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Wrocław University of Technology

Advanced Informatics and Control

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MANUFACTURING CONTROL SYSTEMS

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Preface

The aim of this coursebook is to provide the reader with basic information on the management systems used to control manufacturing processes and plants. Such systems are essential in most of the companies, because nowadays, manufacturing can be extremely sophisticated and challenging issue. The needs of modern society are endless. Products are demanded in amount and variety greater than ever before. They are supposed to be of high quality and are expected to be delivered shortly after the order is placed. It puts great importance on the management and constantly stimulates the research in the area of manufacturing. Therefore, two things have to be emphasized.

First, there is a lot of knowledge that cannot be found in this book. The reason is that the coursebook is only an introduction to the topic. It is supposed to give a general information on the most important systems, techniques and procedures used to control manufacturing. Therefore, unnecessary details has been omitted to allow the reader to focus on the principles and most important facts as well as to prevent from getting lost in the complexity of modern systems. Additional information can be found in one of the many excellent textbooks available, such as [34], [52], or [72], to mention a few.

Second, because of the incessant research and development in the field of manufacturing management, each day new approaches, better techniques and more efficient technologies are being developed. To be up to date, the reader should get familiar with the journals specialized in the manufacturing domain. Among the others, many useful information can be found in *Management Science*, *International Journal of Production Research*, and *International Journal of Operations & Production Management*.

The coursebook begins with a short introduction to so called Integrated Management Systems. In Chapter 1, the history, concept and features os such systems are presented. These are the systems on the highest level of the company management. Their evolution from historical Material Requirements Planning systems, through Manufacturing Resource Planning, to modern Enterprise Resource Planning is also briefly described in the chapter.

One of the most important things to do before any manufacturing can start is to set the general plan of the company production, purchases and resources utilization. Such a plan is called Master Production Schedule. The methods to design such a plan and the ways of its presentation are described in Chapter 2.

Once the general schedule of production is set, the detailed plan of the resources needed to execute this schedule is created. To produce an item many materials are often needed. Therefore, so called Material Requirements Plan has to be determined. However, except for the materials, also machines, workers and other means of production are needed in the production process. The term that quantifies the ability to produce with such means is called capacity. Obviously, capacity of the manufacturing plant should be utilized carefully. In order to do that, Capacity Requirements Plan is calculated.

When the above plans are ready, the production starts. However, during the production process some control is still needed. The most important issues at that stage are referred as sequencing, loading and monitoring. The means of controlling these issues are presented in Chapter 4.

Since the competition in modern economy is very tough, the manufacturing process have to be cheap, reliable and fast. There are many methods, approaches and even philosophies that are supposed to help reaching the mentioned objectives. Some of them are presented in Chapters 5 and 6. The efficiency and cost of production depends strongly on the inventory management. Both size and timing are very important. However, also such utilization of resources, which avoids actions that do not increase the value of the product to the customer, is important. It leads to so called just-in-time and lean manufacturing, both presented in Chapter 5.

Another universal approach, which is nowadays often used in manufacturing, is Optimized Production Technology. This method tends to increase the efficient usage of the manufacturing plant capacity by identifying bottlenecks in the manufacturing process. The methods of identifying and eliminating the constraints during the production are described in Chapter 6.

Not only the processes that takes places in the production plant are of a vital importance for the manufacturing efficiency. Also connections with other companies and suppliers, which together constitutes a networks of enterprizes, is extremely important. Two important aspects - supply chains and virtual enterprizes - have to be managed on this level. The methods to do that are briefly described in Chapter 7.

Chapter 1

Integrated Management Systems (IMS)

This chapter presents the history, concept, standards and features of Integrated Management Systems. After that, the evolution from historical Material Requirements Planning systems, through Manufacturing Resource Planning, to modern Enterprise Resource Planning is described.

1.1 Introduction

Almost from the beginning of the computer era, specialized systems have been used to support managers in many companies and in various branches of economy. Back in those early days, the systems were devoted to manage only the tiny fraction of the company's activity. However, introduction of such systems to enterprises quickly brought benefits to the owners. After the initial period, during which the systems had to be customized to the particular company needs, and during which the personnel had gained experience in their usage, the quality of management quickly increased. It soon became clear that the overall profits of the companies using computer management systems grown and their competitiveness raised.

In the same time, some other trend became visible. Due to the increasing complexity of the delivered products and emphasis on safety and reliability stronger than ever before (especially in the military and nuclear fields), the companies needed to put more and more attention to their production procedures, conditions and documentation. They also needed to evaluate similar aspects of the suppliers operating, in order to provide the conformity of products. Soon, some general standards have been developed and applied in increasing number of enterprises. Today, there are many standards dedicated to various aspects: from quality to occupational health & safety. Some of the currently used standards are described in Section 1.5.

Once the computer systems started to get cheaper and managers became aware of their capabilities, the companies began to buy and install many systems covering different fields of their activity. Unfortunately, the early systems were highly specialized and could have been used to manage only small part of the whole production process, not taking into account the company structure, dependencies between the departments, often very complicated workflow, and so on. These frequently led to incoherent or even contradictory decisions. On the other hand, the raising functionality of the software and the decreasing price of the computer hardware allowed to implement the idea of one system that collects information from all departments and can support management of the company at every level. Such a system, since its ability to integrate functionality of separate management systems, is called **Integrated Management System** (**IMS**).

IMS collects all systems and processes of the organization into one framework. The purpose is to join the separate management systems of the company into one consistent system with an orderly set of documentation, policies, procedures and processes. By doing so, it allows the company that consists of many, sometimes very different, departments to work as a single unit with unified objectives. It also enables a management team to create the aim of an organization. More information on the concept of IMS can be found in Section 1.2. The detailed needs of the company management that are desirably covered by IMS are presented in Section 1.3. To meet these needs, modern IMS has to have many different features. Such features are described in Section 1.4.

The remainder of the chapter describes the milestones of the evolution from the first, simple management systems to modern applications designed to manage all resources of even the largest and most sophisticated enterprises. Everything began in the 1960's, when there evolved a new technique of **Material Requirements Planning**, popularly known as **MRP** - see Section 1.6. Systems based on MRP successfully demonstrated their effectiveness in reduction of inventory and shortening the manufacturing period by improving coordination and avoiding delays. It proved that MRP was an efficient technique for inventory management, but MRP did not take into account other resources of an organization. Thus, in 1970s, MRP was extended to the concept of **Closed-Loop**

MRP - see Section 1.7. In this method, the capacity of the organization to produce a particular product was also taken into account. In 1980s, there appeared a need to integrate the financial resources with the manufacturing operations. It became a key concept of so called **Manufacturing Resource Planning (MRP II)** systems - see Section 1.8. In the 1990s, the new techniques emerged and those already existing in the MRP II were enhanced and connected into a fully integrated **Enterprise Resource Planning (ERP)** system - see Section 1.9. Such an approach attempts to integrate all transactions of the organization in order to produce the best possible plan to manage organization in every aspect. Today, we see further development of the ERP concept.

1.2 Concept of IMS

The concept of integration of management systems appeared very quickly after such systems started to be used in the companies. Managers of many enterprises, in which more than one management system was successfully implemented, soon found out that some form of integration between different systems ought to be possible. In companies, which use management systems that have been implemented separately, there will be duplications, additional costs and even conflicts. Therefore, there should be only one management system. Such a system should contain functions of every other management system of the company [79].

The good example of a non-computer management system that integrates many different functions can be found in one-person companies, such as e.g., handymen, small shop owners, etc. There is a number of activities to be carried out by such a person: finding customers, agreeing rates, obtaining tools or goods, collecting money, paying taxes, etc. In most cases, managing such a company is for its owner simply a skill learned through everyday experience. This skill consists of set of rules, assumptions, guidelines, beliefs and strategies and can be referred as management system and definitely an integrated one. Obviously, this system is not formalized and particular activities are not carried out by procedures collected in the manual [39].

It is clear, that in the larger enterprises there exist more elaborate management systems. They are well documented for recording all the aspects of the company's activities. The most common ones are systems covering the basic operations: purchasing of materials, the selection of suppliers, placing orders, checking goods in, monitoring performance, supplier payment and so on. In many companies, which have a big personnel department, there is a system for recruiting employees, training, payment and so on. The above systems are only examples, usually they exist together with quality, environment and other management systems [81].

Obviously, every organization would like to have a single management system that would cover all aspects of its operations. Today, in many corporations there exist separate management systems with different responsibilities. All these systems, related to different departments or activities, are the part of the overall management system of the company. However, it is only rarely that these systems are brought together so that they can be seen as part of the whole [79].

Such an approach leads to lesser effectiveness and increases costs in comparison to one fully integrated management system. This is one of the reasons, why a full integration is desired [55]. Unfortunately, true integration cannot be achieved by taking the different management systems already in place (for example quality, health and safety, environment) and wrapping them together into one manual. Integration must be carefully planned and implemented in a balanced way [39].

To sum up, IMS is a management system that integrates all of the organization's systems and processes, including planning, management, design, utilization and disposal of the organization's location based assets. IMS helps enterprises in optimizing the use of workplace resources, including the management of a company's real estate, infrastructure and facilities assets.

1.3 Need for IMS

The fundamental purpose of all management systems is to help in managing the company and achieving its objectives. In order to do it, most managers tend to have one organization working as a single team with clearly understood objectives. This can be easily achieved in a small company. In enterprises, where true integration does not really exist, there are different management systems which preferably have their own managers and supporting organization [80]. The separation between functions of different management systems makes their purpose unclear regarding to the enterprise as a whole. This was the principal reason that enterprises ran into difficulties when they first started implementing quality management standards (ISO 9001 and its predecessors) [79]. The integration is needed to avoid such difficulties.

There are also several other reasons for the integration of management systems, such as [87]:

- reducing duplication and therefore costs,

- reducing risks and increasing profitability,
- balancing conflicting objectives,
- elimination of conflicting responsibilities and relationships,
- diffusing the power system,
- turning the focus onto business goals,
- formalizing informal systems,
- harmonizing and optimizing activities,
- creating consistency,
- improving communication,
- facilitating training and development.

It is clearly visible, that the pressure to integrate the management systems of a company comes from within, rather than is demanded by customers.

1.4 Requirements and features of IMS

Most of the modern global enterprises need a system which provides functionality in many aspects, such as quality, environment, occupational health and safety, risk management, information security, human resources management, etc. Therefore, there is a need for a full-scale information system that ensures a comprehensive view of the organization's activities. Particularly, in all types of organizations the strict separation between functions of management systems is disappearing. For example, scope of different management systems, such as occupational heath and safety, and environmental management system, lines up together. Such a situation, at first, generates additional costs and involves internal conflicts. Therefore, some kind of guideline for execution of integration in an easy and efficient way is needed.

PAS 99 (Publicly Available Specification) is a specification of common management system requirements as a framework for integration, published by the British Standards Institution. It is recommended to be used by those organizations, which are implementing the requirements of two or more management standards (for example ISO 9001, ISO 14001, ISO/IEC 20000, OHSAS 18001, SA 8000). PAS 99 takes account of the six common requirements for management systems standards outlined in ISO Guide 72. These six common requirements are [14]:

- Policy and principles.
- Planning:
  - identification of needs, requirements & analysis of critical issues,
  - selection of significant issues to be addressed,
  - setting of objectives and targets,
  - identification of resources,
  - identification of organizational structure, roles, responsibilities and authorities,
  - planning of operational processes,
  - contingency preparedness for foreseeable events.
- Implementation and Operation:
  - operational control,
  - management of human resources,
  - management of other resources,
  - documentation and its control,
  - communication,
  - relationship with suppliers and contractors.
- Performance Assessment:
  - monitoring and measuring,
  - analyzing and handling nonconformities,
  - system audits.
- Improvement:
  - corrective action,
  - preventive action,
  - continuous improvement.
- Management Review.

BSI developed PAS 99 in response to market demand to align enterprises processes and procedures into one full-scale structure that enables organizations to run operations more effectively. Integrated management should consolidate all aspects of the enterprise. IMS is relevant for any organization, regardless of size or sector, looking to integrate two or more of their management systems into one cohesive system with a complex set of documentation, policies, procedures and processes.

Implementation of PAS 99 carries some typical benefits for IMS [89]:

- optimized internal and external audits,
- reduced duplication,
- reduced costs,
- time savings,
- as entire approach to managing business risks,
- improved communication,
- enhanced business focus.

1.5 Management standards

As it was mentioned at the beginning of the chapter, the IMS has to have the functionality of the separate specialized managements systems used in many aspects of the company activity. Therefore, the discussion starts from common rules, policies and requirements considered in connection with the particular systems. However, since such systems are used from decades, many standards have been specified and the new ones are still being developed. These standards concern management at every level and in every department of the company.

The management standards are defined by global standards organizations. One of the leading organizations in this area is **ISO (International Organization for Standardization)** and it provides most of the standards used around the world. Four of most popular management standards are described below.

ISO 9000 is a set of standards and criteria regarding quality control for companies specializing in manufacturing and services. Its purpose is to provide a means for a company to demonstrate a commitment to quality to their customers. It helps organization which needs to demonstrate its ability to consistently provide product that meets customer and applicable statutory and regulatory requirements. One of the aims of Quality Management System is to enhance customer satisfaction through the effective application of the system, including processes for continual improvement of the system and the assurance of conformity to customer and applicable statutory and regulatory requirements [22].

ISO 14001 specifies requirements for an environmental management system to enable an organization to develop and implement a policy and objectives which take into account legal requirements and other requirements to which the organization subscribes, and information about significant environmental aspects. It applies to those environmental aspects of the organization which are controllable and influenceable. It does not state the specific natural environment performance criteria itself [98], they depend on the industry sector and the law in each country.

OHSAS 18000 is an international occupational health and safety management system specification. The OHSAS provides a framework for an organization to control its safety and health risks, improve its performance, and at the same time, comply with legislative and regulatory requirements. As a secondary effect, it may also protect co-workers, family members, employers, customers, suppliers, nearby communities, and other members of the public who are impacted by the workplace environment. It is a non-ISO standard but is compatible with the ISO 9000 and ISO 14000 management systems standards [4], implementation of this standard do not causes conflicts and it can exist without loss with ISO standards family.

SA 8000 is other non-ISO standard provided by Social Accountability International (SAI) a global standards setting organization whose mission is to advance the human rights of workers around the world. The intent of SA 8000 is to provide a standard based on international human rights norms and national labour laws that will protect and empower all personnel within a company's scope of control and influence, who produce products or provide service for that company. Including personnel employed by the company itself, as well as by its suppliers, sub-suppliers, and home workers. SA8000 is applicable to virtually all industrial sectors [48].

Since the concept of a highly integrated management system has become more popular in recent years, many organizations implemented quality system (generally ISO 9001 or its antecedents) as their first documented management system.

1.6 Material Requirements Planning (MRP)

Companies need system which collects, processes, and provides information about the company's entire enterprise, such as order processing, product design, purchasing, inventory, manufacturing, distribution, human resources, receipt of payments, and forecasting of future demand [21]. Such wide functionality has not been achieved immediately.

At the beginning, in the 1960's, there appeared Material Requirements Planning (MRP). The purpose of MRP is to allow each manufacturing unit to inform the supplier what materials or parts it requires and when they should be delivered. The supplier may be a production process within the plant or an outside supplier from which the parts are purchased. MRP calculates and maintains the best manufacturing plan based on master production schedule (see Chapter 2), sale forecasts, inventory status, open orders and bills of material (see Chapter 3). It was created to solve the problem of **"dependent demand"** – specifying how many particular components are required when the number of finished products is known. If implemented in a proper way, it reduces cash flow and increases profitability [30].

MRP manages materials in a such way, that they are in the right place at the right time. It also specifies the latest possible time to start production, buy materials and add manufacturing value. Proper MRP can keep money in the firm and still fulfill all production demands. It is the most powerful tool in leading all activities connected with inventory planning, purchase management and production control.

The input data of the MRP system must include the following items [40]:

- **Master Production Schedule** that details the quantity of end items to be produced within a specified period of time.
- **Bill of Materials** that specifies all assemblies, subassemblies, parts, and raw materials that are required to produce one unit of the finished product.
- **Inventory Records** that specify order/lot size policy and lead time and records all transactions made for parts, assemblies and components.

The input data must also include all constraints and directions to produce the end items, as well as information about routing, labor and machine standards, quality and testing standards, lot sizing techniques (i.e. Fixed Lot Size, Economic Order Quantity, Lot-For-Lot), scrap percentages, and other inputs.

The primary outputs of MRP are as follows [63]:

- recommendations of planned order releases,
- rescheduling notices changing open order due dates,
- notices to cancel or suspend open orders,
- item-status-analysis backup data,
- future planned order schedules.

MRP can also provide extended outputs, but it is not practical to list and describe all possible outputs generated by MRP found in industry. In general, MRP allows to obtain information about exception notices, reporting errors, incongruities and out-of-limits situations [63].

The possible benefits of using MRP can be summarized as follows [16]:

- reduced inventory levels,
- reduced component shortages,
- improved shipping performance,
- improved customer service,
- improved productivity,
- reduced purchasing cost,
- improved production schedules,
- reduced lead times,
- improved communication,
- reduced freight cost,
- reduced overtime,
- improved supply schedules,
- improved calculation of material requirements.

There are also some disadvantages connected with MRP, the most obvious is the amount of information and calculation it needs. Moreover, properly implemented MRP needs detailed master schedule, bill of materials, current stocks, orders outstanding, lead times, other information about suppliers, and a range of related information. Many companies simply do not have this information, or they do not have it detailed enough, in the right format, or with enough accuracy [93]. Moreover, the whole procedure is based on a detailed master schedule that must be designed some time in advance, so MRP cannot be used if there is no master schedule or it is inaccurate, plans are changed frequently and are not made far enough in advance. The other disadvantages of MRP are as follows: [7]:

- It needs a lot of detailed and reliable information. If the inventory data, the master production schedule, or the bill of materials data are incorrect, then the data in the output will be also incorrect.
- It forces realizing orders from the system, because there is no resources to realize an extra orders. It leads to reduced flexibility.
- It assumes that lead time of each item is constant and independent of the order quantity, simultaneous production of other items in the factory, or other factors.
- It takes no account of capacity in its calculations, and thus it can give results that are impossible to realize due to manpower or machine or supplier capacity constraints.
- It can be expensive and time consuming to implement.

The development of many others management systems began with MRP, for instance Closed-Loop MRP, Manufacturing Resource Planning (MRP II) and Enterprise Resource Planning (ERP). Close-Loop MRP, which provides feedback to scheduling from the inventory control system, is described in the next subsection.

1.7 Closed-Loop MRP

In many corporations where MRP has been implemented, its development become necessary after some time. It led to a number of extensions of MRP. Closed-Loop MRP is one of them. It performs the same functions as MRP, but also provides feedback to scheduling from the inventory control system. Specifically, this system provides information to the capacity plan, master production schedule, and ultimately to the production plan [17].

Closed-Loop MRP operates in cycle as shown below [32]:

- **Planning** - MRP determines when orders need to be launched;
- **Execution** - orders are released into manufacturing or to suppliers;
- **Feedback** - changes in conditions are reported to the system;
- **Corrective action** - the system recommends corrective action.

In short, Closed-Loop MRP is realizing functionality of MRP and additionally enables to control the process, depending on current situation. It enables reaction to any disorder in the production process, it also controls supply process.

1.8 Manufacturing Resource Planning (MRP II)

Manufacturing Resource Planning (MRP II) is one of the extensions of MRP concept. MRP II deals with more than simply production scheduling, this is a method for the effective planning of all resources of a manufacturing company including materials, finance, and human relations. MRP II is not only a software, it combines people skills, database's accuracy and computer resources. It increments information integration process [76]. MRP II functions have to be integrated with financial documents such as the business plan, purchase obligation report, annual budget, inventory projections in monetary units and so on.

MRP II in relation to MRP has three additional elements [92]:

- **Sales & Operations Planning** - a powerful process to manage demand and supply in a balanced way, which provides top management with far greater control over operational aspects of the business.
- **Financial interface** - the ability to translate operating plans in production units into financial terms, like dollars or euros.
- **Simulation** - the ability to ask "what-if" questions regarding the production process and to obtain answers.

MRP and MRP II systems use a Master Production Schedule (MPS) to generate production schedules for component items. MRP contains only the coordination of raw materials and components purchasing. MRP II simplifies the management of a detailed production schedule. It schedules the production activities in accordance to the timetable of materials supplies and takes account of machine and labor capacity. The aim of MRP II is to deliver congruous data to all users in the manufacturing process as the product moves through the production line. On the output of MRP II system the final labor and machine schedules are obtained, including machine time, labor time and materials used to realize an order. In general, it provides information about the production costs per unit, as well as final production numbers in a period of time [99].

1.9 Enterprise Resource Planning (ERP)

Enterprise Resource Planning (ERP) system began with MRP and MRP II and has become the most important and the widely-integrated system in operations management technology. MRP and MRP II are used as the basic modules of more extensive ERP systems. It is a total company management concept for using all resources more productively. ERP has been defined by Deloitte & Touche (one of the biggest companies providing support for audits, consulting, enterprise risk services, etc.) as "packaged business software systems that allow companies to:

- automate and integrate the majority of their business processes,
- share common data and practices across the entire enterprise,
- produce and access information in a real-time environment" [34].

The objective of ERP is to coordinate a firm's whole business - from supplier evaluation to customer invoicing. ERP does this using a centralized database to assist the flow of information between the manufacturing, purchasing, finance, logistics, and human resources functions in the corporation. ERP goes even further than MRP II, it makes its information system accessible for suppliers and customers. For example, customer can accesses to the manufacturing schedules, using ERP to check status of their order and to determine a date when product will be supplied [61]. Today, all this activity can be done via Internet. Also suppliers can analyze the production schedule to view when supply of more parts of materials is needed. ERP provides suppliers information needed to make a reasonable decision and to the best adjustment to our production schedule [61].

In an ERP system, data is inputted one time only into a common, complete and consistent database shared by all applications. For example, when Speedo salesperson places an order into his ERP system for 10,000 towels for U.S. Swimming Team, the data are instantly available on the manufacturing floor. Production crew fills the order, accounting printed U.S. Swimming Team's invoice and shipping notifies Swimming Team of the estimated delivery date. The salesperson, or even the customer, can check the progress of the order at any point. This is all accomplished using the same data and common applications. To reach this consistency, the data fields must be defined identically across the entire company. In Speedo's case, this means integration of operations at production sites from Vietnam to China and Australia, at business units across the globe, in many currencies, and with reports in a variety of languages.

ERP systems are possible because of advances in hardware and software that have taken place in recent years. The ERP programs are designed to take advantage of client/server networks with software designed either as a client or as a server. That kind of software is also flexible enough to run on a PC, workstation, or a mainframe and be linked via local area networks [33].

Chapter 2

Master Schedule (MS) and Master Production Schedule (MPS)

2.1 Introduction

As it was stated in the previous chapter, every company needs a good plan of allocation of its resources, e.g., machines and tools should be used properly and efficiently, activities should be well defined and assigned for staff, etc. The plan which specifies this in time is called **Master Schedule** (MS). In its simplest form it may be viewed as a presentation of what the company expects to purchase, produce and sell. MS translates the business plan into a production plan using planned orders in a multi-level optional component scheduling environment. Using MS makes possible for businesses to consolidate planned parts, produce **Master Production Schedule** (MPS) and forecasts for any level of **Bill of Material** (BOM) for any type of part produced by company.

MS is strictly linked with other manufacturing plans, for example with **Sales and Operations Plan** (SOP). Methods used within Master Scheduling help to quantify significant processes, parts and other resources to optimize production as well as to identify bottlenecks in a work flow. MS allows to estimate, when and how much of each resource will be demanded. Moreover, using Master Scheduling helps to avoid shortages, last minute scheduling, costly expediting or inefficient allocation of resources.

