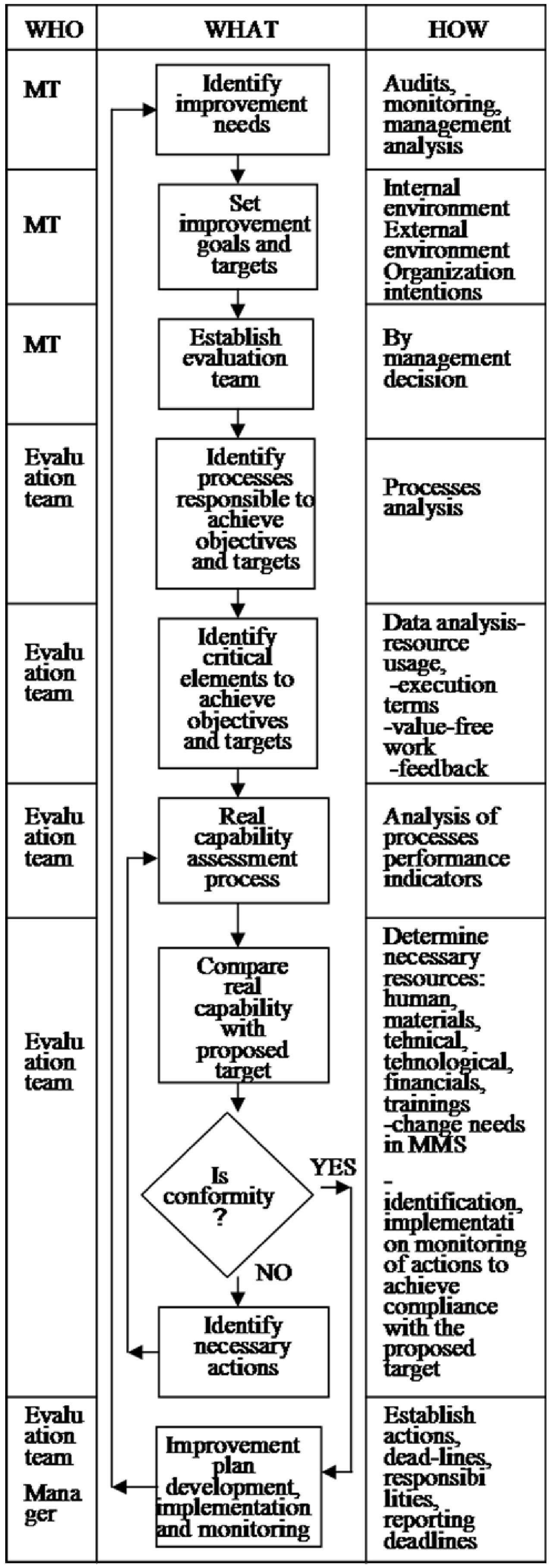

Fig. 3.7: Logical flow charts of continuous process improvement

As regards the studied systems, there have been proposed the following performance indicators of the processes:

Maintenance management process

$$Mean\ time\ of\ good\ function = \frac{time\ in\ operation}{total\ time\ in\ use}$$

Human resources process

$$Personnel\ efficiency = \frac{training\ investment}{turnover}$$

$$Personnel\ fluctuation = \frac{number\ of\ departures}{number\ of\ employees}$$

Maintenance assurance process

$$Maintenance\ efficiency = \frac{maintenance\ cost}{turnover}$$

Contract/Procurement process

$$Procurement\ efficiency = \frac{planned\ response\ time}{achieved\ response\ time}$$

$$Materials\ efficiency = \frac{materials\ processing\ cost}{profit}$$

$$Economic\ efficiency = \frac{planned\ cost}{achieved\ cost}$$

Communication process

$$Time\ /\ response\ efficiency = \frac{planned\ response\ time}{achieved\ response\ time}$$

$$Information\ efficiency = \frac{obtaining\ cost}{profit\ at\ use}$$

Monitoring and control process

$$Monitoring\ efficiency = \frac{planned\ response\ time}{achieved\ response\ time}$$