Because MS touches many company activity fields, its accuracy and viability affect profitability largely. To better customize the plan and precisely fit the resource utilization to the demands as well as to fulfill all production requirements, classical MS is initially created by computer system and then corrected by user. The complexity of the production processes and variety of involved resources, each having its own usage characteristics and contributing to the production in a different manner, causes that MS does not cover all aspects of production, but only key elements that have proven their efficiency in management. These key elements may include: forecasted demand, production costs, inventory costs, production lead time, working hours, inventory (stock) levels, available storage, expected production of items and supply of parts. The choice, which of these elements should be taken into account, varies among factories and companies.

2.2 Role of MS in higher level planning

From the management perspective, MS should give all information concerning planning of production (MPS), sales, resource and stock levels, which is needed to create the plan of manufacturing and later to control this process. On the other hand, MS can be necessary to synchronize operations in large organizations, what may lead to overall efficiency improvement. MS both with MPS are therefore the most important elements of higher level planning in companies which use MRPII/ERP class systems. MS contains prognosis, clients' orders and expected production amounts of final products or crucial modules for each day (week) in the scope of planning. It covers at least a whole length of production cycle (with making orders). Thanks to ATP rating index (see Section 2.14) it is possible to accept new orders from client without the risk of exceeding manufacturability level or due dates. MPS is the most important data source for evolving proper MRP. It also helps in translating between plans in SOP into specific operational decisions.

To this end, the MS generates the set of output values which quantitatively describe key elements from the management point of view and can be used to make proper decisions. Output values can include amounts to be produced, quantity available to promise, staffing levels or projected available balance. Output values can also be used to create MRP (see Chapters 1 and 3). These output values are created using several inputs - see Figure 2.1. The input variables usually contain: forecasted demand, inventory costs, production costs, customer orders, supply, inventory levels, production lead time, lot size and ca-

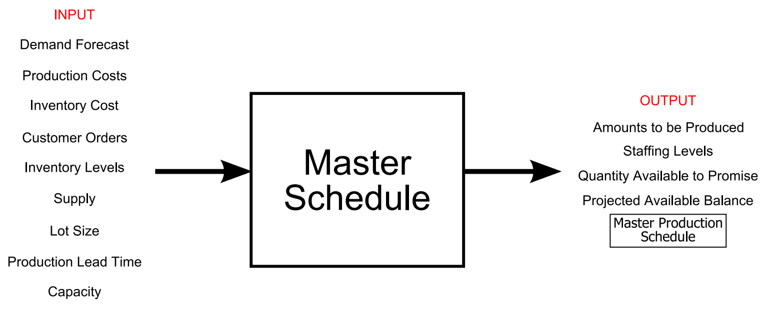

Figure 2.1: Inputs and outputs of Master Scheduling process.

pacity. Inputs can be automatically created by an ERP system (see Chapters 1 and 3), which links sales department with production one. For example, when sales department registers a sale, the forecasted demand can be automatically changed to satisfy new demand. Input values can also be entered manually from forecasts which have been calculated by hand as well.

2.3 Key terms connected with MS

Before the details on creating of MS and MPS are provided, the most important terms connected with high-level scheduling in company, introduced in previous sections, are shortly characterized and distinguished below.

Sales and Operations Plan (SOP) is introduced to integrate sales plan, production plan, customer lead times, inventory plan, products which are still in development and financial plans. SOP allows to synchronize departments in company. It helps to plan production processes basing on customer demand and resources (from suppliers or taken from stock). SOP continuously reviews these data and modifies itself to meet expectations on production performance. Planning horizon in SOPs can be different depending on industry however mostly it covers at least one whole year [34].

Master Schedule (MS) is a table which shows following parameters for key items in the time scale [52]:

- sell prognosis,
- unfulfilled orders (backlog),

- forecasted inventory (PAB - Projected Available Balance),
- size of ATP,
- MPS row,
- and (optionally) other additional information.

Master Production Schedule (MPS) is a schedule table for production department. It describes size of production of particular item (e.g., element, product). In the past, sometimes MPS was understood in the same way as MS, but nowadays APICS (the association for operations management, Advancing Productivity, Innovation and Competitive Success) states that these are two different terms. MPS is therefore just one row from Master Schedule.

Master Scheduler is a person (planner) who is responsible for developing Master Schedule. He should be supported with ERP system. He should also cooperate with SOP committee (part of management team which is responsible for creating Sales and Operation Plan) as well as with MRP planners.

Master Scheduling is a process in which MS is created and during which it is determined how MS can be used in handling of orders.

2.4 Goals of creating MS

It hs been noted, that MS reflects all key aspects of factory activity. Therefore, depending on factory profile, there may be many goals if creating MS. Some of them are described below [72].

- The first goal of creating MS is to prepare schedule of particular items (for example products). Often these are the final products (in **Make-to-stock** (MTS) **production**), main modules (in **Assemble-to-order** (ATO) **production**) or main materials (in **Make-to-order** (MTO) **production**) - see Figure 2.5 for comparison of MTS, ATO and MTO. Scheduling of single items is a main difference between MS and overriding SOP, which takes into account only groups of items. Additionally, the time scale of MS is divided into smaller time units (weeks or days), while in SOP it is always divided into months. See Figure 2.2 for comparison of SOP and MS.
- The second goal is to secure source material for **Final Assembly Schedule** (FAS) in factories which produce in ATO and MTO manner. Final assembly is done for particular client's order. To make it possible in a

given time (**Delivery Lead Time** (DLT)), all components, intermediate products and materials have to be prepared before. It is another responsibility of MPS.

- Moreover, MS is data source for MRP calculations (see Chapter 3). Based on MPS (a row from MS), gross demands are calculated for MRP. In further steps, they are expanded based on the construction structure (BOM).
- MS can be also useful as a data source for creating **Rough Cut Capability Plan** (RCCP). This plan allows to evaluate if MPS is feasible. Creating RCCP is an element of Master Scheduling.
- At last, MPS is the foundation for analysis if the company decide to accept the customer's order. ATP rating index (which bases on forecasted production and already accepted orders) allows to answer the question, how much can be promised to clients. Sometimes **Capable To Promise** (CTP) index is also used.

2.5 Connection between MPS and SOP

In companies which use SOP, MS and MPS are created on the base of Production Plan (which is part of SOP), or, at least, MS and SOP must be checked for coherence. Because SOP has been accepted by main executives (i.e., SOP committee) and many key aspects has been involved in its creation (sales department opportunities, availability of financial means, strategic resources limitations and others), the Master Scheduler is obliged to execute the Production Plan according to SOP. In that case any change in MS would cause the inconsistency between SOP and MS. Therefore, any change has to be agreed with company's executives. See Figure 2.2 for graphical comparison of MPS and SOP.

2.6 The objectives of Master Scheduler

Master Scheduler has to balance three conflicting objectives:

- reducing inventory (stock),
- improving customer quality service,
- improving production efficiency.

	SOP process	Master Scheduling process
Object	Product groups	Final products and intermediate products from planning BOMs
Horizon	Time needed to create resource Commonly: 1-3 year	The longest Cumulative Lead Time Commonly: few months
Periods	Months	Days or weeks
Accent on	Production size	Production diversification
Result	Production Plan	MPS

Figure 2.2: The diferences between MPS and SOP.

Unfortunately, decreasing inventory usually causes also:

- decreasement of customer service quality (often there are no such products in stock, which customer would like to buy, and therefore he has to wait),
- decreasement of production performance (goods have to be produced in smaller series).

On the other hand, increasement of production performance:

- implicates production in bigger series (less setups),
- decreases customer service quality, because it is possible that a required product is currently not in stock.

Notice, that in order to decrease the size of stock, it is necessary to manufacture rather in a small series (low performance). Otherwise, there may be gaps in the inventories causing low customer service quality.

It is possible to fulfill Master Scheduler objectives by establishing rigid constraints for two of them and optimize the third one. In practice it is often enough for the Master Scheduler to meet the following objectives:

- keep customer service quality at specified level (e.g., at 88% for the key product),
- keep fixed level of stock (e.g., amounts in stock for every product should be between 180 and 220 pieces),

- optimally use resources and stabilize processes. Stabilization is important due to MRP planning. MRP should follow MPS changes. However, execution of MRP is impossible if MPS is changed too often.

2.7 MS input data

As it was mentioned above, to prepare MS some input parameters are needed. Usually, the more precise MS needs to be obtained, the more detailed input data have to be delivered. The inputs may contain the following [34]:

- **Production plan from SOP**,
- **Planning structure -** Planning BOM (it has to be different structure than the usual BOM, which is useful rather from the manufacturing process viewpoint)
- **Detailed forecasts.** Detailed forecasts can be also created based on forecasts from SOP with use of the planning structure. It is better, however, if every singular position from MS is created separately and independently analyzed.
- **Current stock level** (from ERP system) and **expected final level** which, e.g., follows from strategy which equalizes production level against a seasonal demand.
- **Current production** and **current orders**.
- **Constraints** on key resources (bottlenecks):
  - production capabilities,
  - human resources,
  - tools,
  - budget.
- **Unfulfilled orders** (backlog) and their desired state,
- **Time fences policy** (see Section 2.11).
- **Additional sources of demand**:
  - internal orders (interplant),

– commercial orders (intraplant),
– requests from servicing departments and forecasts of their demands,
– requests from distribution centers, quality control departments, R&D departments, etc.

Depending on the structure of the company, not all elements presented above must be taken into account (e.g., orders from service departments).

2.8 Creating MPS

MPS is a row in MS and it presents expected production quantity of a given item (e.g., product) from production departments. There are four steps of creating MPS:

First draft of MPS can be simply result of generating MPS from SOP using planning structure. Then Master Scheduler performs RCCP and tries to resolve differences. In other words, Master Scheduler modifies MPS to reduce overloads or unequal workplaces load.

However, Master Scheduler has also to take into account other limitations:

- forecasted inventory (stock) level cannot get lower than **Security Stock** (SS) level,
- time fences policy can constraint possibilities of applying changes in frozen priod (frozen zone),
- asserted stock levels has to be met, etc.

After applying changes to MPS, RCCP is applied once more. This process is repeated until all expectations are met. Then final MPS is ready.

2.9 MS table

The Master Schedule is a set of tables, each corresponding to particular item (e.g., product). Each MS table contains columns which correspond to the subsequent time periods (e.g., weeks or days). In some presentations the numbers of periods are used, but in practice it is much more convenient to use days or weeks as units.

Basic rows in the table are as follows:

DTF=2 PTF=5 PH=6 SS=2 Lot sizing method: FOQ Initial stock=10						
Period	1	2	3	4	5	6
External demand forecast	7	5	3	3	4	3
Customers' orders	9	7	4	2	3	3
PAB	9	2	6	3	-1	-4
MPS	8		10			

Table 2.1: Exemplary MS table.

- external demand forecast (or sell forecast),
- number of unfulfilled orders' positions (with specified completion date),
- forecasted stock status at the end of each period - **Projected Available Balance** (PAB) - see Section 2.10,
- MPS.

For the exemple of MS table, see Table 2.1. The terms used in the table, such as **Planning Time Fence** (PTF), **Demand Time Fence** (DTF) and **Planning Horizon** (PH), are described in Section 2.11. Note, that MPS may not be defined for each period, since item production cycle may be longer than a chosen planning period.

Additionally, to compute some values in MS table, the following planning parameters are used and given in the table:

- lot sizing method (e.g., Fixed Order Quantity (FOQ)),
- lot size and time of lot sizing (depends on selected method),
- current stock status,
- information about product line or items class.

2.10 Projected Available Balance (PAB)

PAB is an inventory balance projected in the future. The manner in which PAB is calculated depends if it concern the period before DTF or after it:

DTF=2 PTF=5 PH=6 SS=2 Lot sizing method: FOQ Initial stock=10						
Period	1	2	3	4	5	6
External demand forecast	7	5	3	3	4	3
Customer's orders	9	7	4	2	3	3
PAB	9	2	6	3	-1	-4
Net requirements					3	6
MPS	8		10			

Table 2.2: Exemplary MS table with net requirements row.

- for first period
  PAB(1) = STOCK + MPS(1) - ORDERS(1),
- for next periods before DTF
  PAB(n) = PAB(n-1) + MPS(n) - ORDERS(n),
- for periods after DTF
  PAB(n) = PAB(n-1) + MPS(n) - max[FORECAST(n), ORDERS(n)].

One of the main tasks of Master Scheduler is to ensure that PAB will not fall below fixed SS level. This constraint does not apply to frozen period (to DTF), in which PAB is allowed to become smaller than SS, since the role of SS is simply to be used in special cases, e.g., emergency, unpredicted demands, etc.

To help Master Scheduler find out if the PAB level is proper, some systems shows **net requirements** in separate row. Net requirements are not empty only when PAB falls below SS (or below zero in the frozen period) and shows the missing difference.

2.11 Time fences

In order to distinguish different ways of dealing with (controlling) changes in the future time periods, so called time fences are used. In the **Demand Time Fence Control**, the **Demand Time Fence** (DTF) is bordered by the current date and a date within which the planning process does not consider forecasted demand when calculating actual demand. Inside the DTF, Master Scheduler only considers actual demand. Outside the DTF, the planning process considers forecasted demand.

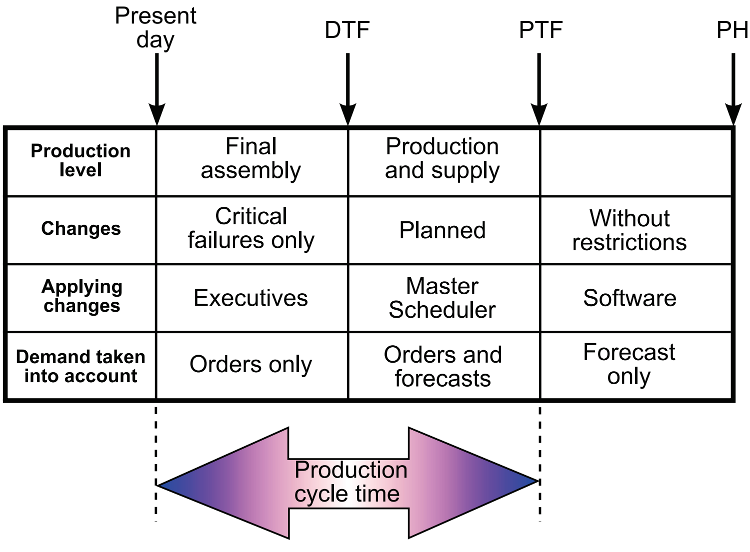

Figure 2.3: The diferences between DTF, PTF and PH.

In the **Planning Time Fence Control**, the **Planning Time Fence** (PTF) is bordered by the current date and a date within which the planning process does not alter the current material plan or master schedule. For discrete items within the planning time fence, the planning process does not reschedule (created earlier) order due dates or create new planned orders for the item to satisfy net demand requirements. However, the planning process can reschedule or cancel an order when it determines that such orders create excess supply. For discrete items outside the PTF, the planning process can generate suggestions to create, change and reduce entries on the MPS or the MRP. See Figure 2.3 for comparison of DTF, PTF and PH.

Time fences are set for the specified product families and contain policies (determined by executives) concerning applying changes to MPS. In ideal situation, changes are applied only between PTF and PH.

In practice, however, changes are applied very often in a flexible period (time between DTF and PTF), i.e., in time shorter than the whole production cycle. This may implicate fast tracked deliveries and additional setups.

Changes in frozen period (time before DTF) should be avoided. Sometimes

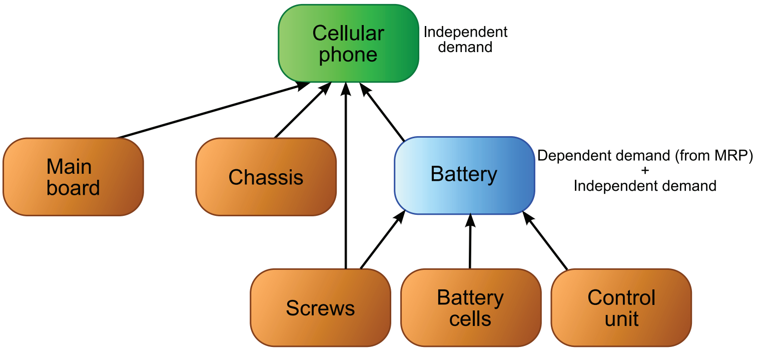

Figure 2.4: The example of the product made of many components.

they are necessary, but can lead to serious and unforeseen consequences. To avoid these changes, additional condition is introduced: any change before DTF must be accepted by executives. This protects Master Scheduler from pressures from other departments.

2.12 Multi-level MPS

Multi-level MPS is useful when intermediate product (which is component of the final product) can be also sold as a standalone product. In Figure 2.4 battery is example of such a product. In this case, there are two different demand sources:

- independent demand (sell forecasts and orders),
- dependent demand (from MRP).

This kind of intermediate product should be also included in MS, but, in this case, it is shown in a separate row as **Additional demand sources** - see Table 2.3.

In practice, there are more reasons, why intermediate product is planned in MS. Consider the following example. Company has two factories. One factory produces components while the other produces final products. Both factories ought to have its own MS, each of which ensures that factory production is stable and effective, and it has appropriate level of stock. However, using in this case two independent MSs, in which demands would be represented as orders, will

DTF=2 PTF=5 PH=6 SS=2 Lot sizing method: FOQ Initial stock=10						
Period	1	2	3	4	5	6
External demand forecast	7	5	3	3	4	3
Additional demand sources			5			
Customer's orders	9	7	4	2	3	3
PAB	9	2	6	3	-1	-4
MPS	8		10			

Table 2.3: Exemplary MS table with additional demand sources.

MRP dependent demand	14
DRP	5
Service	1
Research and development	4
Total	24

Table 2.4: Distinguished additional demand sources as a separate table. In practice it is an additional cell (or, in general, row) in MS.

implicate problems - when both factories uses the same material (e.g., screws in example presented in Figure 2.4). Thus, the demand for the same good has two sources. Therefore, the optimal solution is Multi-level MPS.

In additional row in MS (besides data concerning MRP dependent demand), there can be information about other sources of demand such as demand from distribution centers - **Distribution Resource Planning** (DRP), service departments, R&D departments, etc. - see Table 2.4.

It is very important to include these information in MS. Otherwise, execution of MS can be difficult. Consider for example that the service uses materials or elements, which are needed in production. In such case execution of MS can be delayed.

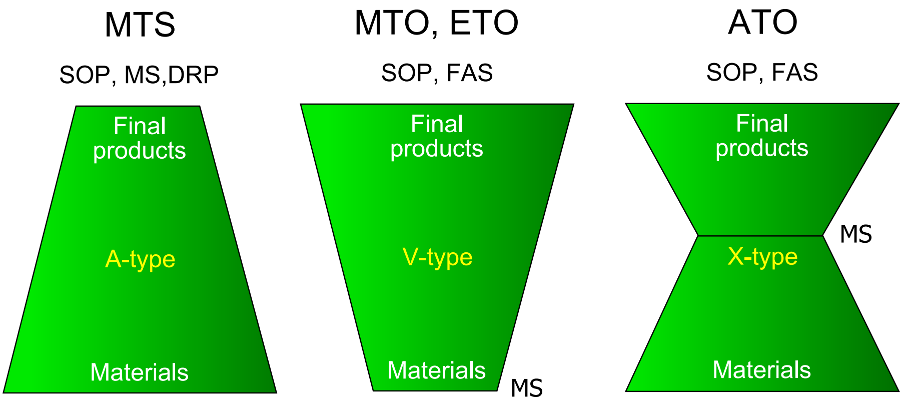

Figure 2.5: Comparison of possible product structures.

2.13 MS and product type

MS has to take into account the way in which the products are assembled. This allows to distinguish three structures: "A", "X" and "V" - see Figure 2.5.

Product structure "A" is characteristic for situation, where there is a limited number of final products and (at the same time) a lot of possible materials. It is often referred as **Make-to-stock** (MTS) production. In this case SOP and MS schedules are created at the highest level of product structure. Moreover, there is no FAS. Usually, there exists extended distribution network planned with DRP.

Product structure "V" exists if there is wide range of products with limited kinds of materials. It often takes place in **Make-to-order** (MTO) and **Engineer-to-order** (ETO) production. Here, MS applies to materials.

Product structure "X" appears if there is a wide range of products or optional elements and (at the same time) limited amount of universal, key subassemblies. The "X" product structure may be viewed as a composition of "A" and "V" product structures. It is often characterized as **Assembled-to-order** (ATO) production. SOP is created (as always) at the highest possible level. MS includes key subassemblies or options. Additionally, FAS is used.

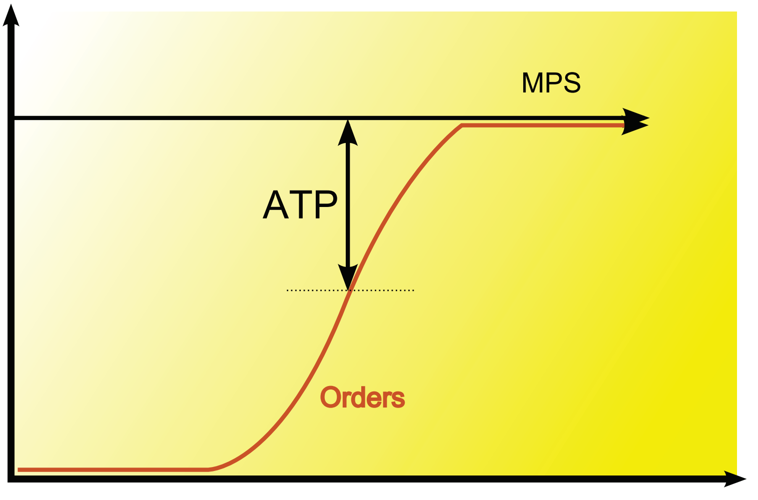

Figure 2.6: ATP value in comparison with MPS.

2.14 Available to promise index

Newly received orders from clients are accepted against planned production quantity (MPS). The difference between MPS and already accepted orders is called Available To Promise (ATP) rating index - see Figure 2.6. It tells how much of goods can be promised to customers when accepting new orders.

ATP index is represented in a separate row of MS - see Table 2.5. Usually, ATP is calculated in following way:

- ATP(period 1) = STOCK + MPS - SUM OF ORDERS and ADD.SOURCES to next MPS,
- ATP(period with MPS) = MPS - SUM OF ORDERS and ADD.SOURCES to next MPS,
- ATP is not calculated for periods where MPS does not exist.

Unfortunately, it is impossible to use this index to fulfill a particular demand with use of cumulative production from different MPS ticks. To solve this problem Backward ATP and Forward ATP have been introduced - see Table 2.6, i.e., the production surplus can be shifted to other MPS ticks.

DTF=2 PTF=5 PH=6 SS=2						
Lot sizing method: FOQ Initial stock=10						
Period	1	2	3	4	5	6
External demand forecast	7	5	3	3	4	3
Additional demand sources			5			
Customer's orders	9	7	4	2	3	3
PAB	9	2	6	3	-1	-4
ATP	2		-7			
MPS	8		10			

Table 2.5: MS table with ATP row.

DTF=2 PTF=5 PH=6 SS=2						
Lot sizing method: FOQ Initial stock=10						
Period	1	2	3	4	5	6
External demand forecast	7	5	3	3	4	3
Additional demand sources			5			
Customer's orders	9	7	4	2	3	3
PAB	9	2	6	3	-1	-4
ATP	2		-7			
Backward/forward consumption	-1		+1			
Backward/forward ATP	1		-6			
MPS	8		10			

Table 2.6: MS table with Back-Forward ATP row.