$$Control\ efficiency = \frac{effects\ on\ profit}{turnover}$$

Continuous improvement process

$$Rate\ of\ complaints = \frac{number\ of\ complaints}{number\ of\ clients}$$

3.4. The dynamics of the organizational change

A successful management of the complexity of the phenomena and processes in the maintenance system within the organizational structures requires the follow up of the fulfillment of all the activities and tasks requested by the processes. A relatively simple example of maintenance system is the system proposed for cleaning with the use of chemical agents and substances (refer to figure 3.8).

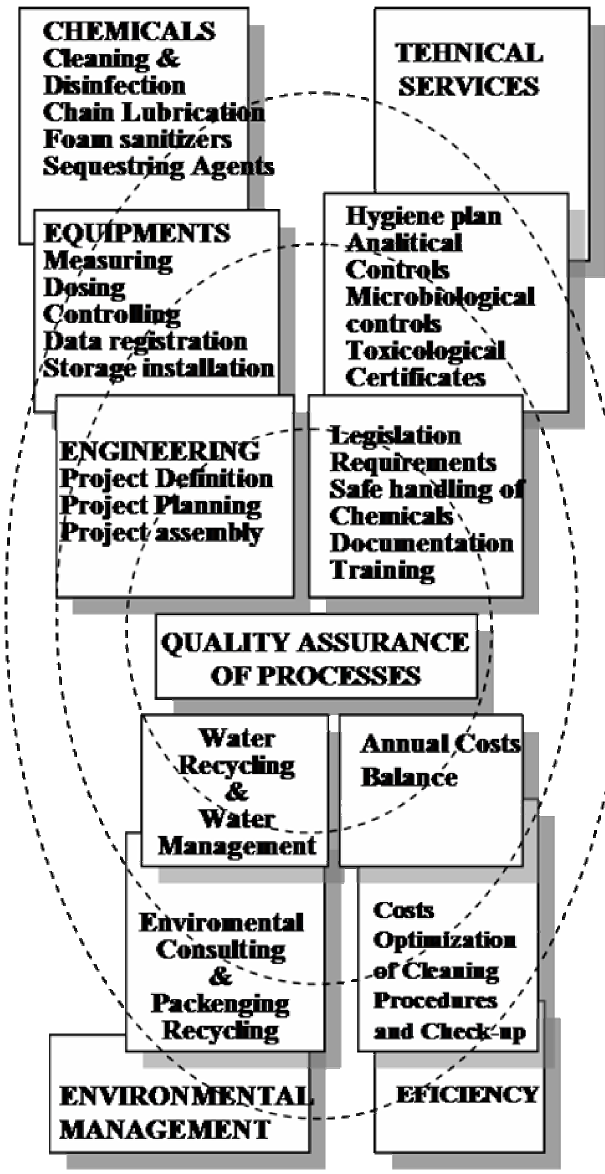

Fig. 3.8: Chemical cleaning maintenance system

The operational grouping of the tasks and activities shall be made according to the activity fields and areas, which finally leads to the processes quality assurance. The performance indicators will be mainly supported by the economic efficiency, namely by the integration within the environment.

In order to meet the requirements and to fulfill the promises, the enterprise organizational structures shall be grouped according to the classical functions: research-development, production, engineering, sales (refer to figure 3.9).

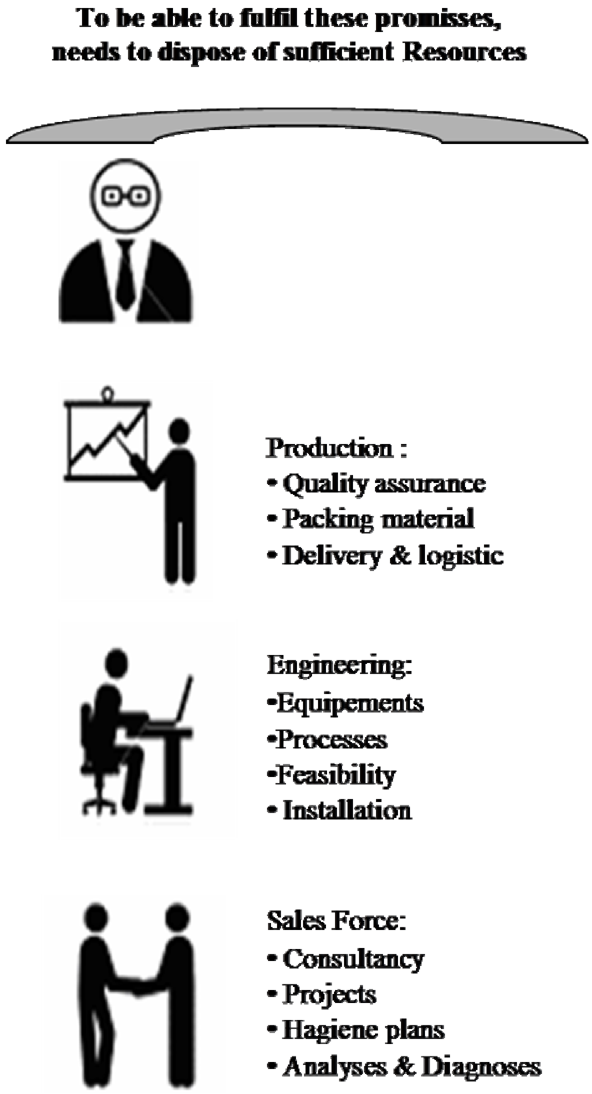

Fig. 3.9: Functional maintenance system

3.5. Conclusions

The originality value of the paper comes from the changes that have to be done in design, in the development of the project, in management and leadership, to obtain the full efficiency of the system.

The system of Total Productive Maintenance goes on, by operationally and functionally materializing the principles of the system of total quality management by using specific methods, techniques, and means. More and more enterprises approach advanced production systems, such as Lean Production, Just in Time, Kanban, Kaisen, implemented within an own philosophy and concept in agreement with the activity field, the industrial branch, and the organization specific culture.

Along with the development of Zero fault, Zero complaints, Full satisfaction at the consumer concepts, there have appeared such systems as Zero break time, Zero halting time, etc.

To pass on to the systems continuous improvement, and to a lasting and sustainable development, there appear more and more frequent implementations of the Six Sigma systems requested by the production complexity and competitiveness level, and by the need to obtain competitive advantages.

The new maintenance enterprises follow up, more and more often, the concepts presented in the paper, under the present externalized conditions of such activities.

The world-wide use and the international character of such systems as those mentioned above, calls for collaboration between enterprises research and production departments and universities and other learning units, which offers theoretical and practical consistency. This paper has benefited by the collaboration with university researchers, production people, and people who currently carry out maintenance activities. Collaboration and cooperation, the exchange of skills and abilities and surveys rendered a wide range of applicability to the results of the research, results that have many permanent updating and continuous improvement facilities.

Questions:
1. What is Proactive Maintenance? Preventive? Predictive? Reactive? **2.** What is MRO? **3.** Explain the FRACAS model? **4.** What is RCM? **5.** What is continuous improvement? **6.** What continuous improvement tools do you know?

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M11 - Key Speaker Session

<u>Theme</u>:
Best Practices in Logistics and Maintenance - A Career Approach

Propose topics:

1. **Erasmus Intensive Programme objectives and contribution to European priorities**
2. **Importance, place and role of Logistics and Maintenance in a industrial system**
3. **History and future**
4. **Actual challenges and trends**
5. **MOST – Mission, Objectives, Strategies, Tactics**
6. **Methods, techniques and tools**
7. **A integrated approach to Logistics and Maintenance**
8. **Internal vs. external**
9. **Career path in Logistics and Maintenance – a SWOT Analysis**
10. **Conclusions and advices, recommendations, suggestions to students**