The other method is Cumulative ATP (CATP) - see Table 2.7. Cumulative ATP is calculated as follows:

- CATP(1) = STOCK + MPS(1) - ORDERS(1) - ADD.SOURCES(1)
- CATP(n) = CATP(n-1) + MPS(n) - ORDERS(n) - ADD.SOURCES(n)

Thanks to CATP it is not necessary to use Backward ATP, however, surplus shiftings made to fulfill demands are not clearly visible. Moreover during accepting of an order, checking only if a new demand not exceed the current ATP limit is not sufficient. Computer system should recompute CATP and validate new order at least to PTF.

DTF=2 PTF=5 PH=6 SS=2 Lot sizing method: FOQ Initial stock=10						
Period	1	2	3	4	5	6
External demand forecast	7	5	3	3	4	3
Additional demand sources			5			
Customer's orders	9	7	4	2	3	3
PAB	9	2	6	3	-1	-4
ATP	2		-7			
Backward/forward consumption	-1		+1			
Backward/forward ATP	1		-6			
CATP	9	2	3	1	-2	-5
MPS	8		10			

Table 2.7: MS table with CATP row.

In a final presentation of MS, given as Table 2.8, two additional rows may be also added:

- dynamically changing SS,
- target amount of items (products) in stock (destination stock level).

SS calculation method depends on chosen algorithm. Often, a simple algorithm called Days of Supply, determines SS that secure continous production based on forecasted demands for next few days.

2.15 Conclusion

As presented in this chapter, construction of Master Schedule is not straightforward, and many factors must be taken into account, according to the company profile. Depending on how precise MS should be, different methods for calculating particular parameters can be used (for example one of the presented methods for calculating ATP index). MS helps to forecast such parameters as overall demand, production levels, inventory levels, orders, etc., what, in turn, allows to reduce costs (for example production or inventory costs) and avoid shortages.

DTF=2 PTF=5 PH=6 SS=2						
Lot sizing method: FOQ Initial stock=10						
Period	1	2	3	4	5	6
External demand forecast	7	5	3	3	4	3
Additional demand sources			5			
Customer's orders	9	7	4	2	3	3
Security Stock	2	2	2	2	2	2
PAB	9	2	6	3	-1	-4
Destination Stock Level						
ATP	2		-7			
Backward/forward consumption	-1		+1			
Backward/forward ATP	1		-6			
CATP	9	2	3	1	-2	-5
Net requirements					3	6
MPS	8		10			

Table 2.8: Final MS.

Chapter 3

Material Requirements Planning (MRP) and Capacity Requirements Planning (CRP)

The first part of the chapter presents a method of scheduling production of the end item's components — the **Material Requirements Planning** (MRP). The concept of MRP, its main inputs and outputs have been described in Chapter 1. This chapter provides many details and describes logic and mechanics of MRP calculations. Major approaches to combining MRP with Just-in-Time (JIT) inventory strategy and some extensions of MRP are also shown.

The second part presents a method of verifying the feasibility of the production plan by comparing it with the factory's capability to produce — the **Capacity Requirements Planning** (CRP). The base processing unit in a manufacturing plant is work center. Generally, work center is such a place in the factory, where particular activity concerning tasks is performed, e.g. welding or painting. The capacity of the plant depends on the capacity of its work centers. Therefore, key terms necessary to determine the **capacity** of a work center are discussed. Some ways to manage the two major capacity problems (**underloads** and **overloads**) are presented.

3.1 Material Requirements Planning

As it was described in Chapter 1, MRP is a computerized inventory control system for scheduling production and purchases of all the component items needed for the final assembly of the end item (the final product). It uses information about end items demand, product structure and component requirements, **lead time** (the time required to make the items in-house or buy them from a supplier) and current inventory levels to calculate the demand for component items, keep track of when they are needed and generate work orders and purchase orders [52].

Fundamental for understanding MRP system is the concept of a dependent demand. Demand for end item creates demand for assemblies, which creates demand for component items and so on. Dependent demand such as demand for components parts can be calculated, whereas an independent demand (the demand for finished products) can only be forecasted [78]. MRP transforms a master production schedule (see Chapter 2) for end items into time-phased requirements for subassemblies, components and raw materials. Some products may be very complex, they can include hundreds of component parts and assemblies. MRP tries to ensure that the components of an assembly are ready at the same time so that they can be assembled together [34].

Since the main objective of any inventory system is to ensure that the required material is available when it is needed, it can lead to a tremendous investment of funds in unnecessary inventory. Therefore, the objectives of MRP system are to determine the quantity and timing of material requirements and to maintain the lowest possible level of inventory. The system does this by determining when component items are needed and scheduling them to be ready exactly at that time. In the process of planning inventory levels, the system also plans purchasing activities (for raw material and purchased components), manufacturing activities (for component parts and assemblies) and delivery schedules (for finished products). Another important objective of an MRP system is to keep track of any change in the requirements. Customers change order quantities or timing, suppliers deliver late or the wrong quantities. With its computerized database, MRP system has the ability to keep schedules valid and up to date [61].

There are three major inputs to MRP process [72]:

- **master production schedule**;
- **product structure file**;

- **item master file**.

3.1.1 Master Production Schedule

The Master Production Schedule (MPS) specifies how much of the end product is to be produced and when it is needed. The MPS shows these information in so called time buckets. These time buckets are usually some conventional units of time, like days or weeks and may extend over several months to cover the complete manufacture of the items. The MPS supplies the MRP process with the information about the demand for finished products. This schedule is needed before the MRP system can plan the production of the component items [29]. For more information on MPS see Chapter 2.

3.1.2 Product Structure File

As soon as the MPS is complete, the MRP system can check which component items are required based on the product structure file. The file contains a **Bill of Material** (BOM) for every produced item. BOM lists for each end product all assemblies, subassemblies, components and raw materials necessary to produce the product. A BOM file includes information about the component items, their description and quantities required to make one unit of the product. A good way to visualize the hierarchical structure of the product is to use a **product structure diagram**. Figure 3.2 shows a product structure diagram of the window shutter presented in Figure 3.1. Each assembled item is a parent in the diagram, each component required to make the parent is called child. The number in the brackets next to each item is the quantity of the given component needed to make one parent [52].

To simplify the computer processing of the BOM file, labels are added at each level of the product structure diagram. The final product or end item (at the top of the structure) is labeled level 0 and the level number increases with each subsequent level of the tree. If more identical items exist at various levels in the BOM they are coded at the lowest level at which they are used. This is called **low-level coding**. This approach helps to conclusively identify the component items and facilitates the computer scan of the product structure level by level, starting at the top, obtaining an accurate and complete count of all components needed at one level before moving to the next [60].

When the BOM is turned on its side and modified by adding lead times for each component, a **time-phased product structure** is constructed. Time in

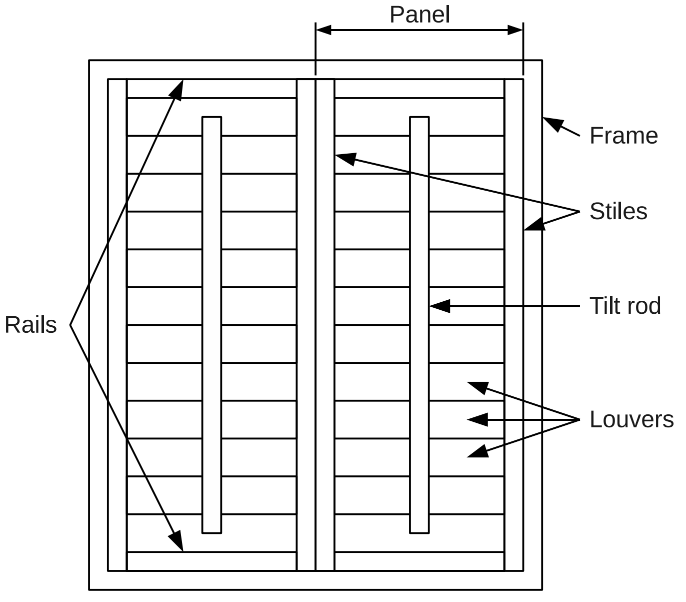

Figure 3.1: A window shutter.

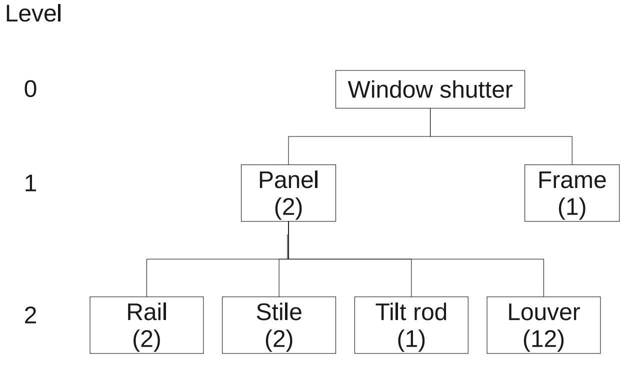

Figure 3.2: A product structure diagram.

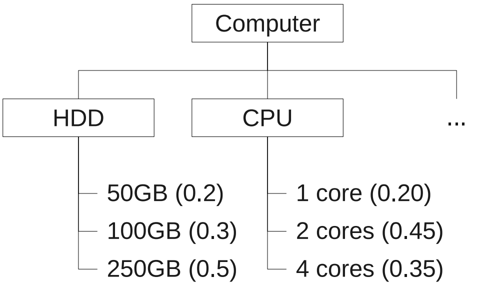

Figure 3.3: A modular bill of material.

this structure is shown on the horizontal axis and each component is offset to accommodate lead times [34].

Several specialized BOMs have been developed, mainly to reduce computer processing time and clarify relationships between components. The most often used are: phantom bills, K-bills and modular bills [72].

- **Phantom bills** are used for temporary components. These components are not inventoried and their lead time is zero — they go directly into another assembly. Such components are for instance subassemblies.
- **K-bills** group small parts like pins, nails and screws together into one artificial item. In this way the order for these items is processed only once in the system reducing the necessary paperwork and processing time.
- **Modular bills** of material are organized around modules (product options) rather than a finished product. This can be helpful if the end item is customer-ordered. This approach reduces the number of bills of material needed to describe all possible options of the final product. Figure 3.3 shows a modular bill of material. The quantity per assembly for an option is given as a decimal number in the brackets and can be interpreted as a percentage of the demand for the parent item.

3.1.3 Item Master File

The item master file is a database of information on every produced, ordered or inventoried item in the system. It provides a detailed description of the item. The database includes various data, for an example on-hand and on-order quantities, lead times, lot sizes and past usage information. The item master file also provides external codes that link it with other related information in the MRP database. The database needs to be up-to-date, therefore the entries in the item master file are altered when a change in the inventory occurs [72].

Good inventory management is necessary for MRP system to work efficiently. The company should achieve 99 percent of inventory records accuracy [34]. MRP calculation process is mostly mechanic and any computer can be relied upon to get it correct. Far more difficult is to obtain and maintain correct information upon which the calculation depends. There are three major requirements [11]:

- bills of material have to be accurate;
- inventory records which reflect the on-hand balances need to be correct;
- lead times need to be realistic and current.

3.1.4 MRP Process

The MRP system uses information about product structure of the end item and the lead times of the component items to schedule production of the components. This involves determining when the purchase and production orders should be released so that the materials are available when needed [52]. The MRP process consists of four basic steps [72]:

- examining the BOM;
- **netting out** inventory — obtaining net requirements by subtracting on-hand quantities and scheduled receipts from gross requirements;
- **lot sizing** — determining the quantities of the orders;
- **time-phasing** requirements — determining when to order an item.

The process is repeated for every item in the product structure file until all items have been scheduled. An MRP table (Table 3.1) is completed for each item starting with level zero item [11]. In the top left corner of the table, the basic information is provided, i.e., the item name or number, low level code, lead time and the lot sizing technique used to determine quantities in which items are made or purchased.

Entries in the table include [60]:

Table 3.1: Net material requirements plan [72]. The terms used in the table are explained in Section 3.1.4.

Item ...	Low level code ...	Period			
Lot size ...	Lead time ...	1	2	3	4
Gross requirements		Derived from MPS or planned order releases of the parent			
Scheduled receipts		On order and scheduled to be received			
Projected on hand	Beginning inventory	Anticipated quantity on hand at the end of the period			
Net requirements		Gross requirements less on-hand inventory and scheduled receipts			
Planned order receipts		When orders need to be received			
Planned order releases		When orders need to be placed to be received on time			

- **Gross requirements** which begin the MRP process. They come from the MPS (for end items) and for component items — from combined needs for parent items. This row shows the total demand for an item, before subtracting the available inventory and the quantity that is due to arrive at the given period.
- **Scheduled receipts** are items already on order from a vendor or in-house shop, due to arrive at the beginning of a future time period.
- **Projected on hand** is the amount of the item that is expected to be available at the end of the time period. This includes the quantity left from previous period, scheduled receipts and planned order receipts decreased by gross requirements.
- **Net requirements** show what actually needs to be produced after on-hand an on-order quantities have been taken into account.
- **Planned order receipts** represent the quantities that will be ordered from a vendor or in-house shop to be received at the beginning of the period.
- **Planned order releases** includes the same values as the planned order receipts row scheduled into earlier time periods (by including lead time)

so that the item is received when needed. When the time comes and the orders are released these numbers are crossed out transfered into scheduled receipts.

The quantities in the planned order receipts and planned order release rows differ from the net requirements by lot sizing rules. These are the techniques used in determining the **lot size** (the quantity in which items are made or purchased). There is a variety of ways to determine lot sizes in a MRP system, to mention a few: **lot-for-lot**, **economic order quantity**, **part period balancing**, **Wagner-Whitin algorithm**.

- Lot-for-lot produces exactly what is required. This technique is consistent with the objective of an MRP system, which is to meet requirements of dependent demand. This would require an MRP system to produce items only when they are needed, without taking into account any safety stocks or future orders. This rule produces frequent orders and separate setups, one associated with each order. If setup costs are significant or management has been unable to implement JIT (see Chapter 5), lot-for-lot can be expensive [34].

- Economic Order Quantity (EOQ) is a statistical technique using averages, usually average demand for a year. The EOQ model defines the lot size Q^* as
$$Q^* = \sqrt{\frac{2DS}{H}},$$
where: D — annual usage, S — setup cost, H — holding cost on an annual basis. Statistical techniques such as EOQ are preferable when demand is independent and relatively constant, whereas MRP procedure assumes known (dependent) demand reflected in a master production schedule [34].

- Part Period Balancing (PPB) is a lot-sizing technique that balances setup and holding costs by increasing the orders size to include the demand for future time periods. PPB uses an Economic Part Period (EPP), which is the ratio of setup cost to holding cost per unit per period. This technique adds requirements for the future periods, until the holding cost of the extra inventory ordered to satisfy the future demand approximates EPP [52].

- Wagner-Whitin algorithm is a dynamic programming model for lot-size computation. Despite the fact that it provides good results the technique is seldom used in practice due to its complexity [25].

The last row of the table, planned order releases, determines when orders should be released, so that they are received when needed. The row is filled out by time phasing the planned order receipts. Time phasing subtracts an item's lead time from its due date and determines when to order an item. Planned order releases at one level of a product structure generates gross requirements for the next lower level. After the MRP process is complete, the planned order releases are compiled in a planned order report [72].

3.1.5 MRP Outputs

The main output of the MRP process are **planned orders** from the planned order release row of the MRP table. These include purchase orders, work orders and various reports. Work orders are the orders that are to be released to the in-house production and purchase orders — to be send to outside suppliers. Based on the MRP output, changes in previous plans and schedules may be recommended. One of the advantages of the MRP system is its ability to show the impact of change in one part of the production process on the rest of the system. It calculates the ordering and usage of materials and components into future time periods and generates warnings of the potentially missed due dates or lack of components [72].

3.1.6 Response to changes in MRP

As changes in design, schedules and production process occur, bills of material and material requirements are altered. Changes in material requirements occur also whenever the master production schedule is modified. Regardless of the cause of the change in MRP data, it is not uncommon to recompute MRP requirements about once a week [34]. This is done in one of the two ways: **regenerative MRP** and **net change MRP**. The first one deletes all previous MRP schedules and reruns all the MRP calculations. This is a time-consuming process for most manufacturing companies, therefore it is often done over a weekend. Net change MRP, on the other hand, recalculates only those MRP records that have been affected by changes. It requires less time and is often done overnight. Nowadays several "on line" net change MRP systems have been developed. These systems can perform the calculations almost immediately. However, an on-line net change may still not always be possible so an overnight update may be required [11].

One of the strengths of MRP is its ability to replan the production. However, frequent changes generate so called **system nervousness** and can create chaos in purchasing and production departments. Operations management personnel can reduce this nervousness by evaluating the need and impact of changes before actually sending requests to other departments [34]. Frequent changes can become disruptive and inefficient, especially in short-term plans. Therefore it is common to put some restriction to the amount of change in the production plan. **Time fences** are periods of time during which changes in the MRP plan are restricted. During such periods only some minor changes or perhaps no changes at all are allowed [52]. Another tool that can be helpful in reducing the system nervousness is **pegging**. Pegging, in MRP systems, means "tracing upward in the BOM from the component to the parent item". This helps the production planner in determining the cause of the material requirement change and deciding if the change in the production schedule really necessary. [60]. The operation manager can react to changes, but it does not mean he/she should. Perhaps some minor scheduling or quantity changes do not need any response from the manager, even if he or she is aware of them.

3.1.7 Connection of MRP and just-in-time

MRP plans the production and makes sure that material are available when they are required. JIT controls the flow of materials within the production process. Both systems are different from each other in many aspects, but have the same basic aim that is to reduce the inventory level by maching the supply of materials to the demand. Therefore a combination of both techniques might bring considerable benefits to the company [95]. For more information about JIT see Chapter 5.

MRP is a very good planning tool in process-focused facilities, where lead times are relatively stable and poor balance of work between the work centers is expected. Such facilities include for instance machine shops, hospitals or restaurants. In these enterprises, MRP can be integrated with JIT through so called **small bucket approach**. In this approach MRP still plans the production, but the MRP time buckets are reduced from weekly to daily or even hourly. The inventory is moved through the production process on a JIT basis. Nissan achieved success with this approach by computer communication links to suppliers. The schedules are updated every 15–20 minutes. Suppliers provide deliveries 4–16 times per day. Master schedule performance is 99% on time, on-time delivery from suppliers is 99.9% and for manufactured parts — 99.5% [34].

Another approach to integration of the two systems is **balanced flow approach**. In this approach, the planning of MRP is again combined with JIT execution. The JIT part uses kanban cards (see Chapter 5) and reliable suppliers to pull the material through the facility. In order to increase productivity, a flow of materials to assembly units is carefully balanced and a small lot sizes are preferred [45].

3.1.8 MRP Extensions

Throughout recent years a number of extensions of MRP has been developed, the most significant are: **Closed-Loop MRP**, **Material Resource Planning** (MRP II) and **Enterprise Resource Planning** (ERP).

Closed-Loop MRP

Closed-Loop MRP is an MRP system that provides feedback to scheduling from the inventory control system, in particular to the capacity plan, master production schedule and the production plan. Nearly all commercial MRP systems are closed-loop [34].

Material Resource Planning

MRP II extends the idea of MRP to other areas of the company. Inventory data can be supplemented with information about labor-hours, material cost (not only the quantity) or any other resource. A few examples of this data integration are purchasing, production scheduling, capacity planning and warehouse management. Thanks to including information about other resources in the item details, employees of different departments (such as marketing, financing, engineering and manufacturing) can use the information contained within the MRP II system and cooperate each others actions [29]. Table 3.2 shows an example of a schedule developed by MPR II system containing information about the quantities, labor hours and material cost of the order.

Enterprise Resource Planning

MRP II has soon become insufficient. There was need for a system which includes order entering, purchasing and direct interface with customers and suppliers, such as Electronic Data Interchange (EDI). Advanced MRP II systems that tie customers and suppliers are known as ERP systems. For instance "a company may now use a fully integrated ERP system to receive an order electronically from a customer in Brazil, issue the necessity purchase order to suppliers in Italy, change inventory levels, notify shippers on both ends of the

Table 3.2: MRP II schedule [34].

Item	Resource	Week 1	2	3	4
Window shutter	Quantity:				10
(lead time: 1 week)	Labor: 1 hour each				10
	Material cost: $0 each				0
Panel	Quantity:			20	
(lead time: 2 weeks)	Labor: 5 hour each			100	
	Material cost: $0 each			0	
Louver	Quantity:	240			
(lead time: 3 weeks)	Labor: 2 hour each	480			
	Material cost: $5 each	1200			

transaction, update the MRP system, provide files for updating payables and receivables, convert all transactions in the proper currency" [3].

3.2 Capacity Requirements Planning (CRP)

Up to this point, it has been assumed that the company can satisfy any demand for a product and produce or order any quantity of the item at any time. The MRP system ensures that material requirements are met. Nevertheless, material is not the only resource necessary to produce goods - a certain amount of labor and machine hours are also required. The MRP plan has to be verified by checking for the availability of labor and machine hours. This process is called **Capacity Requirements Planning (CRP)**. CRP consists in comparing the **load** (the amount of work that needs to be done) from a production plan with the capacity of the system. In short, CRP enables to identify underloads and overloads. An overloaded work center is the one to which more work has been assigned than it can process. Similarly, the underloaded one is capable of producing more than is assigned. The objective of the CRP planner is to level the load — smooth out the resource requirements so that the capacity constraints are not violated [41].

There are three major inputs to the CRP system [72]:

- the planned order releases from the MRP process;
- a **routing file**, that defines machines and workers needed to complete an

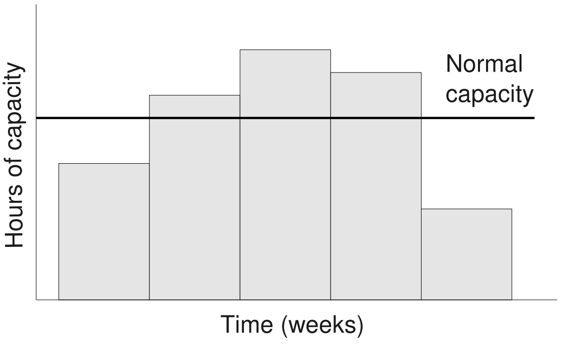

Figure 3.4: Load Report.

order, the time of processing of each operation and the order in which they are to be processed;

- an **open orders file**, that includes information about the status of orders that are currently processed.

To verify the feasibility of the MRP plan a **load report** (also called a load profile) is generated. A load report shows the resource requirements in a work center. Comparing information from this report with the work center capability to produce items, enables to identify any capacity problems [34]. Load reports can be displayed graphically - see Figure 3.4.

Capacity is the capability to produce, or in other words, the amount of work that can be done by a worker, machine or an entire plant. It is usually expressed as standard work hours and is calculated as follows:

$$\text{Capacity} = (\text{No. of Machines or Workers}) \cdot (\text{No. of Shifts per Week}) \cdot (\text{No. of Hours per Shift}) \cdot (\text{Utilization}) \cdot (\text{Efficiency}).$$

The first three components of the equation are obvious. They give the theoretical amount of available work hours. For instance, if an employee works 8 hours a day, then it gives total amount of 40 hours of work per week. However, no employee is able to work non-stop. **Utilization** is the percentage of available working time that a worker or a machine actually works. It is an indicator of how intensively a resource is being used. Actions that reduce the working time are, for example, scheduled maintenance, machine setup time or lunch break.

Efficiency shows how well a machine or worker performs the task in comparison to the standard output level. These standards can be based on records of past performance or can be developed from specialized work-measurement techniques. Efficiency is also expressed as a percentage value. An efficiency of 100 percent is considered normal or standard performance [77].

Load is often expressed as standard hours of work assigned to a work center. The ratio of load to capacity, called the **load factor**, enables to easily identify the capacity problems. Work centers with the ratio less than one are underloaded. It means that the machine or employee capacity is not fully used. Centers for which the ratio greater than one are overloaded and will not be able to complete the scheduled work without reduction of the load or some adjustment in the capacity [41].

Underloads can be leveled by:

- moving work that is scheduled for later periods;
- acquiring more work;
- reducing normal capacity.

Underloaded condition means that the work center could produce more items. If underload is not dealt with, a apart of the work center's capacity is wasted. Perhaps it could be possible to change the production plan and move some work scheduled for later time periods. This could be an excellent solution if the work center in the later time periods is overloaded. It would solve both problems. However, the MRP plan was created based on relations in the product structure. It may not be achievable to accelerate the production of an item because some of the item's components will not be ready. Even if moving the work would be possible, the components, produced before the time they are needed in the next assembly, generate additional holding cost. Whenever the initial production plan is changed, the MRP process should be rerun. If the management is not able to change the production within the factory, the company can try to acquire more work. For instance, it can accept additional orders from the current customers or search for new ones. If no additional work can be acquired, reduction of the work center's capacity will be necessary to reduce the production costs. This usually involves reducing the length of working day or the number of employees [72].

Overloaded conditions can be far more expensive than underloads. The underloaded work center implies only a waste of the center's capacity. In contrast, the overloaded work center will not be able to complete the work on time. Overloads can be reduced by [72]:

- increasing normal capacity;
- increasing efficiency of the operation;
- rerouting jobs to alternative machines, workers or work centers;
- splitting lots between two or more machines;
- pushing work back to later time periods;
- subcontracting;
- revising the master schedule;
- eliminating of unnecessary requirements.

Perhaps the best possible solution is to increase the work center's capacity. It often involves adding some overtime to the workers assignment, hiring additional workers or increasing the centers' utilization or efficiency. The last alternative is not easy to perform. Increasing efficiency and utilization requires highly qualified workers and machines of high performance. Training employees and investing in new technologies requires a lot of time and money to put into effect, but it can bring considerable benefits to the company.

If the capacity cannot be increased in sufficient time, sometimes it can be possible to move the work within the factory. If two or more machines or workers can perform the same operation, the management is able to transfer the work to the less occupied work centers. Moreover, if the work centers are free at the same time, it is possible to split the work between these centers and perform the operations simultaneously. If no other machine is available in a desired time, the work can always be postponed and performed in a later time period. However, postponing a production of one component item can delay the assembling of the entire product. This can result in a penalty for late delivery, loss of the order or even the customer. Moreover, pushing work to later time periods may cause overloads at those periods. There is also one other risk: if the company is occupied with an old order, it cannot accept new ones. This means a lost profit and perhaps a chance of acquiring new customers [72].

If the management is not able to move the work within the factory, subcontracting is a solution worth considering. Outsourcing a part of the work might enable the company to finish the rest of the order on time. If none of the previously mentioned alternatives can be applied a revision of the MPS is necessary. This means that some orders will be delayed or canceled. The management should then consider which customers and orders are the most important to the company and should be scheduled on time and make some arrangements for the less important ones [34].

Chapter 4

Production Activity Control (PAC)

When the basic plans and schedules, described in previous chapters, are established, the production can be started. However, the production itself should be also carefully managed, which is referred as **production activity control (PAC)**. The main issues of PAC are **scheduling** (described in Section 4.1) and **monitoring** of production process (see Section 4.5), mostly in a **job shop** environment. In Section 4.2, objectives of scheduling are described. The few next sections of the chapter are devoted to other issues connected with PAC, i.e., loading (Section 4.3), assigning (4.3.1) and sequencing (4.4). Some techniques that allows to solve these issues are presented: Hungarian method (Section 4.3.1), priority rules (Section 4.4), and Johnson's rule (Section 4.4.2). Except for problems concerning establishment of proper sequences, schedules and loads, the monitoring is another important aspect PAC. This issue is described in Section 4.5, and in Section 4.5.1 the most popular tool applied to monitoring, so called Gantt's chart, is presented. Also the problems of controlling input and output of the production process are considered - see Section 4.5.2. The last section of the Chapter is devoted to advanced planning and scheduling methods.

4.1 Scheduling

Scheduling is the last stage of planning before production actually takes place. It specifies when labor, equipment and facilities are needed to produce a product or provide a service. Scheduling function differs based on the type of process [72]:

- in process industries such as pharmaceuticals and chemicals the scheduling could include decisions determining the mix of ingredients, when a system should stop producing one type of mixture, clean out the vat and start producing another.

- For mass production, the schedule of production is determined by the assembly line. Products flow through the assembly line from one station to the next in the same order every time. Scheduling decisions involve determining how fast to add items into the line and how many hours to per day to run the line.

- For projects scheduling decisions are so large in number and interrelated that specialized techniques have been developed, such as PERT (Program Evaluation and Review Technique) and CPM (Critical Path Method).

- Job shop production is a type of production environment usually seen in small and medium manufacturers that are oriented towards customer-specified orders. Each order (also called a job) can follow a different route in the factory according to the customer's order specification. This involves qualified workers and machine centers that can perform many different operations. For this type of production environment, scheduling decisions can be very complex. They determine to which machine a part should be routed for processing, which worker should operate the machine that produces a part and the order in which the parts are to be processed. In other facilities, like hospitals, scheduling determines which patient to assign to an operation room, which doctors and nurses are to care for a patient during certain hours of the day, the order in which a doctor is to see patients and when meals should be delivered or medications dispensed.

Production Activity Control (PAC) is includes scheduling and monitoring of production in a job shop production evironment. It also known as production control or Shop Floor Control (SFC). PAC is usually performed by the production control department of the factory. What makes scheduling in a job shop so difficult is the variety of the processed jobs, each with distinctive routing and processing requirements. Additionally, although the volume of each customer order may be small, there is probably a great number of different orders in the shop at any time [72].

4.2 Objectives in scheduling

There are many possible objectives taken into account during scheduling, many of them are in conflict with each other [8]:

- machines setup costs (machine setup are the additional operations needed to be performed so that different jobs can be processed on the machine, for instance the drill change);
- work-in-process inventory (the amount of work that is not yet completed, these items are either being processed or waiting in the queue to be processed on the machine);
- machine idle time;
- jobs' lateness;
- number of jobs in the queues to machines;
- jobs' completion time;
- jobs' time in the system;
- machine or labor utilization;

Regardless of the primary scheduling objective, manufacturers usually have a production control department whose responsibilities consist of **loading**, **sequencing** and **monitoring** [72].

The MRP system plans for material availability, CRP covers the material plan into machine and labor requirements and projects resource overloads and underloads. Loading is the process of assigning jobs to work centers so that costs, idle time, or completion times are minimal [34]. However, when several orders are assigned to one machine center, they must be prioritized so that the worker will know which ones to do first. Sequencing specifies the order in which the jobs that are waiting in a queue to a machine center are to be processed. This sequence is often based on certain sequencing rules [8].

Monitoring involves maintaining progress reports on each job until it is completed. Feedback from the production process enables the shop planners to be in close communication with everyone involved with an order. This communication is important because items may have to be rescheduled as changes occur in the system. Apart from timely data collection and various reports, monitoring involves the usage of **Gantt charts** and **input/output control charts**.

Gantt charts show planned activities against a time scale and input/output control charts enable to monitor the input and output of each work center. Both charts are useful tools in monitoring the work progress [60].

4.3 Loading

Loading is the process in which work has to be assigned to limited resources. In a job shop environment workers can operate different machines and some machines can perform many operations, although perhaps not equally efficient. It is obvious that the job should be processed by a worker or machine that can perform it the most efficiently. If no constraints in the production process are violated PAC can proceed to sequencing the work at the work centers. However sometimes the work must be reassigned. The problem how to best allocate work to work centers can be formulated as an instance of the **assignment problem** [72].

4.3.1 The Assignment Problem

The assignment problem is a problem in which N jobs are to be assigned to N machines or workers so that some measure of cost is minimized. Each job is assigned to exactly one machine and each machine is assigned to process exactly one job. The problem can be treated as a special type of linear programming for which a simple solution method has been devised — the **Hungarian method**. Using a matrix (NxN) of all possible assignments of jobs and machines, it assigns particular jobs to particular machines. The matrix contains the cost associated with each possible assignment. This cost could be calculated for instance as inverse of the worker effectiveness at the particular job. Table 4.1 shows a matrix of possible assignments of three job to three workers. The procedure is as follows [52]:

1. Subtract the minimum value in each row from all other row values. For the resulting values subtract the minimum value in each column from all other column values.
2. Cross out all zeros in the matrix using the minimum number of horizontal or vertical lines.
3. If the number lines equals N, an optimal solution has been reached and assignments can be made where zeros appear. Otherwise, modify the matrix by subtracting the minimum uncrossed value from all other uncrossed

Table 4.1: An assignment matrix.

	Worker A	Worker B	Worker C
Assembling	4	10	5
Packing	15	2	7
Labeling	3	8	4

values and adding this same amount to all cells that are at the intersection of two lines. The other values remain unchanged.

4. Repeat steps 2 and 3 until an optimal solution is reached.

4.4 Sequencing

Loading assigns jobs to work centers. However, if more than one job is assigned to a single machine, the operator needs to know in which order to process the jobs. The process of prioritizing jobs, i.e., determining the order in which jobs should be done at each work center, is called sequencing. If no particular order is given, the operator would probably process the job that arrived first. This sequence is called **First-Come, First Served** (FCFS). If jobs are stacked on arrival to a machine, it could be easier to process the job that arrived last and is now on top the stack, this is called **Last-Come, First Served** (LCFS) sequencing. A common practice is to process the job that has the highest customer priority [72].

If the jobs are to be finished before a certain date, **Earliest Due Date** (EDD) rule sequences the jobs in the ascending order of their due dates. EDD usually manages to keep the jobs' tardiness low. The two other sequencing rules that use the information about the job's due date are **critical ratio** rule and **slack time remaining** rule [52].

The slack time rule gives priority to the jobs of which slack time is least. Slack time is the difference between the time remaining until the job's due date and length of the work remaining to be performed.

$$\text{SLACK} = (\text{due date} - \text{today's date}) - (\text{remaining processing time})$$

If today's date is not given, it is assumed that it is day 0 [8].

The Critical Ratio (CR) rule uses the same information as the previous rule. For every job a ratio of the time remaining until the due date and the time needed to complete the job is calculated:

CR = (due date – today's date)/(work time remaining processing).

Jobs are processed in the increasing order of their ratio. The value of the ratio also gives an information about the progress of the job. A job with a CR less than one is falling behind schedule. If CR exactly equals one, the job is exactly on schedule. And if CR is greater than one, the job is ahead of schedule and it has some slack [34].

Other sequencing rules take into consideration the processing time of a particular operation and order the work either by the **Shortest Processing Time** (SPT) or **Longest Processing Time** (LPT). LPT assumes that the longer, bigger jobs are often important and they should be selected first [34]. SPT focuses on shorter jobs and is able to complete more jobs earlier than LPT. However with either rule, there is always a risk that some jobs can be excessively late because they were always put at the back of the queue [72].

4.4.1 Sequencing Jobs Through One Process

The simplest possible sequencing problem consists of a queue of jobs at one machine or process. No new jobs arrive to the machine during the analysis, processing time and due dates are fixed. The choice of the best sequencing rule depends on what is to be achieve. The flow time (called also the completion time) for a job is the time that it takes a job to flow through the system. It will be different for each job depending on its place in the sequence. The makespan for a set of jobs is the time it takes to complete these jobs. It can also be defined as the longest flow time for the jobs in the set and in this scenario it will not change. The tardiness of a job measures the amount of time between the moment of the job completion and its due date. If a job is completed before or at the job's due date the tardiness is zero. These are only some examples of the possible criteria of sequence evaluation. In practice there does not exist a universal sequencing rule that would minimize all of them. Different rules should be tested using a computer simulation to see which of them provides a sequence with the best balance of the relevant criteria in our situation [52].

4.4.2 Sequencing Jobs Through Two Serial Process

A very few factories consist of only one process. The next step in complexity is adding another machine. **Johnson's rule** provides a sequence that minimizes the makespan for a system where the jobs flow through a two step system. In this kind of system every job must be processed on the first and than on the second machine. These could be for instance assembling and than packing work centers. The time required to complete a job can be different at each machine. The jobs flow through both machines in the same sequence. The Johnson's rule is as follows [34]:

1. List the time required to complete each job at each process.

2. Select the job with the smallest processing time at either process.

    - If that time occurs at the first process, put the job as near to the beginning of the sequence as possible.
    - If that time occurs at the second process, put the job as near to the end of the sequence as possible.
    - Ties can be broken arbitrarily.

3. Remove the scheduled job from the list.

4. Repeat steps 2 and 3 until all jobs have been sequenced.

4.5 Monitoring

In a job shop environment it is not easy to keep track of the status of a job. They follow different paths through the shop, visit many different machine centers and make queue competing for similar resources. Competition for resources, machine breakdowns, quality problems and setup requirements are just a few of the things that effect in longer lead-time. Therefore, maintaining progress reports on each job until it is completed becomes essential. Such a process is called monitoring. Monitoring is important because items may have to be rescheduled as changes occur in the system. Apart from timely data collection, it involves the usage of Gantt Charts and input/output control [72], they will be widely described in the next subsections.

In a big factory paperwork concerns everyone, each job has own work package, which specifies what work need to be done at a particular work center and where the item should be routed next. Workers are usually required to sign off on a job, either manually on the work package or electronically through a magnetic card or a PC located on the shop floor. They indicate the performed work [72].

The production control personnel transforms the gathered data into various reports, including progress reports, exception reports and hot lists. However,

Figure 4.1: A Gantt Chart [72].

to make this work the collected data needs to be up-to-date and accurate. The data should be also easily accessible by the operation personnel. The mentioned reports enable workers and managers to draw conclusions. Progress reports are generated to show the status of individual jobs, the availability or utilization of certain resources and the performance of individual workers or work centers. Exception reports can be produced to emphasise deficiencies in certain areas, such as scrap, rework, shortages, anticipated delays and unfilled orders. Hot lists point out which jobs receive the highest priority and must be done immediately [94].

4.5.1 Gantt Charts

Gantt charts, originally used to plan or map out works activities, are always drawn to a linear timescale. They are excellent visual aids. Many kinds of Gantt Charts were developed over the years but all of them serve the same purpose, that is visual representation of a schedule over time. An example of a Gantt Chart is presented on the Figure 4.1. As we can see they can display both planned and completed activities against a time scale [50]. The charts have been used since the early 1990s and are still popular today. They may be created by computer or by hand and are a common feature of project management software [69].

4.5.2 Input/Output Control

Input/output control monitors the input and output from each work center in the shop, it verifies if the capacity plan is being executed as planned. Because the output of the one work center is the input to another, it was common to examine only actual output from a work center and to compare it with the output planned in the shop schedule. Input/output control is a tool, which in a simple way identifies workcenters that are not executing to the plan. Information on the status of each work center is up to date [46]. Input/output technique helps also to control the length of queues in front of work centers. The queue time is one of the major factor affecting on job lead time [27].

Job shop environment is hard to observe, jobs follow different paths through the shop, it is not always easy to keep track of the status of a job. Using input/output control in environment, where performance of different work centers is interrelated may result in inaccurate conclusions about the source of the problem. Reduced output at a work station can be caused by a problem at this particular work center, but it may also be caused by problems at previous work centers in the production process. Moreover, trying to increase output only at that work station can cause problems in the next work stations. Such situation has the same effect as pouring more water into the top of the funnel without changing anything else. Therefore, to identify the source of a problem we need to compare actual utilization and planned usage. Secessions from the plan are calculated and we observe theirs cumulative effects. The role of management is to react to any extraordinary situations, like resulting backlog, greater queue size [61].

Input/output control provides the information necessary to regulate the flow of work through a network of work centers. Bottlenecks exist particularly in every production system. If the source of the problem has not been correctly identified, increasing the capacity of the wrong work center will not increase the output of the system. To eliminate problems caused by the bottleneck work centers, the problem causing the backlog can be dealt with – the capacity of the work center can be improved, or input to the work center can be reduced. Increasing the input to the bottleneck work center will not increase the center's output, it will only block the system further and create longer queues of work-in-progress. For an example, if you are a beekeeper and you are pouring honey into jars, labeling and boxing of the jars could be done at 10 jars/minute, but if your twisting machine can only twist 5 jars/minute your capacity is only 5 jars/minute.

4.6 Advanced Planning and Scheduling Systems

Often scheduling and capacity are treated separately. While discussing MRP (Chapter 3) capacity requirements were initially ignored. It has been assumed that the necessary capacity would be available. Underloads and overloads were pointed out later by the CRP (Chapter 3). Therefore MRP can be perceived as an infinite scheduler. Also the process of scheduling that has been discussed so far, loading into work centers, leveling the load, sequencing the work and monitoring its progress, is called infinite scheduling. With this approach the initial loading process assumes infinite capacity, leveling and sequencing decisions are made after any capacity problems have been identified [11].

An alternative approach is called finite scheduling and schedules activities within the capacity bounds. In this way a resource will never be loaded beyond its capacity. Loading and sequencing decisions are made at the same time, therefore more calculations are required. The main advantage of finite scheduling is the ability to produce more realistic and achievable schedules than the infinite scheduling techniques. However, in some situations work can not be smoothed with this approach. Some other means have to be applied [11].

Finite scheduling systems use a variety of methods to develop their schedules, including: mathematical programming, simulation, network analysis, constraint-based programming, genetic algorithms, neural networks and expert systems. Because the scheduling system makes most of the critical decisions, a lot of time time is spent incorporating the characteristics and requirements of the production system into the database and knowledge base of the scheduling software. Finite scheduling software can be an add-on to the ERP system, with libraries of algorithms and heuristics form which to chose. This class of software is known as Advanced Planning and Scheduling (APS). For instance SAP (Systemanalyse und Programmentwicklung) one of the world's leading ERP software provider has developed its own APS called the Advanced Planner and Optimizer (APO). Another example of APS from a large supply chain management software provider i2 Technologies is called Factory Planner. Both systems use **constraint-based programming** and **genetic algorithms** to develop schedules. As schedules are executed, another type of software, a Manufacturing Execution System (MES), monitors work progress, material usage and availability. If shop conditions are changed, alerts will be sent to the APS system indicating that scheduling revision is required [72].

Constraint Programming (CP) is an approach to solving combinatorial optimization problems. The problems are solved by defining them as instances of the Constraint Satisfaction Problem (CSP). An instance of the CSP is described by a set of variables, a set of possible values for each variable and a set of constraints (between variables) that specifies which combinations of values for the variables are allowed. Constraints are used not only to express the valid solutions but also to remove values from the set of possible values for each variable, deduce new constraints and detect inconsistencies. This process is called constraint propagation [9]. In manufacturing environment, when one job or person is assigned, the options for next job assignments are reduced or further constrained.

Genetic algorithms are inspired by the proprieties of natural evolution process. They became popular through John Holland's publication [36]. In general, this approach in the search for the optimal solution keeps a set of feasible solution (a population). Alternative solutions (the offspring) are generated (forming a new population) based on the previous ones with some differences. This usually involves crossover and mutation. The offspring is then evaluated against an objective function and compared to subsequent solutions. This technique has experienced a rapid development over that last years and can be applied to a variety of optimization problems and engineering applications [56].

Scheduling problems can be enormous in size, especially with a large number of products along with a complex job shop environment and consideration of supply chain management (Chapter 7). The increase in computer calculation power has helped but still a lot of problems can not be solved without effective algorithms. The complexity of the scheduling problems can be reduced by grouping parts or products into families and focusing on scheduling bottleneck resources [72]. This is where another technique (the theory of constraints) can be very helpful. The theory of constraints concentrates on scheduling the bottleneck resource and will be discussed later in Chapter 6.

Chapter 5

Just-in-time (JIT) and Lean Manufacturing (LM)

In the chapter Lean Manufacturing (LM) and Just-in-Time (JIT) approach are discussed. LM allows to reduce inventory levels and inventory costs (such as insurance) to minimal required level, what can lead to significantly lower overall production costs. JIT approach is one of methods which allows to introduce LM philosophy in a company. In the next section, the Toyota Production System (TPS), precursor of LM, is presented. Next, the main goals of LM are characterized. Later, other approaches which help to apply LM or improve production in any other way (Kaizen rules, Kanban cards, five "Why" questions, 5S-method) are presented.

5.1 General information on JIT and LM

Old, classical systems have warehouses loaded with inventory to support production and/or sale. Instead, LM systems are designed to keep inventory levels and costs at a minimum. Using world-wide communication technologies, modern production lines and stores, a company can get required inventory almost instantly rather than waiting for day of delivery in former systems. That is why such (modern) systems can be called "just-in-time". JIT production is one of widely known modern advancement of the manufacturing processes.

Both the research and practice show that proper implementation of JIT techniques can significantly reduce inventory. Notice that inventory levels are probably the best indicator of performance of JIT solution [1]. Main aspects of JIT philosophy are [38]:

- try to reduce inventory to level of zero,
- do not overproduce, i.e., produce goods at the amount required by customers,
- try to shorten lead times,
- achieve the smallest economical lot size (the best solution would be lot of one product) and therefore reduce setup costs,
- minimize inventories trough optimizing material flow between supplier, production process and point of sale of the finished good,
- high quality must be preserved,
- expect dependable and reliable delivers from suppliers,
- implement Total Quality Control (TQC) program; this will help minimizing scrap and rework and therefore will minimize delays in production cycle.

JIT inventory management philosophy seems easy, but applying this philosophy to real-world problems is not so simple. In such environment, the supplier should provide materials and other purchased goods exactly when they are needed. It is important to have required agreements with supplier which will cover all conditions for procurement. Delivery of ordered good should take place at direct point of use in manufacturing factory. Handling materials in one part of a production line and then moving them to a correct location (for example assembly line) is time consuming and not cost-effective, so such schematics should be avoided. This is supplier's task to ensure smooth flow of materials to support production. This is done though instant communication and coordination between suppliers and recipients of particular material.

It is obvious that there are work relationships between suppliers and administration of a manufacturing plant. The supplier should be treated (by manufacturer) as a part of the plant and therefore included in all planning which includes his materials. Some employees in production factory should be chosen to represent the company on fixing up delivery details (schedules, delivery quantities, etc.) [2]. There are several techniques which can help controlling the flow of materials from supplier to recipient (factory).

JIT approach requires components, raw materials, products in process as well as finished products to be held at the lowest possible level. This implicates very carefully planned schedules with fluent flow of resources during production process. Modern manufacturing plants avail complicated scheduling software which help in planning process. This software can plan production for each period of time including ordering the correct stock. Computed information can be exchanged with suppliers and/or customers through EDI (Electronic Data Interchange). This will ensure that every detail is correct and reduces possibility of human error.

Suppliers are required to deliver supplies right to the production line only when they are needed. For example car manufacturing factory needs particular number and type of tires for one day's production. Supplier is expected to deliver these tires to specified loading bay at specified time (with high accuracy which implicates very narrow time slot).

Main advantages of JIT manufacturing:

- no need to storing goods; this saves insurance costs and rental costs,
- because goods are obtained only when they are required, less human resources are needed in factory,
- possibility of stock perishing is smaller (because of the amount),
- possibility of stock becoming obsolete or out of date is smaller,
- helps avoiding leaving on stock unsold finished products; this can happen when there are sudden changes in demand,
- much less time is spent on quality check and re-working products because there is significant stress on getting the work right at the first time.

Unfortunately applying JIT can also have drawbacks:

- there are almost no place for human errors because minimal stock is preserved for re-working faulty goods,
- production is highly reliant on supply delivers and when stock becomes empty, the whole production process is interrupted and delayed,
- because there are no spare products, all unexpected orders cannot be met, however, on the other hand, JIT method helps to avoid such situations (can predict such situation).