Main objectives of the Erasmus Intensive Programme

To improve the quality and to increase the volume of student and teaching staff mobility throughout Europe, so as to contribute to the achievement by 2012 of at least 3 million individual participants in student mobility under the Erasmus programme and its predecessor programmes (ERA-OpObj-1);
To improve the quality and to increase the volume of multilateral cooperation between higher education institutions in Europe (ERA-OpObj-2);
To increase the degree of transparency and compatibility between higher education and advanced vocational education qualifications gained in Europe (ERA-OpObj-3);
To improve the quality and to increase the volume of cooperation between higher education institutions and enterprises (ERA-OpObj-4);
To facilitate the development of innovative practices in education and training at tertiary level, and their transfer, including from one participating country to others (ERA-OpObj-5);
To support the development of innovative ICT-based content, services, pedagogies and practice for lifelong learning (ERA-OpObj-6).

Contribution to EUROPEAN PRIORITIES of the Erasmus Intensive Programme

Are part of integrated programmes of study leading to recognised double or joint degrees. (ERA-MobIP-2)
Present a strong multidisciplinary approach. (ERA-MobIP-3)
Focus on subject areas which are currently under-represented in Erasmus student mobility (over-represented areas: business studies, social sciences, arts, humanities, languages, law). (ERA-MobIP-7)

Description of Erasmus Intensive Programme objectives and contribution to European priorities

ERA-OpObj-1

The project will create a frame for internationally teaching and learning in the IP topic bringing together 35 student from 5 different countries and 7 universities, and 9 professors which will teach/work and learn together in an internationally environment with high quality of teaching and teaching materials due to the quality of staff involved in the project, from high quality universities and with excellent conditions available at the UPT site where the IP project will take place.

ERA-OpObj-2

There are 7 universities from 5 countries involved in the IP project that will cooperate, work and learn from each others, exchange good practices in teaching and learning. There exists multiple cooperation agreements between these universities, but after this IP project there will be a common agreement/protocol sign for future cooperation regarding joint educational programmes, common curricula development, improve educational tools and develop of exploratory research.

ERA-OpObj-3

Due to the topic of the IP project, there will be a harmonisation of curricula regarding the support function of logistics and maintenance for industrial systems. This specialisation needs a common qualification across European universities because the challenges of logistics and maintenance are critical in a globalised environment, with higher competition / clients needs and exigencies.

ERA-OpObj-4

The UPT has long and rich experiences in with enterprises and industry and also with Chambers of Commerce, Industry and Agriculture of Timisoara (CCIAT) and other actors and decision factors locally and nationally, for a better development of the specialisations and curricula, to meet the need of industry where the student will work after graduation.

The IP will develop activities in cooperation between HEI and industry as follows: 3 enterprises visits (that have an object of activity related to the topic of IP) with presentation of the current situation and problems from the key personnel in charge of logistics and maintenance, and with comparative case analysis and possible solutions given by the students; 1 key speakers session with invited experts in the field of logistics and maintenance that will present also the current problems and with debates on the theme, brainstorming session for ideas/solutions finding. In this way, both the enterprises key personnel and student/teachers can gain experience from the dialog, ideas exchanges, and best practice sharing in the field.

ERA-OpObj-5

The IP project allows the exchange of good practices in teaching and learning activities at European level, bringing together 7 different universities from 5 countries, each with different innovative practices in education and training, with different teaching materials and educational tools, different approaches to this interdisciplinary topic of the IP project. Each staff/student will bring to their home university the new/different teaching and learning approaches that is not available in a single institution (and will improve the existing teaching and learning situation/conditions).

ERA-OpObj-6
The project will involve ICT-base content by using web-base content, on-line teaching materials and evaluation, using software related to the IP topic in game-base and simulation-base teaching, with new and modern tools. Thus the website platform is available and can be use for lifelong learning before the IP itself (for information regarding the IP) and long after this project (for teaching materials).