5.2 Toyota Production System (TPS)

Toyota Production System (TPS) was the precursory production system which introduced lean thinking about production processes. TPS allows to easily point and reduce waste in production flow. This translates directly to better economical results. This section describes TPS and shows its origins. Key aspects of this system are presented, such as main principles of system and methods of improving production efficiency.

Sakichi Toyoda invented in 1902 system called jidoka (automation with human touch, which means embedding quality into production process, error-proofness). This system allowed to stop the loom when strand was broken. This invention started automation of work in weavings (and afterward in other industries), in which one employee could operate at the same time more than one loom (or other machine). This approach became key element in Toyota Production System. In 1930 Toyota retrained from textile industry to automotive one. Kiichiro Toyoda's concept of serial production (which was actually sourced in USA) started serial production of cars in Japan. During this type of manufacturing, production and transportation happened at the same time in synchronized production flow. In the same time Kiichiro Toyoda (with Taiichi Ohno) was working on JIT system, which (to get the best possible production quality, production performance, the lowest possible costs and stock) could fulfill consumers' orders. One of the most important and breakthough ideas was an idea of "pulling" (requesting and deliver for request - instead of "pushing" used before).

The main principles of TPS are as follows [100]:

1. Reduced setup times:
   Any setup process is wasteful because it does not add any value to processed product and, moreover, it ties up equipment and work time. Organizing procedures, training workers or using carts helps to reduce setup times significantly. In Toyota it was possible to reduce setup times from months to even hours.

2. Small-lot production:
   When production is done in large lots or batches, it requires quite high setup costs, larger inventories, high capital cost of high-speed machinery (dedicated for specified task), larger defect costs, and extended lead times. Since Toyota developed method to reduce setup times and costs, it became

possible to produce elements in smaller amounts (and it is economically deducted).

3. Employee involvement and empowerment:
   Toyota Production System organizes workers in teams. Every team is responsible for its tasks and development. Teams should train themselves to do specialized tasks. Teams are also responsible for keeping workplace clean, as well as for minor equipment repairs. In every team there is a leader who is responsible for the rest of the team but he also works with other team members on the production line.

4. Quality at the source:
   Only discovering and correcting mistakes or errors can allow to eliminate product defects without additional loss. In Toyota Production System, workers who work on the production line are responsible for discovering and immediately fixing small defects (this is because they are at the best position to see such mistakes). If a defect cannot be immediately fixed, special cord (Jidoka) can be pulled to stop the entire production line (this avoids repeating the same defect).

5. Equipment maintenance:
   As mentioned above, workers are responsible for maintenance and minor repairs of equipment because they can see defect signs almost as soon as they appear. Maintenance specialists are called only for complex problems or failures. These specialists also train workers in maintenance and improve performance of equipment.

6. Pull production:
   JIT production approach originated directly from TPS. In this system pull production method is used. In such a method quantity of produced components is dictated directly by demand from immediate next stage of production. This leads to reduced inventory and shorter lead times. This is where Kanban scheme (see Section 5.6) is used in TPS (flow of small containers of materials between departments or production stages).

7. Supplier involvement:
   Since TPS treats suppliers as extended parts of whole manufacturing plant, they are needed to be trained as well as employees. These trainings allows to reduce setup times, defects, inventories, machine breakdowns, outages etc. Suppliers are also responsible to deliver the best possible parts.

TPS in nowadays meaning have been developed by Taiicho Ohno, Shigeo Shingo and Eiji Toyoda between 1948 and 1975, but this system has been continuously improved (even till today).

The most important objectives of Toyota Production System are [49]:

- to eliminate overburden (muri),
- to eliminate inconsistency (mura),
- to reduce waste (muda) as much as only possible.

The best effects can be achieved through introducing processes which allows to deliver required results as smoothly as possible. In this way it is possible to design out "mura" (inconsistency).

It is also very important for design processes to be very flexible. It must be assured that any change will not result with stress or "muri" (overburden), because it may generate "muda" (waste). Thus, these improvements in production process which eliminates waste are very valuable.

In TPS seven kinds of waste ("muda") are distinguished [85]:

1. Overproduction
   Overproduction is (in its simplest meaning) producing of an item a long time before it is actually needed in a further production step. Overproduction easily leads to interruptions in smooth flow of materials. It also increases possibility of parts becoming obsolete or out of date. Thus, overproduction directly leads to quality degradation. TPS is strictly connected with JIT approach where every item is made exactly when it is needed. On the other hand overproduction is referred to "Just-in-case" approach. Moreover, production "to stock" increases storage costs and allows to multiply defects (there are many faulty components produced before defect is detected). To solve these issues, it is important to introduce scheduling and to produce only what can be immediately sold or shipped. Also improvement of machine changeover and set-up is important.

2. Motion (of operator or machine)
   Waste of motion is strictly related with ergonomics and can be seen in any kind of bending, stretching, walking, reaching, and lifting. Moreover, there are many safety issues, which can cause problems for modern organizations. These processes, which require excessive motion, must be

analyzed and tuned to reduce it. It will improve safety, and reduce lead times. This improvement should be also discussed with plant personnel.

3. Waiting (of operator or machine)
   Anytime, when goods are still (not moving nor being processed) waste of waiting can be observed. In traditional production plant more than 99% of production cycle is spent on waiting (mostly for processing in the next production step or for transport to the next stage). This commonly happens because the material flow is not tuned well enough, production runs too long or work centers are too far from each other. Goldratt says that one hour lost in a bottleneck process flow is more than one hour lost for the entire factory. This lost can never be recovered [26]. One of the methods to reduce waiting is linking processes directly so one feeds directly the second one (and work centers are close to each other).

4. Conveyance
   Transporting components or elements between work centers adds a cost but no value to the final product. Excessive transportation of elements can cause damage and becomes opportunity to slip quality down. Additionally, material handlers have to be used to move some materials. This is another cost which adds no value to the final product. Sometimes transportation can be difficult to reduce because it may need to move equipment and/or whole work places. Moreover, it is often difficult to say which stage should be next to the other one. Here, visualization of each process and flow can help to reduce excessive transportation.

5. Inappropriate processing
   In many organizations or manufacturing plants very high precision equipment is used for processes which can be done using simpler tools. This state is often called “using a sledgehammer to crack a nut”. Because preceding or subsequent processes are often located quite far from each other (determined by location of expensive/universal tools), such approach often results in poor plant layout. Additionally, it is often to utilize that equipment to the greatest extent possible (overproduction with minimal change-overs). This is done for recovering high cost of equipment. Toyota instead uses a low-cost automation and machines which are very well maintained (sometimes not very modern at all). Using smaller, cheaper equipment where possible, grouping machines (and operating them employees) into teams (called manufacturing cells) and combining production stages allows to reduce waste of inappropriate processing significantly.

6. Inventory (raw material)
   Excessive inventory in stock can lead to increased lead times, consume productive floor space (for stocking), implicate delays connected with identification problems and also inhibit communication. Moreover, overproduction and waiting can hide some problems which should be identified and resolved to improve performance. Achieving fluent flow between work centers can allow improve customer service quality as well as decrease inventories and costs connected with them (insurance, rentals, etc).

7. Correction (rework and scrap)
   In many organizations defects and costs associated with them are often a significant part of the total costs in manufacturing plant. These costs can include quarantining inventory, rescheduling, re-inspection and capacity loss. Because employees are the ones who are the nearest to manufactured components (and final products) they are responsible for checking for defects or failures. This workers' involvement in TPS is called Continuous Process Improvement (CPI). Under CPI, there is a very good opportunity to decrease amount of defects at many facilities.

5.3 Goals of LM

LM allows to reduce some costs (direct or indirect) connected with any step of production flow. Introducing proper LM (which part is JIT) is a crucial for efficiency of overall manufacturing plant or any other company.

LM is a philosophy, which requires things to be [65]:

- right things,
- delivered at the right time,
- delivered at the right place,
- in right quantity.

This allows to create a fluent work flow (minimizing waste at the same time). On the other hand, this philosophy must be flexible to meet changing requirements (for example customers' needs). To meet these requirements, the following four goals should be aimed [65]:

- Improve quality:
  Company must realize and understand customers' needs. When this goal

is achieved, whole production process will have to fit to these needs (some flows must be rearranged, or processes - redesigned). Only this will allow to stay competitive.

- Reduce time:
  Next goal is to reduce time needed to perform whole activity (from the beginning to the end). This is one of the easiest and the most effective way to reduce waste and make costs smaller.

- Eliminate waste:
  Every activity which does not add value to manufactured good or served service, but needs time, space or resources, is a waste.

- Reduce total costs:
  Only production to customer demand is expected. Any kind of overproduction implicates additional costs because of storage, insurance and/or other factors, and therefore increases total costs.

In real life it is almost impossible to meet all requirements and goals in 100%. LM compromises many elements to maximize all financial and efficiency indices.

5.4 Kaizen

Kaizen philosophy is one of many ways to create good LM production flow. This approach is common in many LM procedures and is also one of main elements in TPS. The word Kaizen origins in Japanese language, where “kai” means “to change” or “improve” and “zen” means nothing else than “good”. Thus, the literal meaning of Kaizen is simply to change things to make them better. In Chinese language meaning of Kaizen is quite similar, but in Chinese this word has also “benefit” in its meaning, so the considered change (or changes) are supposed to lead to benefits. Kaizen will not only implicate business benefits, but the social ones as well. These two goals (business and social improvement) have to be concerned in order to achieve real Kaizen methodology.

The term Kaizen is often used in the same meaning as strategy referred as CPI. Like many similar methodologies, Kaizen’s goals are to minimize or even eliminate waste and therefore improve productivity in manufacturing plant. Waste is (as defined above) any activity or process which adds cost to manufactured product but does not add any value. On the other hand, it is important to remember that introducing Kaizen is not just removing components or processes from production flow to reduce total cost. This is methodology which should eventually introduce standards of eliminating waste and improve operating performance.

This improvement of operating performance may include many components. Five of these components are specified below [49]:

- teamwork,
- personal discipline,
- improved morale,
- quality circles,
- suggestions for improvement.

Taking a closer look at these components, differences between Kaizen and other strategies (less personal) are more visible. If Kaizen is introduced correctly, it will allow not only to improve efficiency in manufacturing plant, but also make workplace more human-like (though reducing mentally and physically overly hard work). Moreover, Kaizen will help to introduce training which will teach employees how to manage everyday problems and nuisances (identifying problems and creating solutions at employee's own). It is important to mention that some small changes introduced by employees transform to one big long-term improvement.

Of course, these small changes should be coordinated, because if it can lead to one big long-term improvement, it can also lead to one big disaster. That is why any brainstorm or discussion panel should be guided by some sort of an expert. Developing traditions or commons where Kaizen is a way of living, will allow to expand a pool of improvement contributors from just executives to a whole company (including employees who work at the production line). In well maintained Kaizen, employees are not managed with strategy "command and control", but allows them to introduce small changes and make some experiments. Every member of a team (and therefore of whole company) is allowed to propose some changes and can present how do they think their work can be improved (they know that best). And if they can have their workplace improved, then the whole company is improved. In the same way waste can be eliminated (for example procedures that are not needed at all).

Sometimes it can be difficult to introduce new thinking methodology which will revolute the whole company (as Kaizen can be read in some organizations). That is why there are three stages of introducing Kaizen in a company [19]:

1. Re-align the focus of managerial techniques
When introducing Kaizen, workers are given ability for contributing any continual improvement method or idea. Then worker's ideas are put in practice. It they were good, worker can see benefits of change (job becomes less physically demanding - but still safe, worker is more productive and more efficient). In this way he becomes a member of a group which work leads to make work easier, more pleasant and generally better.

2. Improve equipment
Next goal (after employees) are equipment. It is important to think, how equipment and using the equipment, can improve work. For example sometimes changing layout of machines in manufacturing plant can lead to much better results. Moreover sometimes it would be good to install new devices or remove old ones.

3. Create a plan
It is important to have a plan of improvements. Without the plan it is impossible to see where changes improved some processes and where things turned worse. It is important to monitor and log changes, times, costs and results.

5.4.1 Kaizen in practice

Sometimes introducing Kaizen-like thinking is not so easy. Kaizen is aimed to meet two main goals: maintenance and efficiency improvement. These two goals can be sometimes opposite. To clear this apparent misunderstanding, it is needed to recall that maintenance aspect pertains to operating and technological standards. Of course, if there are no such standards, they must be pinpointed. These standards are called Standard Operating Procedures (SOP). SOPs are widely used in Kaizen-implemented companies or manufacturing plants. It is very important to understand SOPs for production line or even for the whole company.

On the other hand there is "improvement" which is also crucial part of Kaizen approach. When SOPs are precised and introduced, it is time to revise and improve some old standard habits. Smoothly better and better, more restrictive standards are introduced to improve work in company (of course they cannot deplete company of its resources or employees). At the same time improvement and better work conditions should be introduced. New fresh ideas are needed to constantly improve quality, productivity and efficiency. Remember that such improvements are small all the time, but the continuity makes these gradual changes so significant and effective. Managers who engage whole company in this improvement process (employees contribute their effort mental and physical) will quickly see if Kaizen gives benefits as expected. It will be therefore possible to see easily if Kaizen suits company or not by observing employees, changes, improvements and feedbacks.

There are other terms commonly connected with Kaizen: SMED, Total Productive Maintenance (TPM), Zero defect, Fool proof Poka-Yoke and JIT. These methods can be obviously improved. Sometimes one method can support other one to create bigger and better methodology. This is an essence of Kaizen - Continuous Improvement - some method can improve other one.

5.4.2 Ten rules of Kaizen

To easily introduce and manage Kaizen philosophy, there are ten rules of Kaizen. Respecting these rules allows to maintain Kaizen approach in manufacturing plant and constantly use Kaizen's benefits. The rules are as follows [37]:

- Rule 1: Challenge the status quo.
  The proper Kaizen approach requires to perform continuous improvement. When something breaks, this must be fixed. But beyond this, this thing have to be studied to make it working (and be) better.

- Rule 2: Think of how to do it, instead of why it cannot be done.
  Thinking in the way "why it cannot be done" should be excluded. Instead "how it can be done" approach should be adopted. This former approach (why it cannot be done) leads to big, long lasting changes. When everyone in company (manufacturing plant or other) change their tune to "how it can be done" approach, good changes can happen rapidly and fluently.

- Rule 3: Stop making excuses. Start questioning current practices.
  When a fault or mistake is encountered, it cannot be ommited. Instead, deep inquiry should be performed to see, why failure or defect happened.

- Rule 4: Do not seek immediate perfection.
  Many work-flow managers look for everything and want to have it right now. It is important to remember that Kaizen is continuous improvement, but not rapid. Perfection is goal, however it is almost impossible to achieve it within one single step. Small improvements should rather be looked for. These small quick improvements create momentum that can be difficult to stop. This is what Kaizen is the best at.

- Rule 5: Correct mistakes at once.
  It is good, to repair things as soon as it is only possible (by calling a meeting or forming a project plan). Sometimes this just cannot give permanent solution for problem but can help treat direct signs of problem (temporary solution - bandaid). Then better (target) solution can be found. This can be described as "stop the bleeding using a bandage and then get the patient to the surgery" philosophy.

- Rule 6: Do not spend money on Kaizen.
  There is often a chance that solution for a problem will cost nothing. It is easy to spend money on a new equipment or software which can potentially solve given problem. But taking a bit closer look to an issue and studying it deeply, it is possible that solution can be found without spending any money.

- Rule 7: Wisdom is brought out when faced with hardship.
  Good solutions can be checked only in really hard conditions. Only this verification can tell which ideas are good and which become not as good as they were before.

- Rule 8: Ask "Why?" five times and seek the root cause.
  Remember to ask "Why?" question five or more times. In most cases answers to these questions should lead to root cause of considered problem.

- Rule 9: Seek the wisdom of ten people rather than the knowledge of one.
  It is almost impossible to get needed knowledge from one man for given problem. In most cases it is better to listen to others (commonly more than one man). This will probably reduce efforts to solve considered problem.

- Rule 10: Remember that opportunities for Kaizen are infinite.
  So far nine rules of Kaizen were presented. If at least one or two of them are remembered, obeyed, and put in use, it is this last one - Kaizen is a mindset and set of Kaizen rules never ends.

5.5 Five "Why?" questions

The 5 Whys method (as part of CPI methodology) helps to find and define root cause of a particular problem using exploration of relationships connected with this problem. In most cases using 5 Whys method allows to find a primary problem.

This methodology was invented by Sakishi Toyoda. Later this method became a part of TPS in Toyota Motor Corporation. Taiichi Ohno, the architect of the TPS, describes the 5 Whys method in the following way: "the basis of Toyota's scientific approach (...) by repeating why five times, the nature of the problem as well as its solution becomes clear." [85]. This method is a very important element of TPS, since it allows (in most cases) to find a root cause without engaging additional resources or costs.

Let's consider a simple example of 5 Whys questions method:

Particular worker in a manufacturing plant is not efficient enough (the problem).

- Why is your performance at work so poor? (the first why)
  Because the machine I am using is extremely noisy and it makes me tired very quickly.

- Why is your machine extremely noisy? (the second why)
  Because of the rubbing between its moving parts.

- Why is there any rubbing between the moving parts? (the third why)
  Because these parts are not lubricated enough.

- Why are they not lubricated enough? (the fourth why)
  Because there is no lubricant in the storage.

- Why there is no lubricant in the storage? (the fifth why)
  Because it has not been ordered.

Root cause: The ordering of the resources was poor.

Solution: Put more attention to the resources ordering.

Sometimes, asking more than five questions can lead to root cause (for example six, seven or even more). The number of five is rather experimentally derived value, which means that in most cases five questions should be enough to find natural cause of problem. It is important to avoid logic traps or loops as it could prevent to find a solution. Moreover it is necessary to put away assumptions as they could lead to mistaken answers during reasoning.

5.6 Kanban cards

The other method to make production lean is to introduce Kanban cards in the manufacturing plant. Kanban cards will allow to reduce amount of elements produced to stock and (in consequence) costs implicated by stocking. Thus, becomes a part of Lean Manufacturing.

In Japansese language "ban" means "card" and "kan" means "visual". So Kanban is nothing other than "visible cards" or "visual cards". This is an aid, which triggers an action.

Suppose that in a manufacturing plant here is assembling station where chairs are assembled from the components. The assembler have to use some specified number of staples to finish the chair. The staples are brought from the pallet, which at the beginning contains 50 boxes of staples. When the pallet becomes empty, person who is responsible for this, takes a card which was attached to a container and then sends this card to place, where these boxes of staples come from. This implicates manufacturing of another lot of staples which are sent to assembler. Notice, that new container of staples will not be made until a cards is received back from assembly line.

This is the simplest form of Kanban system. Better example would involve two or more pallets (and kanban cards). In this way assembler can work while the second pallet of staples are being produced to be ready when first one runs out.

If a little bigger manufacturing plant is taken into consideration, there could be 20 or more assembly stations. Each assembly station can empty full pallet of staples in 20 or 30 minutes. Therefore, there is a need for the continual flow of cards which come back to staples production place. This flow will implicate a continual flow of containers full of new staples sent to assembly points.

This approach is called a "pull" type of production. The decision of how many staples are produced is linked with customer demand - in our case: assembly stations. This is done with cards which come back to staples manufacturing line.

Of course systems with other visualization than cards can also be used. For example, empty pallets which return from assembly line to staples production department can also be read as Kanban "cards". Each pallet, which comes back, indicates that there is a need to produce particular number of additional boxes of staples. Of course other types of bin, components, containers, boxes or cages can be used instead of pallets. Components can also be stored on shelves in assembly department. Empty shelf then indicates requirement of more components to be manufactured to refill the shelf.

In Kanban systems, the method of signaling lack of components is flexible. Almost any way of signaling low stock level is good, if it suits manufacturing process and methods.

Kanban can also be considered as a supermarket. There is a small amount of every product (or component) which is needed to create a chair. This amount is stored in particular place with a specified space allocation for every element. In production process, assembler comes to so called supermarket and choices elements which he needs. When element is removed from the shelf, appropriate information is sent to "regional warehouse" or direct supplier with request to replace just used element. This "supermarket" can then receive daily delivers of requested components, which replaces those "bought" by assembler. If then "supermarket" is changed to "warehouse", the considered example is obtained.

"Supermarket" model is a bit different than the simplest Kanban model (with one Kanban card). It allows to put components manufacturing plant in a place distant from the assembly line. Instead of sending small amounts of elements, bigger quantities are shipped once a day.

Kanban then creates a production system which is highly responsive to customers' needs. In the above example production highly depends on customer demand. External demand (for ready-to-sell products) influences internal demand for components (for example staples). Kanban does not foresee future needs (which is quite difficult) - it reacts to customers' needs.

Kanban should not replace all material flow systems existing within manufacturing plant. Other systems (for example Reorder Point (ROP) or Materials Require Planning (MRP)) can remain in use. The biggest profits from Kanban can be obtained when low value and high volume components are sent. For high value and low volume elements, using other management systems may lead to better profits. Kanban is very strictly connected with JIT delivery. Though, Kanban cannot be considered at equivalent name for JIT delivery. Kanban can be a part of bigger JIT system. For example, Kanban can include industrial re-engineering. Industrial re-engineering allows to group machines and employees to create cells. These "cells" allow particular products to be manufactured in a continuous flow.

Kanban groups employees into teams (employees become team members). These groups are responsible for specific work activities. Teams and individual employees are engaged in continuous improvement of overall production process.

Kanban should not be used as a system itself. It should be an integral part of Kaizen and 5S.

5.7 5S method

Five S method (5S) refers to five Japanese words, which characterize an approach to organization and management in a place of work and manner of work. It leads to increase production performance through waste elimination, processes improvement, and reducing processes which are unnecessary. In a narrower meaning, 5S describes standardization of order in place of work [59]:

- Seiri - sort, is related to practice which leads to sorting all tools, materials etc. in the place of work. Employee should have only these tools/materials which are necessary. Things which are not required should be stocked or thrown away because they pose a danger in place of work. Moreover they can lead to mess and therefore disrupt efficient work.

- Seiton - storage, is related to order in workplace. Tools, devices and materials have to be systematically stacked for easier and more efficient access. Every tool or material should have its place. There must be room for everything and everything must be in right place.

- Seiso - shine, is related to need of clean and ordered workplace. In Japanese companies (factories) after the shift, work space is cleaned and every tool and unused materials goes back to the stock or other appropriate place.

- Seiketsu - standardize, allows to control and keep consequences. Every action should be standardized to make it easier to perform. Everyone must know what is he responsible for. Obligation of having workplace clean becomes daily routine.

- Shitsuke - sustain, is related to maintaining work at specified level (standardized level). Previous 4S must be observed strictly everyday. These rules should lead to self-control.

5.8 Conclusions

Introducing JIT in a modern industry allowed elements, parts and components to be delivered in particular sequence at specified time and location. This approach, however, requires reliable and dependable supply chains. Moreover many manufacturers require from their suppliers to deliver components in lots containing one component. This is crucial for products configured by final customer. Such components have to be delivered at exact time to exact place on the assembly line.

To deliver elements in “lots of one” suppliers have to reduce their stock levels because it is impossible to store in stock so many kinds of components in large number. This is where LM is necessary. Thanks to this approach, speed of overall production cycle can be increased. Reduction of lead times and stock levels implicates reducing capital inventory investments and other carrying costs.

JIT manufacturing combines many approaches and philosophies (i.e. Kanban, Kaizen, Five “Why?” questions, 5S, etc.). Thanks to this, the great improvement in many processes (mostly in production) is possible. Obviously, not every method described above must be adopted in every production process. Sometimes, it is neither possible nor effective.

Chapter 6

Optimized Production Technology (OPT) and Theory of Constraints (TOC)

6.1 Optimized Production Technology

Increasing demands for product and reduction of lead times require company to manage its resources effectively and to control them in order to provide flexibility and competitive speed of response. Observations have shown that the **constraints** on production in manufacturing organizations are those processes in which production requirements exceed capacity, causing inefficiency of the firm. In this case many organizations have invested in manufacturing planning software and have adopted the **Optimized Production Technology (OPT)** strategy.

OPT is an approach to manufacturing management, originally developed by an Israeli physicist Eliyahu Goldratt in 1970. In general, this is an another set of planning tools in which constrained operations are considered to be critical for a scheduling. This strategy was designed with assumption that the shopfloor scheduling is the most complex problem facing the manufacturing organizations.

OPT can be considered to consist of two parts: a philosophical element and a finite scheduling algorithm. However, it is more complex than MRP and is claimed to be more effective [31]. It has not been as widely adopted as either MRP or JIT but the recent research shows that OPT can be as efficient as these two strategies [20].

The system is based on the concept of existence of two fundamental manufacturing phenomena [26]:

- **Dependent events** – a series of events that must take place before another one beginning.
- **Statistical fluctuations** – fluctuations in quantities, derived from many identical random processes. Process times fluctuate around an average.

The aim of OPT strategy is to analyze the constraint (also termed as **bottleneck**) and allow to ensure maximum utilization of that constraint in order to improve throughput [20]. The main idea of OPT is that the production output is limited by the bottleneck operations. Improving the utilization of the bottlenecked facilities can only increase throughput [44]. Bottlenecks are processes that restrict the flow of work. Processes may be bottlenecked because either their capacity is less than the level of demand or because their capacity is used inefficiently [71]. The OPT is responsible for scheduling constrained capacity in an efficient way. First, the schedule for constrained capacities is built and next it is extended for the other capacities.

To apply that theory it is important to create a set of tools able to honestly monitor the company in terms of achiving the main goal, which is in this case making money. Using that tools makes possible for everybody in that company to predict how the decision, they are faced with, will impact on profit. These tools are:

1. **Throughput** – The rate at which the system generates money through sales.
    - Throughput must be measured in the same units as the goal, i.e., PLN.
    - Because it is a rate, so the time is very important. Therefore, to compare the profitability of two products it is necessary to compare PLN/unit and time/unit (hour, day, etc.) of two products that the system can produce.

   - It is important to subtract from the money obtained by the sale the amount that was passed to the suppliers in exchange for like raw materials or components. For example, the company sells a wooden flower pot for 100zl. Each flower pot is made of a raw wood worth 20zl. Therefore, the plant produces contribution of 80zl per unit. The throughput will be equal to 800zl if a plant produces and sells 10 flower pots in one hour.

2. **Inventory** – Money the system has invested in purchasing goods intended to sell, which would include a plant, a property and an equipment.
   - The first category is the inventory which moves through the operation and ends up being sold to the customers.
   - The second category is accounted for investments. These include all the items owned by the company because they are necessary to produce throughput (building, machinery or computers).

3. **Operating expense** – All the money the system spends to convert inventory into throughout.
   - The payment for all employees are considered as operating expense. Since the person gets paid at the end of the week, his/her pay is treated as operating expense – no matter if he/she is on holiday, sick leave or at work.

"To reduce operational expense and reduce inventory whilst simultaneously increase throughput" – is a mission of that theory [26]. The "**cost world**" is replaced here by the "**throughput world**" by using these three objectives. A major difference between these two approaches are [2]:

- The cost world views the reducing operating expenses as the most significant means of improvement. The different links in the organization can work and can be measured independently of each other.
- The throughput world views the cutting operating expenses as the least significant of improvement measurements. The coordinated efforts of different links in the organization is essential to achieve good global results.

Traditional approach is to balance capacity at all work stations in order to anticipate demand from master production schedule. It completely differs from OPT strategy where Goldratt questions this statement. He claims that the capacity of the plant must be unbalanced and therefore bottlenecks are inevitable. Two reasons why the production capacity cannot be balanced to the demand of production are as follows [28]:

1. non-determinance – this factor refers to non-fixed nature of information, which is used to derive the production schedule. For example, the process time for an activity may vary each time it is performed and the rate usually quoted is an average of these times. Moreover, it can be shown that statistical fluctuations around these average can have a significant influence on plant performance.

2. interdependence – this factor causes dependence one stage to another. The effect is accumulation of the fluctuation, caused by non-determinance from stage to stage downstream of the production process.

Goldratt proposed nine rules to help managers understand OPT [96]:

1. Balance flow, not capacity.

2. Level of utilization of a non-bottleneck is determined not by its own potential but by some other constraint in the system.

3. Utilization and activation of a resource are not synonymous.

4. An hour lost at a bottleneck is an hour lost for the total system.

5. An hour saved at a non-bottleneck is just a mirage.

6. Bottlenecks govern both throughput and inventory in the system.

7. A transfer batch may not, and many times should not, be equal to the process batch.

8. The process batch should be variable, not fixed.

9. Schedules should be established by looking at all of the constraints simultaneously. Lead times are a result of a schedule and cannot be predetermined.

The main steps to develop OPT are described as follows [26]:

1. Preparation – planning project and identifying hardware and software requirements.

2. Plant analysis – identifying how processes work and how they are managed.

3. Bottleneck analysis.

4. Computer modelling.

5. Data definition – is conducted by establishing data which is required to be fed into system.

6. Defining output – obtaining master production schedule.

To deal with unbalanced plant the following steps are recommended [28]:

1. Identify bottlenecks in order to be protected from disturbances and from potential delays, to assure their full utilization, since they determine the rate of throughput.

2. Organize the resources in a way which makes bottleneck resource used at one of the earliest stages of production.

3. Instead of trying to eliminate overcapacity of non-bottlenecks at random, arrange some resources such that one has sufficient overcapacity to fully support the bottleneck.

6.2 Theory of Constraints

The principles of the OPT software and philosophy are the roots of the **Theory of Constraints (TOC)**. In a management novel *The Goal* published in 1984, Goldratt introduced the management philosophy called TOC, which is an expansion of OPT. The title comes from the assumption that any manageable system is limited in achieving more of its goals by a few constraints. According to TOC, "the goal of an industrial organization is to make money in the present and in the future" [91]. To quantify the goal of making money TOC uses financial measures such as: net profit, return on investment and cash flow. The results should be obtained through increase in income and simultaneous reduction of inventory and operating expenses.

Constraints can be internal or external to the system. An external one exists when an industry or factory cannot sell as much as it produces. In this case the organization should focus on mechanisms that create bigger demand for its products or services. The most obvious internal constraints are technical, e.g., related to capacity. The demand cannot be met because of insufficient resources. In this case company should exploit resources. Greater exploitation of them often allows to increase capacity without making an investment.

Some constraints are connected with organization's policies, human behaviour, routines etc. The company needs to give up the policies and procedures, that used to lead it in the past to a good results, but now are insufficient. The company cannot any more increase significantly its capacity by following them. What is more, older employees do not want to change their point of view on the company. Thus, the management should take an effort to convince them to a new way of conducting a business in order to obtain better result.

TOC is a systems methodology which attempts to ensure that the system as a whole, rather than just part of will benefit from any changes undertaken as part of a continuous process of improvement. TOC supports managers with a set of tools that help them to find answers to the basic questions, relating to change. These questions must be answered in sequence to make the improvement process effective [18]:

1. What to change?
    - The first step in the improvement process is to determine what to change. Improvement requires change, but change does not always lead to improvement. Sometimes, it can even make things worse. Change results in an improvement only when it is focused on the right element to alter. If a system is viewed as a chain composed of many links, the strength of a chain is determined by the weakest link. When the weakest link is strengthened, the change is an improvement but in case when a non-weakest link is strengthened, the change is not an improvement.
2. What to change to?
    - The next step in the improvement process is to determine what to change to. Once the core problem is identified, the development of the solution may simply be the elimination of the core problem. However, elimination of the core problem can also be hampered by the existence of two opposing forces, pulling the decision makers in opposite directions, resulting in a tension or conflict. The tools associeted with this question help the decision makers search for a solution by challenging the assumptions underlying the conflict.
3. How to cause the change to happen?

- The last step in the TOC improvement process is the implementation of the solution. Its success depends on the degree of understanding and support of participants in the improvement process and their reaction on the change implementation. Participants might have doubts because they perceive some critical obstacles that prevent the change from being implemented. The tools designed to find solution to this question, identify these obstacles and establish a series of intermediate objectives to overcome them.

In order to ease the process of obtaining answers to the above questions, TOC suggests the following five focusing steps [26]:

1. *Identify the constraint.* Technical constraints are easy to find. Very often employees know where is the bottleneck in the plant, usually more than one. It is more difficult to find market constraints and constraints connected with the policy.

2. *Decide how to exploit the constraint.* Make sure that the constraint's time is not wasted (constraint capacity is used at 100%). It should not be idle and, if possible, some tasks should be shifted to other resources (non-bottlenecks). One unit lost at the constraint is a unit lost for the system as a whole.

3. *Subordinate all other processes to the above decision.* Constraint should not be limited by any other aspect of the system. Other parts of the system should not do more than the constraint can handle.

4. *Elevate the constraint.* If, after the previous steps, the resource is still the constraint, an investment should be made (by buying another machine or hiring more people).

5. *If, as a result of these steps, the constraint has moved, return to the first step.* Do not allow **inertia** to become a system constraint. Inertia is concentration on resource which is no longer the constraint.

The fundamental principle of the TOC is subordination of the local aims to the global one. It is important not to use too many particular indicators in order to keep local and global goals coherent. It is undesired to exploit the local goal and measure it by a various indicators without understanding the global, long-term one, which is making money in TOC. If this the case the main purpose is forgotten. For example, the management or the owner of the company sets several measures to evaluate employees at their work. There is certainly rise on inventory where the supervisor is expected to efficiently use time. To meet expectations he/she organizes work for his/her inferiors and they produce more than is necessary [73].

6.3 Drum-buffer-rope

The five focusing steps have been applied to manufacturing, project management, marketing and finance. These steps combined with **The Drum-Buffer-Rope (DBR)** scheduling system are the key elements of TOC. DBR is the TOC production application, logical system which balances the flow of the system. DBR helps the plant to obtain accurate flow of materials in order to produce goods in accordance with market demand, with a minimum lead time, operating expenses and inventory. It is named after three essential elements of the solution [75]:

- The **drum** is a pace the constraint has in manufacturing the products. It can be called as the resource which controls the overall output of that plant and sets the pace for all other resources. The drum synchronizes the orders by keeping pace with the weakest link in the production planning system.

- The **buffer** protects the drum, so that it always has work flowing to it. It is a protection time expressed in time units. The roots of disruptions can be various: breakdowns, fluctuation in setup times or unavailability of certain resource. Buffers are planned only in critical areas like drum.

- The **rope** is essentially a communication device that release the material and ensures that raw material is not inserted into the production process before they are due. The rope supplies the constraint with just the right amount of work.

Any schedule should be characterized by such adjectives [2]:

1. Productive – is related to the market demand and must be measurable against the aim of the company.

2. Realistic – is related to the capability of being done with the resources available.

3. Reliable and robust – are related to the capability of the available resource to face with the inevitable disturbances.

Often in DBR exists such a term as **Capacity Constraint Resources (CCRs)**. It is used in order to express the resource for which available capacity limits ability to meet product demand fluctuations or product portfolio required by the market. There are a few CCRs in any manufacturing which are precisely identified. The orders that require to be processed by using them, are planned through their capacity potential and through the market demand for that order. The schedule set up for the CCRs determines the drum pace for the system.

The essential operational steps of DBR scheduling are as follows [2]:

1. Identify the constraint.

2. Prepare a schedule for the constraint (Drum).

3. Determine the constraint buffer. It is intended to keep specific number of hours of work, the type of parts that are held in the buffer, and that will keep on changing according to the production schedule of the constraint.

4. Determine the timing of material release into the production system using the constraint schedule and constraint buffer.

5. Ensure that the constraint works accordingly to the schedule prepared for it (schedule is called a drum).

6. Put other resources on order ethics, i.e., when there is a material, work on it on a first come first serve basis, otherwise do nothing.

7. For goods that do not need a constraint stage to be made, market demand is their constraint. For these goods, subtract shipping buffer from the customer due date to determine the material release timing. The **shipping buffer** is an estimation of the lead time to the completion of the order.

8. Prepare a plan of utilization of common parts. Common parts are the components required by more than one product. We must prepare a schedule for them in order not to extend the manufacturing lead time.

9. Material is released.

The final product is made of some amount of components. What should be done if two components simultaneously require the same constraint? It is recommended to compute the time processing requirement per unit of the components and give priority, i.e., take the one with lesser time and then the second one. Moreover, this method can help the company to obtain less delayed products at the end of the planning period.

The buffer in front of the bottleneck is monitored continuously. Any decrease in the buffer is called a **hole**. Thanks to this corrective actions the company can achieve planned results.

DBR is only one part of a two-part complete action, however two parts are needed to make a process efficient. **Buffer management** is this missing part. If DBR is the motor for production, then buffer management is the monitor. Buffer management is the guide which shows the way of tuning the motor for peak performance.

The first part, DBR, is the planning stage of the approach, the agreement on how to operate the system. The second part, buffer management, checks the system effectiveness. For example, if two or more workers approach a manager at the same time complaining about two or more breakdowns, it is buffer management that decides the priority of the maintenance work. It provides a rational basis to take decision in such situations.

Configuration of the drum, the buffer and the rope will determine the characteristics and the behaviour of the whole system. Buffer management will enable to monitor that behaviour.

6.4 Throughput Accounting

Nowadays, management wants from their company to grow as much as possible and in a short time. It plans to achieve it by expanding their product, market or customer base. The fundamental element of the objective posed by management is making money through sales, in other words the company takes care of increasing throughput. Companies need to use financial tools that move them toward that goal, that admit it to go in a right direction. TOC supplies the firm with that tools, called **Throughput Accounting (TA)**, which are alternative to **Cost Accounting (CA)** (CA is an organization's internal method used to measure efficiency). TA improves a company's ability to make more money now and in the future. In fact, to run a business effectively, the organization needs to be able to judge the immediate and future impact of decisions. TA does not allocate costs to products and services. It can be viewed as business intelligence for profit maximization. It helps to confront management challenges, including outsourcing products, process improvement, and purchasing capital equipment. Conceptually TA seeks to increase the velocity, at which products move through an organization, by eliminating bottlenecks within the organization [84].

TA improves profit with better management decisions by using the following variables defined in the Chapter 6.1:

- Throughput (T),
- Inventory (I),
- Operating Expense (OE).

Organizations, that wish to increase the rate at which they approach to the goal, should require managers to test proposed decisions against these questions:

- How Can We Increase Throughput?
- How Can We Reduce Investment?
- How Can We Reduce Operating Expense?

To answer these questions the following formulas are introduced:

- Net Profit (NP) = T-OE,
- Return On Investment (ROI) = NP/I,
- Productivity (P) = T/OE,
- Investment Turns (IT) = T/I,
- Cash Flow = T-I-OE.

Precisely, the objective of any company will be to maximize these values by minimizing expenditures. Management can use these factors to support decisions on strategy by predicting the effects their decisions would have on the throughput, investment and operating expense. The example of a TA financial statement is shown in Table 6.1.

6.5 TOC Thinking Process

TOC is made up by a set of tools and techniques for a logic analysis and problem solving known as **TOC Thinking Processes (TTP)**. That tools are one of the major strengths of that theory. The main purpose is to translate intuition to the rational format to fully understand existing situation. Solutions to the problems

Sales	$ 400,000	
Total variable expense(tve)		
Raw materials	$ 100,000	
Outsourcing	$ 50,000	
Commissions	$ 10,000	
total tve	$ 160,000	
Throughput($T)	$ 240,000	sales-tve
Inventory($I)		
Raw materials	$ 30,000	
Work in Process	$ 4,000	
Finished goods	0	
Total $I	$ 34,000	
Operating Expense($OE)	$160,000	
Net profit(NP)	$ 80,000	$T-$OE
Productivity	1.5	$T:$OE
Return on Sales(ROS)	20%	

Table 6.1: Throughput Accounting financial statement.

are constructed by these tools in order to facilitate collaboration between the stages. TTP consist of graphical trees, which are helpful to verbalize the cause and effect relationships between ordinary situations, but which are difficult to capture in graphs or project plans. These tools allow to work through the sequential layers of agreement to obtain a suitable solution. TTP perform a number of functions often simultaneously, so the situation can be understood, analyzed and synthesized in a systematic and logical way [88], [90].

TTP allow to work through the sequence described in the Chapter 6.2:

1. What to change – description of reality and identification of the conflict and core problem. In short, it can be perceived as the step of diagnosis.
2. To what to change to – verbalization of vision/solution and description of strategy to achieve the desired state.
3. How to make the change happen – it is planning and team building step. It is time for developing the detailed plans that describe what needs to happen and implementing the strategy.

Before describing all types of TTP and their relation to the above questions, two logics should be introduced: sufficiency logic and necessity logic. Sufficiency logic consists of "If...,then...,because..." form and can be expressed as "If..., and if..., and if..., then..." or the "in-order-to, we-musts", describing why situations exist or why actions will result in particular outcomes. Necessity logic takes the form of "In order to..., we must...", describing requirements or prerequisites associated with desired outcomes. TTP are based on these two logical constructs. The different TTP are briefly described below [88].

6.5.1 The Evaporating Cloud

The Evaporating Cloud (EC) is one of the six TTP initially developed by Eliyahu M. Goldratt to enable the improvement of any system. It is a perfect tool to use in case of finding a solution to conflict between two parties or two points of view. That two conflicted parties are trying to achieve the same goal, so EC has to find win/win situation for both.

There are many business situations where someone is placed in a lose/lose situation with the dilemma which of the situation should be chosen. For example:

- On the one hand, supervisor wants to schedule the plant to provide good resource efficiencies; which tends to call for few set-ups and big production batches.

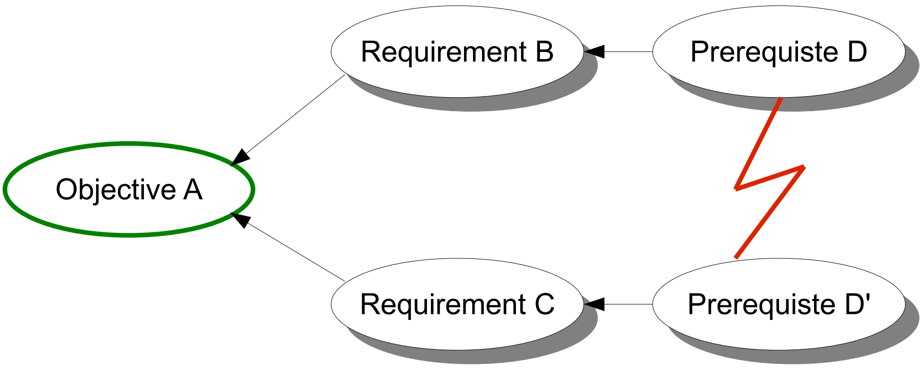

Figure 6.1: The Evaporating Cloud.

- On the other hand, that supervisor wants also to schedule the plant in such a way that customer orders are met on time; and this often calls for smaller batches and more set-ups.

There is a conflict because these two parties are contrary to each other. The dilemma occurs: do one, do the other, do one for a while then do the other for a while or compromise. In fact, the compromise is the most common. Since these both actions aim to reach the common goal this conflict should be overcome.

The EC is a construct of necessity logic, an example in shown in the Figure 6.1. That logic should be read in the following way: in order to achieve A we require B because there is impossible to have A without B, or: there is impossible to reach D and Not D at the same time.

EC is a tool that gives a user the ability to construct a solution that has no compromise. This is one of the most common tools in practice from the TOC's theory. There are many variations of the EC but all have the same mechanism of working and problem solving:

1. Draw the cloud and define the conflict and the common goal.
    - Identify why both parties cannot be met (D and Not D boxes).
    - Identify the underlying requirements (B and C boxes).
    - What is the common goal that ties B and C together (box A)?
2. Gain agreement that the definition is correct.

3. Two traditional questions can be asked:
   - Does Want D block Need C? Draw an arrow from D to C.
   - Does Want D' block Need B? Draw an arrow from D' to B.
4. If above questions do not lead anything to the resolution go to next step that goes deeper to the conflict.
5. Challenge each of the assumptions that are made by both sides in the conflict. Assumptions support the logic of the cloud. Every arrow is supported by one or more assumptions.
6. The links between BD and CD' are desired to be broken because it helps to change the situation. If the resolution of the conflict, preservation of the goal and the needs of two parties are found it will be a win-win solution.

The simple example is shown in Figure 6.2.

6.5.2 The Current Reality Tree

Current Reality Tree (CRT) is another TTP used in TOC. It is a tool that offers possibility of understanding of an existing problems and their underlying causes. In other words, every symptom is an effect of some causes, one or more, so the main goal for CRT is to realize how various problems are related to each other. It is important for CRT to identify root and core problem so as the right solution can be found and applied. This tool detects the constraints in a given situation that limit the desired goal.

CRT helps to answer the first question in TOC – "what to change?". CRT is drawn as a "tree" which shows the causes and their effects for a particular problem. The scheme is shown in Figure 6.3.

CRT uses a sufficiency logic, cause and effect relationships: "if..., then..." or "if...and if...and if..., then...". These components show in a logical order how effects become causes of other effects.

The CRT cause-effect technique is essential for three purposes [68]:

- To understand the rooted causalities of performance problems, and to assess the connection between them.
- To detect the area of potential core problem which contributes to all the performance problems.
- To mark the core problem area that can be responsible for all problems.

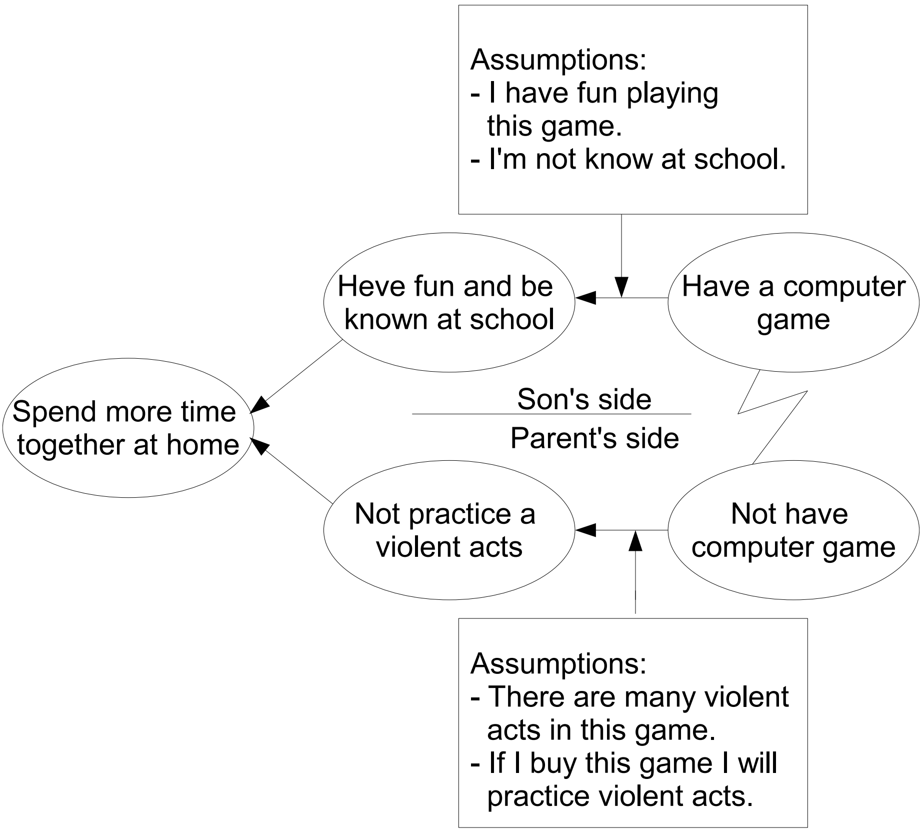

Figure 6.2: Example of The Evaporating Cloud.