ERA-MobIP-2
The IP project directly responds to new European needs regarding harmonisation of the specialisations, diploma and curricula in the IP subject area, that are not unitary across Europe. The project aims to builds a consortium of universities that will implement joint educational programmes, curricular development, improve educational tools/techniques on the IP topic.

ERA-MobIP-3
The project presents a strong multidisciplinary approach due to the modern issue of support function that consist of related and strong connected topics of **internal and external logistics** (every resources used by the companies to make products and/or services that are requested by the customers, activities such as transports, manipulation, flow of materials/products, stocks, inventory, production control, forecasting, planning and scheduling, supply chain management) and **maintenance** (referring at products/equipments availability, maintainability, reliability, accessibility, service, continuous improvement).

ERA-MobIP-7
The IP project focus on subject areas which are currently under-represented in Erasmus student mobility, like industrial engineering, manufacturing and processing and transportation, because address to the support functions of logistics and maintenance in industrial systems.

Project background
The "logistics and maintenance" specialisation need a common qualification across European universities, because this issue problems is critical in an globalised environment, where competitions is higher, clients needs/exigencies has raised very much. Cost reduction in every activity is a must now for industrial system (see current global crises), there is a need for shorter cycle times, due times, terms and deadlines, and support function of logistics and maintenance can fulfill this needs more easily than as separate functions.
In current situation, there is a need for cooperation between universities and industry to better develop of specialisations/curricula to meet industry need where graduated students will work.
This project's preparatory work is based on a previous IP project and consortium formed in 2008, for an IP held at IUT Bethune (Universite d'Artois) in France. The initial consortium includes 5 HEI partners and was enlarged with 2 new HEI from Poland and Slovakia (last one is first time involved in an Erasmus IP projects). The previous IP topic was focused only on "logistics", not enough for a strong supporting function. Experience gain from the previous project leads us to propose the topic of "logistics and maintenance" as an important and unitary support function for industrial systems.

The ties with the existing teaching programmes and innovative character
Due to the topic of the IP project, there will be a harmonisation of curricula regarding the support function of logistics and maintenance for industrial systems, because the issue included in the topic exist disparately and partially in existing specialisations in Europe.
The project presents a strong multidisciplinary approach due to the modern issue of a support function that is **logistics and maintenance**. Thus the IP project will develop a common

European basis on teaching/learning/evaluation/research in the field of logistics and maintenance.
The project will foster the European transnational exchange of knowledge, competence learning and curricula development through an exploratory, innovative and multidisciplinary approach.
An important aspect of the IP project (not possible in another type of projects) is putting the students with different formation and culture in situations of learn and work in mixed teams, assisted by staff with also different universities and countries with different teaching culture and tools, with different teaching pedagogical approach. Each staff/student will bring to their home university the new/different teaching and learning approaching that is not available in a single institution (and will improve the existing teaching and learning situation/conditions).
This specialisation in “logistics and maintenance” doesn’t exist in UPT or in Romania at cycle (BA, MA or PhD), there exist only separate discipline. The integrated/ unitary approach as a support function of logistics and maintenance for industrial systems is new and modern and fulfils actual industry needs. The clear definition and curricula of this qualification will be innovative.

M12

Company Visit Form

LogMain 2011 Timisoara

Company:

1	**2**	**3**

Student Name ____

1. **In what industry the company is positioned?** ___________________________________

2. **Which is the main factor for success of the company?** ___________________________

____

3. **What types of product/services offers?**

   1. _________________________________

   2. _________________________________

   3. _________________________________

4. **Analyze the company's logistics/maintenance using SWOT model:**

S	W
O	T

5. Who are the competitors for this company (intern/international)?

6. What are the strategic moves of the company regarding logistics/maintenance?

7. Other observations?

8. Conclusions?

Guide to take notes:

- *notes must be individual, handwritten*
- *use short and clear sentences*
- *complete all parts of the form*
- *present relevant information and in a concise manner*
- *personal thoughts, remarks and conclusions are expected and appreciated*