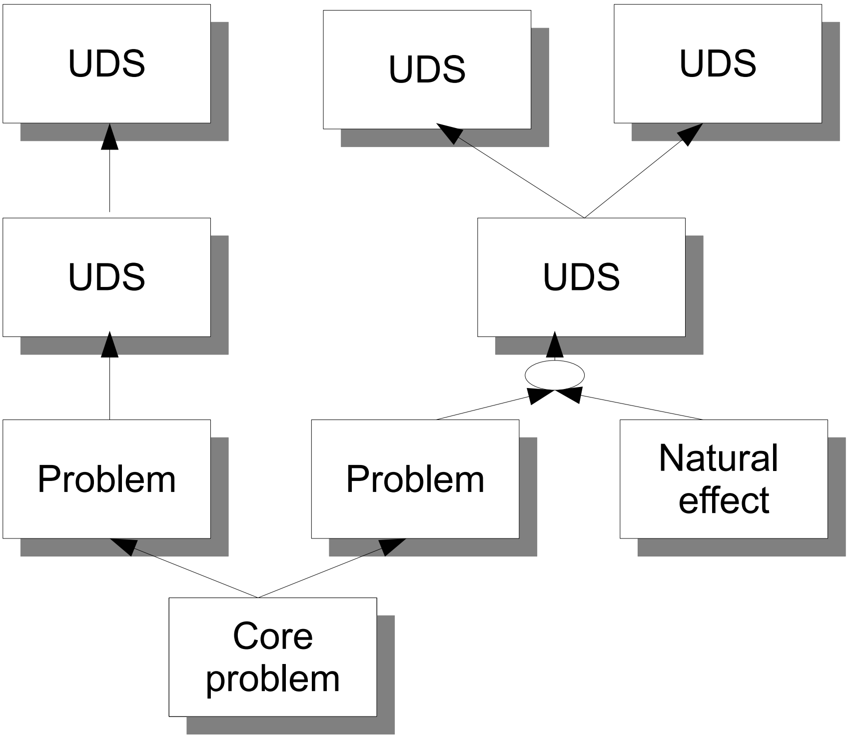

Figure 6.3: The Current Reality Tree.

The analysis of the situation faced by company should be conducted as follows:

- It is necessary to know exactly the problem and causes that leaded to it before constructing the diagram.
- Making a list of all **Undesirable Effects (UDE's)** at the company, as well as recognizing the causes of UDE's.
- Analysis of a relationship between the UDE's because some UDE's can be caused by another.

The example of CRT is shown in Figure 6.4. The power of CRT can be found

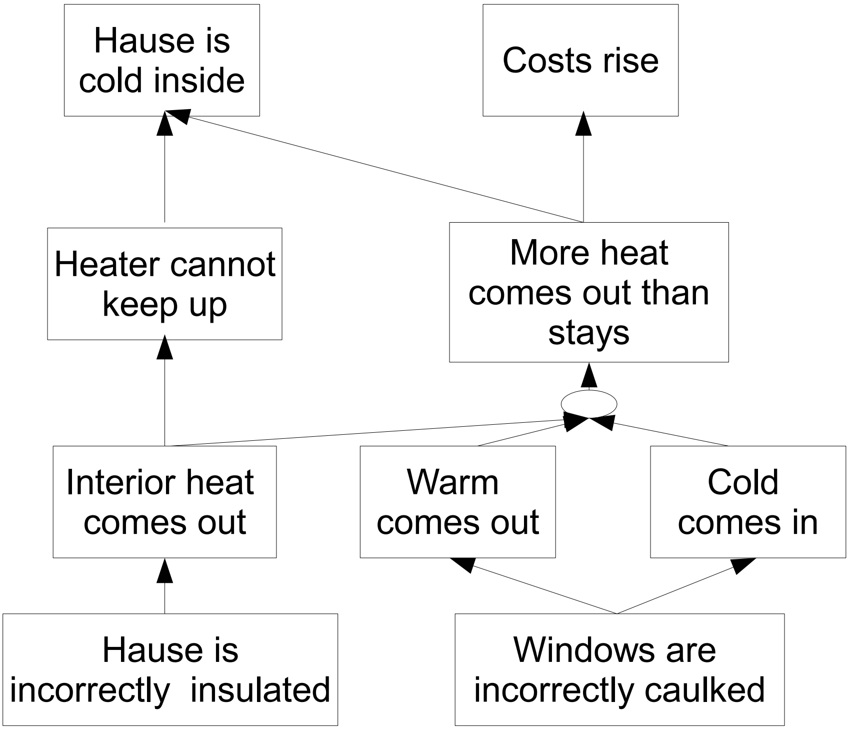

Figure 6.4: Example of The Current Reality Tree.

in the following characteristics [68]:

- Many unrelated performance symptoms can be connected together through a CRT.
- The technique actually forces a rigorous validation of the cause-effect connections.
- The technique can be used to highlight cause-effect relation. It leads directly into the Future Reality Tree where the solution is developed.
- Analysis of a problem is easier due to CRT visual representation. It not only helps recognize the root cause of a problem, but also helps to understand the interaction between the different UDE's.

6.5.3 The Future Reality Tree

The Future Reality Tree (FRT) is similar to the CRT in structure, but with new actions and policies proposed to create a new vision of the future reality of the system. FRT might be thought as CRT with all the UDE's changed to desirable effects (DE's).

FRT is an effective tool for gaining consensus on a plan of action. It uses cause-effect logic to develop a plan to create a future condition, for example to eliminate a suite of performance problems in production. FRT can be con-

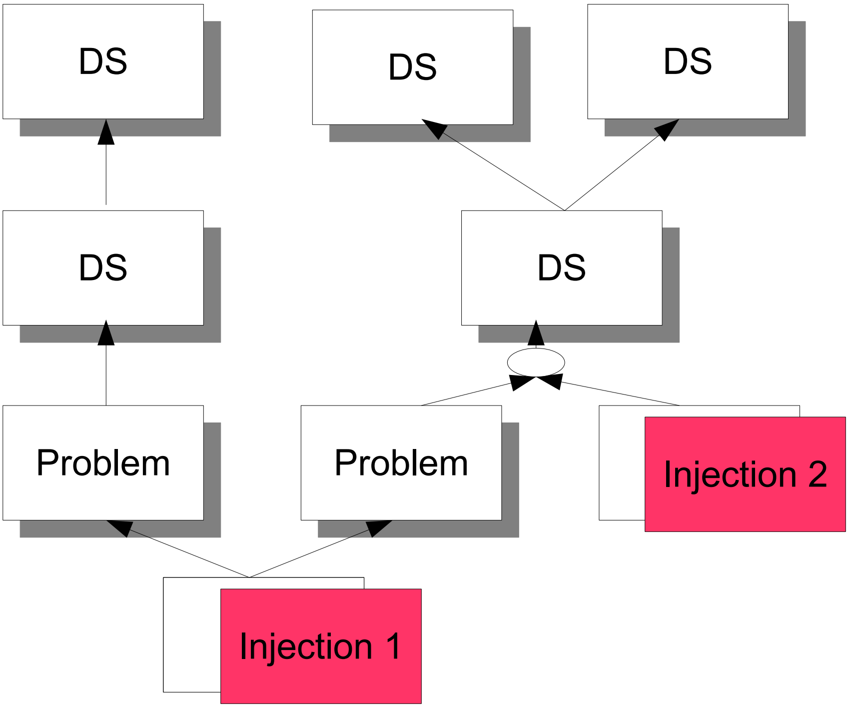

Figure 6.5: The Future Realty Tree.

structed from a CRT with a core conflict, and from a EC. FRT allows to map out future expectations that will introduce something new (that is called injection) into reality, to break a current problem or core conflict. The presence of the new idea or ideas, as **injections**, causes a change from undesirable outcomes of the present to desirable outcomes of the future. Since injections can be developed as new causes, then the resultant effects are able to be predicted and changed. This TOC tool can check where an action or decision might lead or ensure that the negative side effects that can arise are identified in advance. If any of the lower-level causes are removed, everything above is subject to change because of "if-then" logical construction [88]. The scheme is shown in Figure 6.5.

The comparison of FRT and CRT is shown in Figure 6.6. Causes-effect relation is illustrated there. If in CRT one or more causes will be removed or modified, the effect cannot be considered any more as a problem. Fuel, sources of ignition may be isolated from one another to prevent from the fire. On the other way, removing oxygen (possible injections) by covering the fire with water, CO2, or a blanket is also good seen [88].

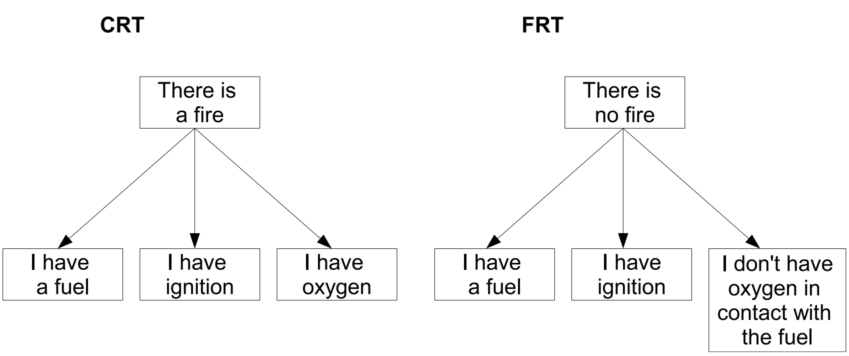

Figure 6.6: The Future Realty Tree versus The Current Reality Tree.[88]

Typical uses of the FRT are:

- Ensuring that all the elements of a solution are present.
- Identification in advance of the negative side effects that can occur even from the best idea.
- Predicting an effect of implementing actions (positive or negative).

6.5.4 The Negative Branch Reservation

The Negative Branch Reservation (NBR) is a modification of the FRT. The combination of the FRT and NBR completes the answer to the basic TOC question – “To what to change to”. It is the tool that helps to define the concern about a risk and the logical cause-and-effect steps that will lead to it.

Reservation exists when an injection introduced in the FRT results in a branch that leads to an undesirable, negative result (Figure 6.7). This situation should be modified by changing the original injection or by adding a new one. Usually it is not the whole solution that leads to the concern but some aspect

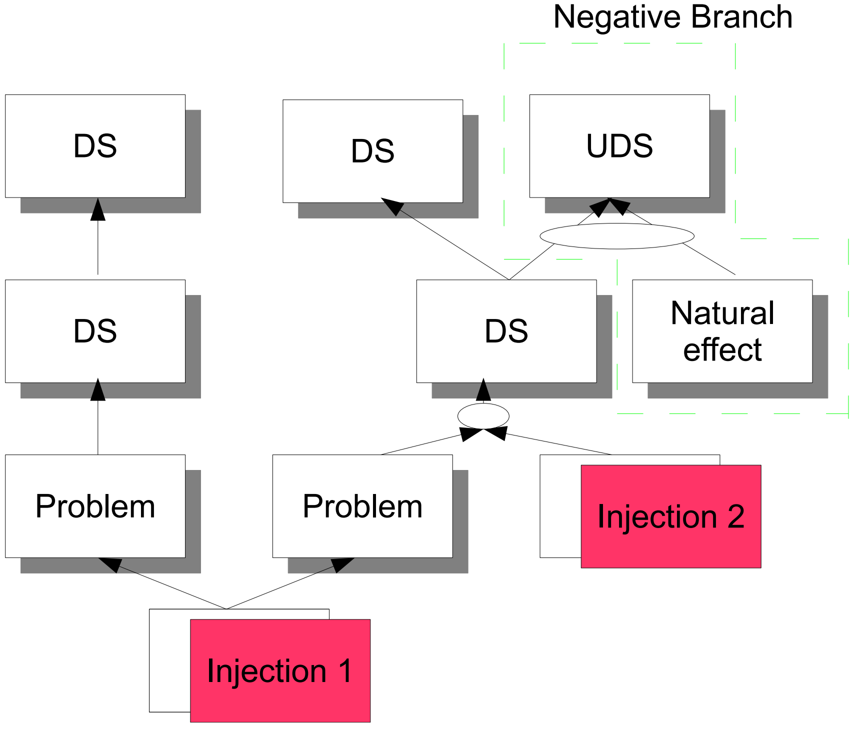

Figure 6.7: The Negative Branch.

of it. The negative branch identifies which aspect of the solution is causing the concern and analyses the logical links form the solution to the predicted negative outcome (the concern).

In the following example (Figure 6.8), it is determined that it is possible to achieve something good for the organization by instituting a new policy. To get the desired good stuff and to avoid the possible negative consequences of our action there is considered the replacement of the lack of understanding of the policy with another action like education and explanation of the purpose of the policy. So that, the misinterpretation and consequently a bad stuff can be avoided [88].

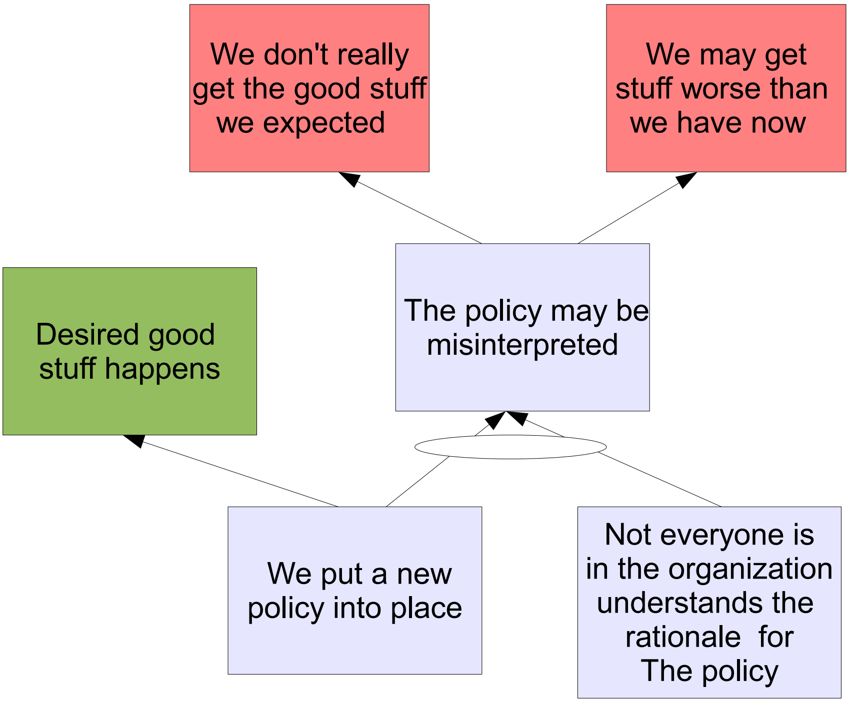

Figure 6.8: Example of The Negative Branch.[88]

6.5.5 The Pre-requisite Tree

The Pre-requisite Tree (PRT) is the next tool created for TTP theory. PRT gives an answer to the last TOC basic question relating to change – "How to cause the change to happen?". The PRT is the tree that allows us to overcome the obstacles that stop the company from implementing a plan. Timelines, responsibilities and accountabilities can be assigned to the PRT.

An example of PRT is shown in Figure 6.9. The diagram should be read from top to bottom. PRT is composed of two elements, **an obstacle (OBS)** and **an intermediate objective (IO)**. The IO is the action that must be undertaken to overcome the OBS. There might be several independent OBS to an injection or several dependant OBS in a chain. The OBS are either things that exist now, which are needed to be removed or overcome, or things that don't exist now and must be obtained [90].

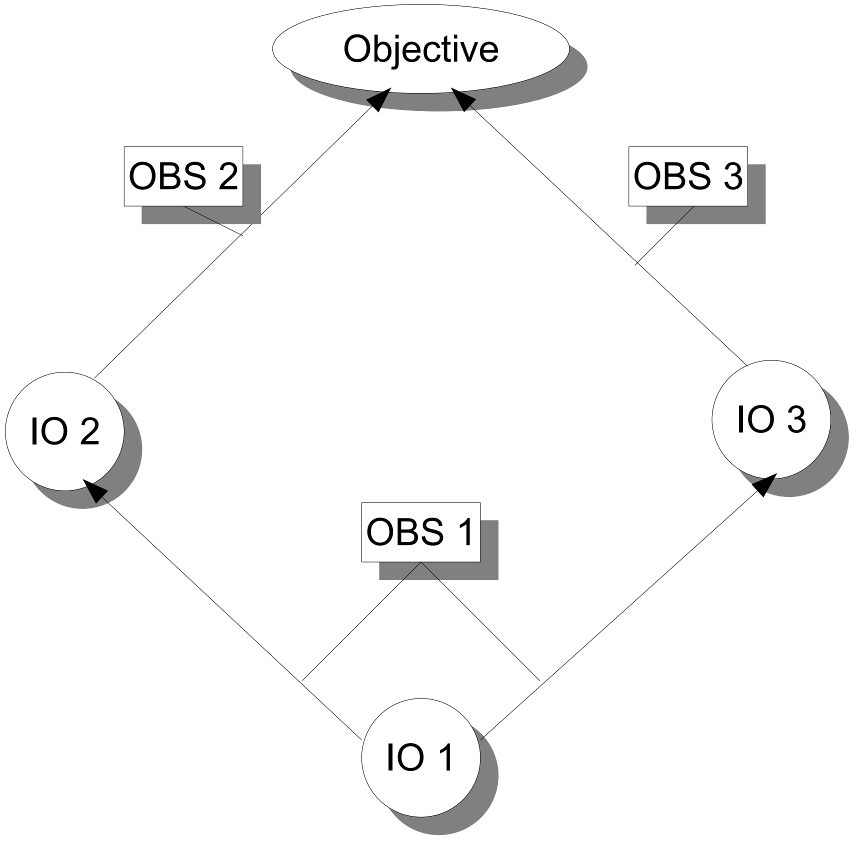

Figure 6.9: The Pre-requisite Tree.

For successful implementation, the company must answer the following questions:

- Where is the firm going?
- What are the obstacles?
- How can the obstacles be overcome?
- How all these elements come together to reach the objective?

The analysis of the situation should be conducted as follows:

1. Determine the objective – "What do you want to achieve?".
2. Identify the first level of OBS – "Why the objective cannot be reached?". The most direct and immediate things that stand on the way to reach the goal.
3. Identify the first level of IO – "What conditions must be created to overcome the OBS?". Each OBS-IO connection is a separate branch of the PRT. OBS can require more than one IO.
4. Repeat steps 2 and 3 for each level of OBS and an intermediate IO.
5. The process should be stopped when the lowest level IO in each branch is known how to be resolved.

The example of PRT is shown in Figure 6.10.

6.5.6 The Transition Tree

The final stage of TTP is a tool called **The Transition Tree (TRT)**. Thanks to TRT and PRT, the third question "How to cause the change?" can be answered. So, what differ TRT from PRT? The main difference is that PRT mentions only what obstacles stand on a company's way of reaching specified goal. PRT also shows the way to overcome obstacles. TRT tells the user whether the intended actions are sufficient to move an organization toward an objective. In case of a negative answer, TRT suggests where and what additional action should be applied.

From the definition, TRT is as a cause-effect planning tool which facilitate drawing a detailed action plan in order to be sure that the desired goal will be achieved. TRT is a communication and empowerment tool which allows the recipient of it to follow a path of action with clear understanding of what to expect along the way. It combines specific actions with existing reality to produce new planned effects. The TRT builds a plan based on the instigator's actions. The TRT includes all the information needed to create a detailed plan, assess its ability to deliver results, and includes those results to allow development of alternative actions to offer new solutions [88].

It is a simple logic that puts the actions in context with the objectives. The TRT includes **the need for action**, **the action**, and **the effect** of the action, that desired and expected result (**objective**). These components are shown in Figure 6.11.

The mechanism of problem solving is as follows:

1. Determine the objective – "What do you want to achieve?". Put this objective on the top of your plane.

2. Determine the first action on the very bottom of a plane – "What should be the first step in order to reach the objective?".

3. Identify the reality and the need – reality is a current situation that is not satisfying, and the need is something to break this situation.

4. Examine the connections – carefully examine the connections between reality-need-action and effect which arises from that relationship in terms of their clearness and completeness. It is important to consider if these causes produce the specified effect and move an organization towards the goal.

5. Verify the first level – make sure that the first level is the beginning, because it is essential for TRT. Maybe something must happened first to give the current situation? If yes build it downwards, if not go to the next step.

6. Determine the next action – look at the effect above reality-need-action relationship and think about a new action which when combined with that effect moves you closer to objective.

7. Determine the next reality/need which arises from the lower level.

8. Determine the next effect of the previous step.

9. Repeat the steps from 6 to 9 until you reach an objective.

In Figure 6.12 there is an example of TRT use.

6.6 Critical Chain Project Management

Critical Chain Project Management (CCPM) in a novel approach to managing projects developed by Goldratt. It is an extension of TOC designed specifically for project environments [10]. CCPM consists of tools for planning, executing and managing projects in single and multi-project environments. This approach was created for the companies that were being affected by delays in the production. Those companies were affected by the following troubles: production time longer than expected, missed deadlines and budget exceeded. The idea of CCPM is to protect the duration of the project against the effects of structural and resource dependency, variation, and uncertainty of individual tasks.

Critical Path Method (CPM) and CCPM are key elements of schedule network analysis. To understand CCPM further it is necessary to know CPM.

CPM is used to determine the shortest time to complete the project (or a phase of the project). It analyzes every possible sequence of tasks and identifies the longest duration path through a network of that tasks. This sequence is called the critical path because it sets the minimum time required to complete the project. Critical tasks (activities) are tasks on the critical path. Scheduled task in the CPM can be characterised by the following four parameters:

- Early Start (ES) – Earliest possible time on which a task can start,
- Early Finish (EF) – Earliest possible time on which a task can finish,
- Late Start (ES) – Latest possible time on which a task can start,
- Late Finish (EF) – Latest possible time on which a task can finish.

Duration of each task is estimated. First the calculation of the earliest possible start date and finish date is done. Then, project management software, by using the calculated project finish date, determines the latest possible start and finish date for each task. The critical tasks have no float – a one day delay on one of these tasks immediately translates into a one day delay on the project. Float time is a period of time a task can slip before it delays project schedule. The example of the CPM is shown in Figure 6.13.

The weakness of CPM is that it does not consider resource dependencies and Critical Path can change during project execution. Contrary to CPM, in CCPM the Critical Chain is defined as the longest chain (not path) of dependent tasks. In this case, dependency refers to resources contention in a projects as well as the sequence and logical dependencies of the tasks themselves.

CCPM eliminates some disadvantages of the Critical Path Method, e.g.:

- Student Syndrome – start of a task at the last possible moment before a deadline.
- Parkinson's Law – work expands so as to fill the time available for its completion.

CCPM is the analysis technique which modifies the project schedule in order to account for limited resources. It is based on optimum use of Buffer (amount of time added to any task to prevent slippage of schedule). CCPM uses safety Buffers to manage the impact of variation and uncertainty around projects. There are three types of buffers in a planning part:

- **Project Buffers (PB)**: Amount of buffer time at the end of the project. It is placed between the last task and the completion date in the project. It protects the project from being late because of any delays on the longest chain of dependent tasks. Those delays will consume only some part of that buffer but will leave completion date unchanged.
- **Feeding Buffers (FB)**: Amount of buffer time at the end of a sequence of tasks. It is placed at the end of each path that feeds the Critical Chain. Delays on paths of tasks feeding into the longest chain can impact the project by delaying a subsequent task on the Critical Chain – this is why FB was introduced.
- **Resource Buffers (RB)**: RB are placed alongside of the Critical Chain. The aim of that buffer is to ensure that the appropriate people and skills are available to work on Critical Chain tasks as soon as needed.

Buffers location is shown in Figure 6.14.

CCPM uses the Buffer Management (BM) to assess the performance of a project. Monitoring project progress is monitoring of the consumption of the buffers. BM shows the amount each buffer is consumed due to the project progress. Tasks are monitored on their remaining duration, not their percentage complete. Resources report upon tasks in progress is constructed for each day until the estimated task completion day. The result is a project completed with the buffer fully consumed on the day it was estimated and committed.

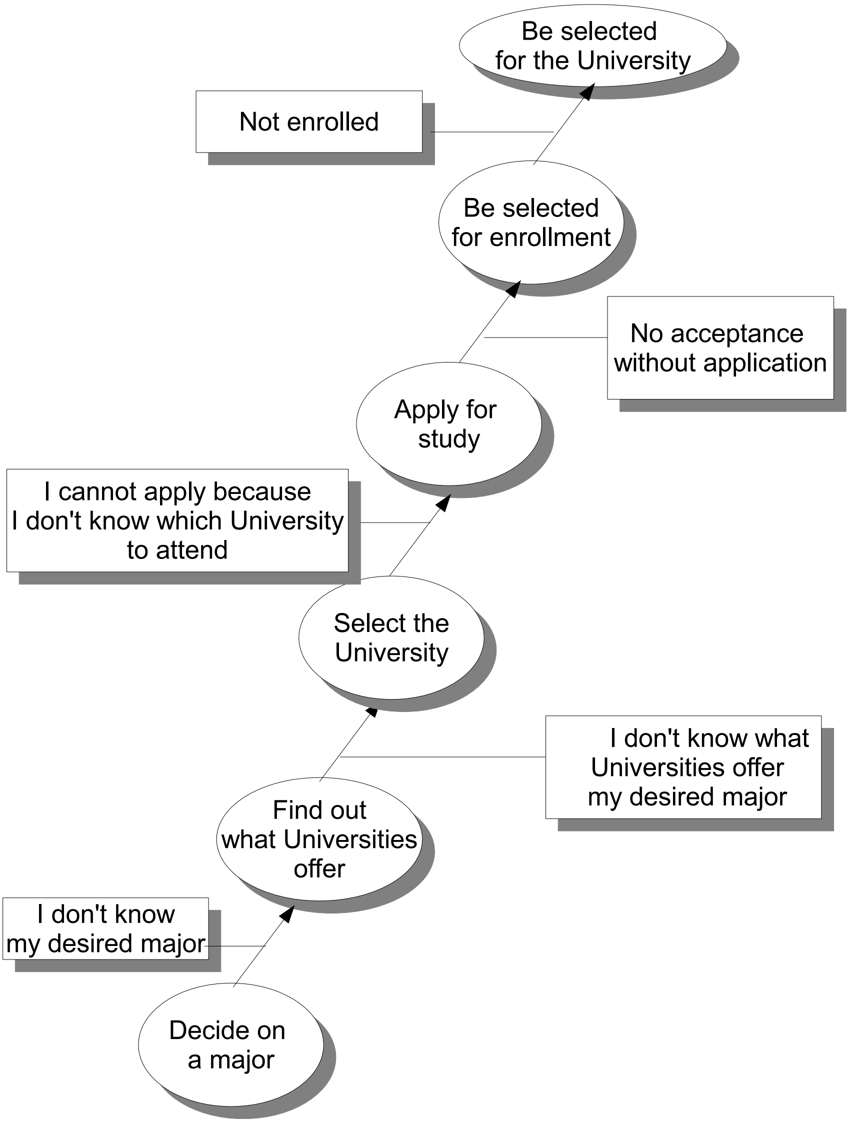

Figure 6.10: Example of The Pre-requisite Tree.

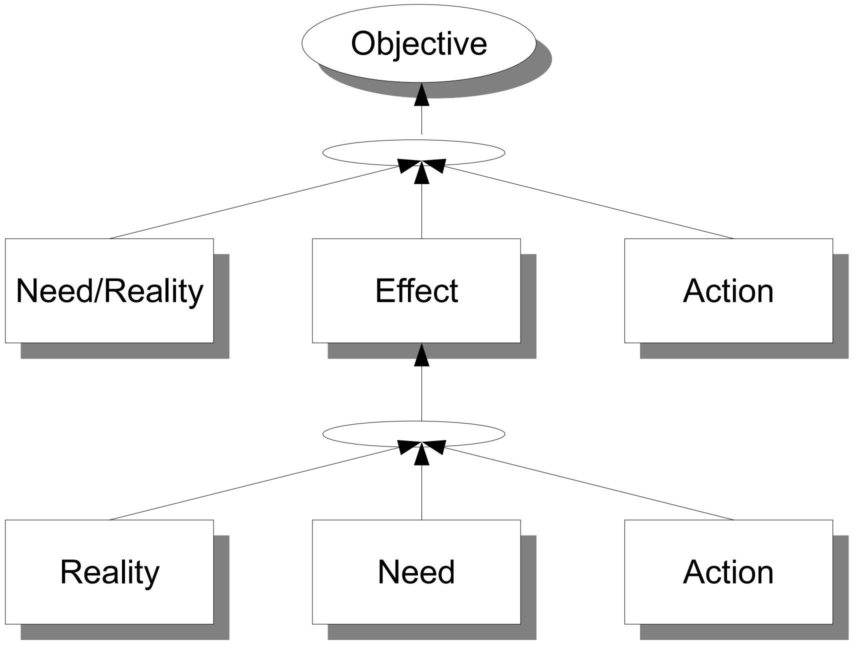

Figure 6.11: The Transition Tree.

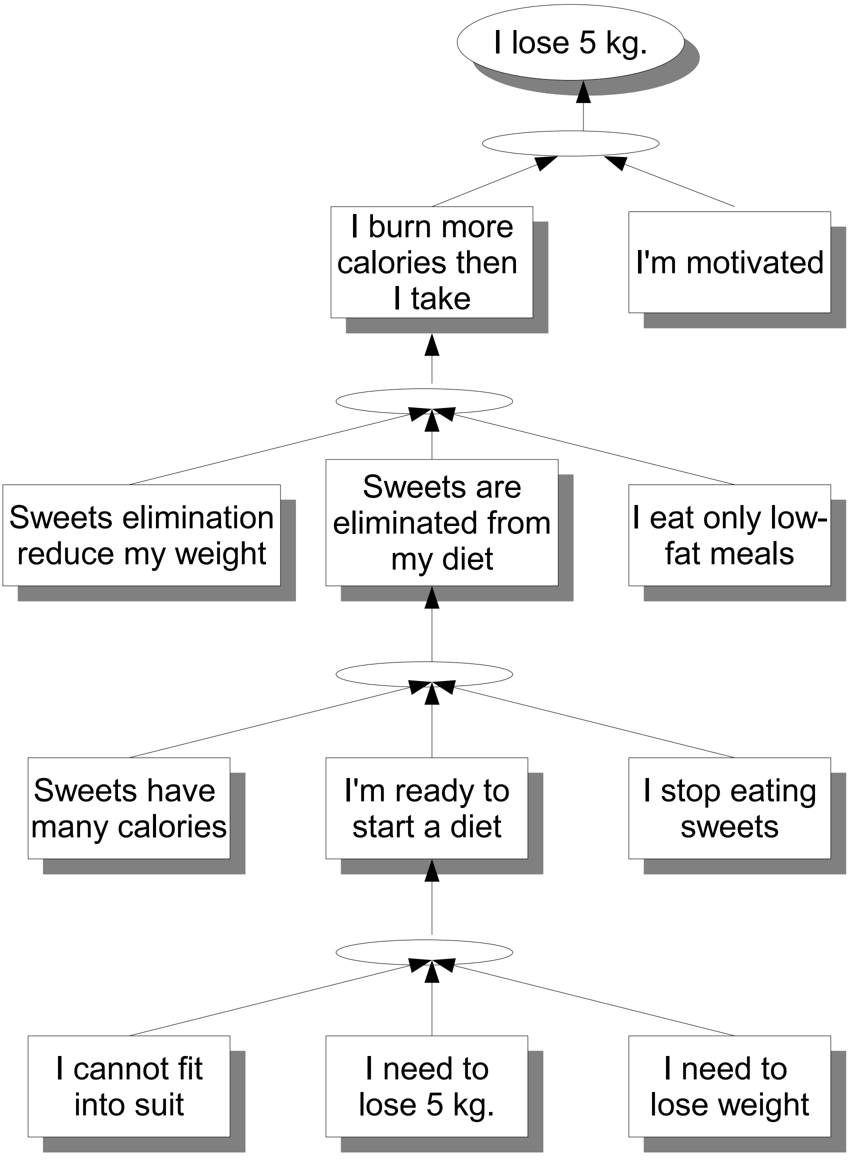

Figure 6.12: Example of The Transition Tree

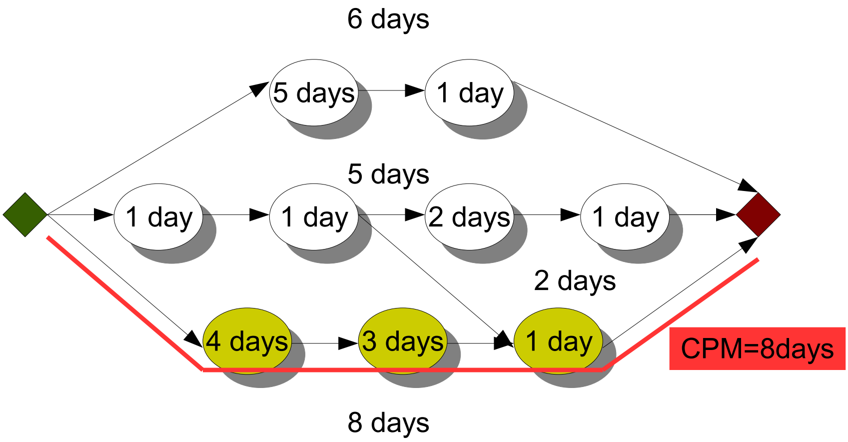

Figure 6.13: Example of The Critical Path

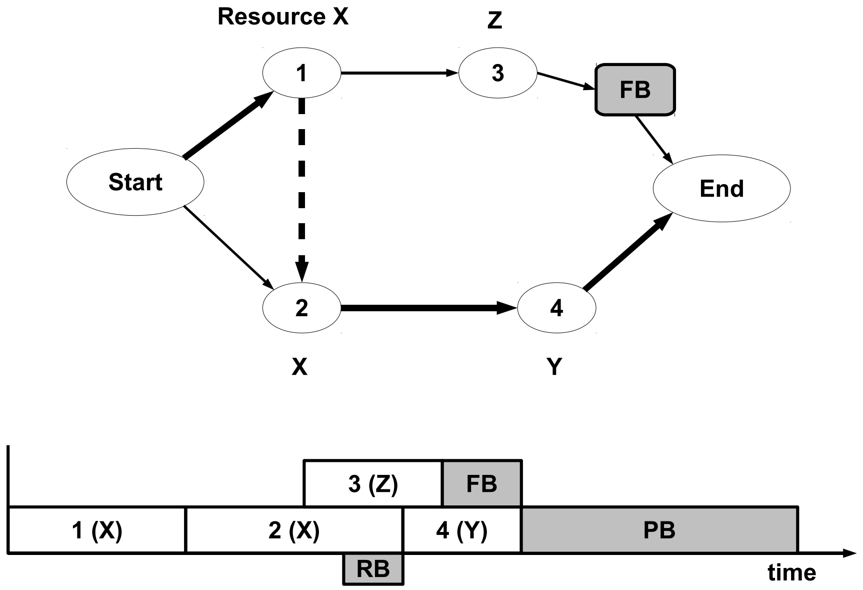

Figure 6.14: Locations of the buffers.

Chapter 7

Decision supporting in Virtual Enterprise Environments and Supply Chain Management

This chapter is devoted to decision support systems in supply chain management and in virtual enterprises. In order to understand how computers can help managers in such business models, it is necessary to characterize these models and analyze problems to face with. The first two sections describe supply chain management and a virtual enterprise, respectively. In the third section, the main concepts of decision support systems in such business models are shown.

7.1 Supply Chain Management

"A **supply chain** is a network of organizations and their associated activities that work together, usually in a sequential manner, to produce value for the consumer" [43]. These networks include e.g. retailers, manufacturers, transportation companies, distributors. It is important to note, that a company can be a part of few supply chains.

Systemic, strategic coordination of the traditional business operations and the tactics across these business operations within a particular company and across businesses within the supply chain in order to improve the long-term performance of the individual companies and the supply chain as a whole is called **Supply Chain Management** (SCM) [53]. Thus a supply chain exists whether it is managed or not, while supply chain management requires overt management efforts by the organizations within a supply chain.

The goal of SCM is to meet customer requirements without any mistakes. In order to provide quality of service and satisfy customers, world-class companies along the supply chain are guided by the *Seven Rights of Fulfillment* [62]:

- the right product,
- to the right customer,
- at the right time,
- at the right place,
- in the right condition,
- in the right quantity,
- at the right cost.

When a supply chain is not well managed or is not managed at all, changes in demand in the supply chain may increase as they move up the supply chain (small fluctuations in demand at the customer level are amplified as orders pass up the supply chain through distributors, manufacturers, and suppliers). This phenomenon is known as the **Bullwhip Effect**.

This effect was observed, inter alia, by Hewlett-Packard. The company's executives noticed some fluctuations in the sales of printers at one of their reseller. However, there were much bigger swings in orders from the reseller. What is more, when they examined the orders from the printer division to the company's integrated circuit division they discovered even larger fluctuations [47].

Consequences of the Bullwhip Effect can be tremendous:

- excess/fluctuating inventories,
- shortages/stockouts,
- longer lead times,
- higher transportation and manufacturing costs,

- mistrust between supply chain partners.

In order to minimize the effect, the customer demand should be visible to every member of the supply chain as soon as possible. This can be done only by information sharing. The solution for the problem is known as a demand-driven supply chain

SCM is thought to be one of the most important new business concepts [58]. In the era of globalization firms are forced to develop supply chains which can quickly respond to customer needs [86].

7.2 Virtual Enterprise

A **Virtual Enterprise** (VE) (also called a virtual organization or a virtual corporation) is an emergent business model and it does not have one good definition yet [83]. However, a VE is usually defined as a voluntary temporary alliance of possibly geographically dispersed enterprises that share skills or core competencies and resources to respond to business opportunities. For the external observer a virtual corporation appears as a unitary enterprise [64]. Contrary to traditional corporations, there is no hierarchy and no vertical integration in a virtual corporation. Virtual organizations differ from classical supply chains in duration (VE can be a short-term alliance) and extensive use of information and communications technology (**Information Technology** (IT) is essential for co-operation in a VE). Table 7.1 shows more differences between supply chains and virtual organizations.

Actually, a Virtual Enterprise is not a new concept, but recent rapid growth of information technology caused a decline in coordination costs. Companies are now able to form partnerships of specialized firms coordinated through decentralized information systems [83].

Virtual Enterprises go through four phases during their life cycle: creation, operation, evolution and dissolution [101]. The first thing to do in the creation phase is the definition of the business to be developed and it may be triggered by a client need or by a market opportunity detected by an enterprise [15]. Then the enterprise searches potential partners and negotiates with them. When all contracts are signed, the next phase starts. In the operation stage participants of the VE do the intended business. If product is completed and new market opportunity is created or any unexpected events occur, the Virtual Enterprise can be reconfigured (some members leave the VE and others join it). When the mission of the VE is fulfilled the VE is finally dissolved.

Table 7.1: Comparison between supply chains and virtual enterprises. Source: [67].

	Supply Chain	**Virtual Enterprise**
Main purpose	Increase competitiveness across the product value chain	Exploit specific business opportunities
Organisational structure	Stable organisation	Dynamic and temporary network
Coordination	Usually the largest company coordinates the partnership	All VE members participate equally in management decisions
Duration	Long-term business cooperation based on contracts	Temporary network for specific business opportunity
Participation	An enterprise can participate in different SCs, but exclusiveness can also occur	Multiple networks
Suitability of the product life cycle concept	Throughout the entire life cycle	Focus on the creative phase
Speed of industrial innovation	Usually found in traditional and stable industries	Most suitable for innovation-driven industries
Usual market qualifiers' competitive criteria	Quality, lead time and service level	Quality, cost and lead time
Usual market winners' competitive criteria	Cost	Service level
Main demand characteristics	Are predictable and it is needed as a mechanism to forecast the sales	Are volatile and it is necessary to consult (via broker) the market needs

The most important advantage of a virtual organization is a synergy through use of core competencies of members of the organization. A virtual organization merges dispersed resources and competences and becomes a compilation of unique merits of its members [13]. Every activity is intended to be done by the member who can do this best. Membership in a virtual corporation is especially beneficial for small firms, which do not have enough resources to compete with big companies. In VE they can accomplish economy of scale.

Another advantages of a Virtual Enterprise are flexibility and adaptability. Because of less levels of bureaucracy, a VE can adapt to a dynamic environment more quickly than traditional hierarchical organizations. In virtual organizations order-to-delivery cycle times can be reduced. As a result, the feedback from the market is received earlier.

However, there are also disadvantages of a virtual organization. The selection of partners is the first challenge that the creator of the VE has to face with. Members of the VE should have complementary competencies, enough capacity, proprietary experience and be prepared to cooperate in a virtual organization. What is more, the manufacturing cost and time to market should be taken into consideration. Any mistake in this phase may cause failure in the future.

Some difficulties may be caused by decentralization and lack of formal leadership in a virtual organization. It may be hard to check partners because of geographical dispersion. Cooperation of different companies in different cultures and managed in different styles is not easy as well [13].

The above advantages and disadvantages are strongly connected with information system in Virtual Enterprise. Information Technology plays a major role in overcoming disadvantages and getting advantages of virtualization.

7.3 Decision support systems

Manager's work can be divided into two phases. Identification of problems and opportunities occurs in the first phase. The second phase is decision making, e.g. how to solve the problem. In the identification phase information plays the major role. It comes from many sources, e.g. databases, magazines, newspapers, government's reports, personal contacts, etc. Because of a large amount of data it is difficult to catch the vital information.

For many years it has been thought that decision making is quite an art, that reflects the practical experience gained through the process of trial and error. However, the environment in which managers have to work is becoming more and more turbulent, complicated and complex. For that reason it is harder nowadays to make decisions than ever before. Firstly, there are more alternative solutions and a choice of the best one is difficult. Secondly, the cost of a mistake might be high, because of the complexity and a possible chain reaction in other parts of the organization. What is more, many decisions should be made under time pressure and manual data processing is even impossible [42]. In order to support business or organizational decision-making activities a computer-based information systems are necessary.

7.3.1 Conventional systems

Conventional strategic thinking is focused on individual firms. In order to reduce costs and achieve organizational effectiveness, companies deploy enterprise-focused systems such as **Enterprise Resource Planing** (ERP) systems. However, independent facility management (i.e. vendors, manufacturing and assembly plants and distribution centers) in supply chain or in a VE can result in poor system efficiency [86]. The solution is a management of the entire supply chain.

7.3.2 Advanced Planning and Scheduling systems

In 1990s a new breed of add-on software to ERP appeared — **Advanced Planning and Scheduling** (APS) systems [58]. These applications collect operational data and help managers analyse and optimize flows of goods in the supply chain [43].

Along a supply chain many decisions have to be made and coordinated every minute. Managers have to decide e.g. which job has to be scheduled next on a certain machine or if it is rational to open a new factory. Every decision should be prepared. This preparation is the work of planning and it can be divided into the following phases [23]:

- recognition and analysis of a decision problem,
- definition of objectives,
- forecasting of future developments,
- identification and evaluation of feasible activities (solutions),
- selection of good solutions.

Plans are always restricted to a predefined planning horizon. We can distinguish three planning levels [6]:

	procurement	production	distribution	sales
long-term	•materials programme •supplier selection •cooperations	•plant location •production system	•physical distribution structure	•product programme •strategic sales planning
mid-term	•personnel planning •material requirements planning •contracts	•master production scheduling •capacity planning	•distribution planning	•mid-term sales planning
short-term	•personnel planning •ordering materials	•lot-sizing •machine scheduling •shop floor control	•warehouse replenishment •transport planning	•short-term sales planning

flow of goods →

Figure 7.1: The Supply Chain Planning Matrix. Source: [24].

- long-term planning (strategic decisions that should create the prerequisites for the development of an enterprise or a supply chain in the future),
- mid-term planning (an outline of the regular operations, in particular rough quantities and time periods for the flows and resources in the given supply chain),
- short-term planning (all activities as detailed instructions for immediate execution and control).

The last two planning levels are called operational.

Typical tasks within a supply chain can be classified in two dimensions: "planning horizon" and "supply chain process". Such classification is called the **Supply Chain Planning Matrix** (SCP-Matrix) [24] and is shown in Figure 7.1.

There are many different APS systems made independently by different software companies. However, APS usually are formed from several software modules covering a certain range of planning tasks [70]. Figure 7.2 shows these software modules covering the SCP-Matrix.

Since SCM is driven by demand, available and planned customer orders form an input to the planning module. Note that there is a difference between demand forecasting and demand planning. The plan is made by adding to the formal demand forecasts those exceptional influences expected to happen and their impact on sales [82].

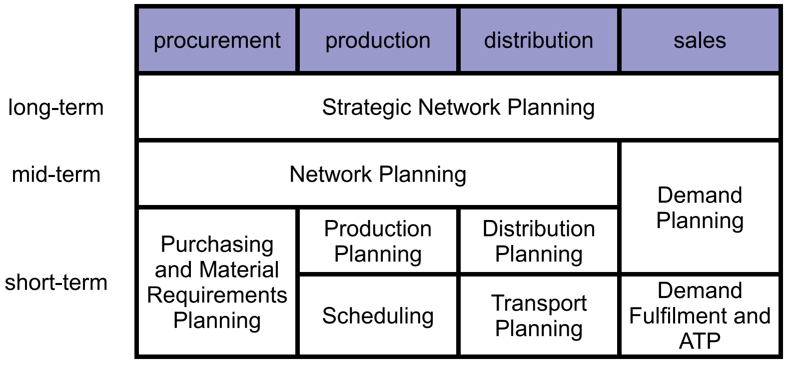

Figure 7.2: Software modules covering the SCP-Matrix. Source: [54].

In the strategic network planning module the location of facilities, warehouses, and geographical customer areas to be served are determined. Also, the capacity of these facilities as well as the transportation means (ships, trucks, railway, etc.) to use are decided upon [82].

Master planning looks for the most efficient way to fulfil demand forecasts over a mid-term planning interval (usually a full seasonal cycle). In this module not only demand forecasts are balanced with available capacities, but also demands (production amounts) are assigned to sites in order to avoid bottlenecks [82].

Operations which may become bottlenecks are planned in the production planning module. In case of the loading of machine groups both production planning and detailed scheduling should be performed simultaneously [82].

In the purchasing and material requirements planning module procurement quantities are calculated. Furthermore, this module is needed for planning of non-bottleneck operations because only potential bottleneck operations are planned in production planning and detailed scheduling [82].

In the distribution planning module transports of goods to customers (directly) as well as via warehouses and cross docking are planed. When production amounts are not equal to current period's demands, some changes are applied to guide the flow of goods within the SC [82].

Transport planning consists of forming truckloads for different destinations and sequencing customer locations on a vehicle's trip (vehicle routing). However, there is a trend in Europe towards utilizing a third party logistics provider (3PL) for transportation. Often a 3PL can consolidate orders from different SCs, so it performs transport planning by itself using special purpose software [82].

The demand fulfilment and available-to-promise module performs two functions. The first is tracking customer orders from order entry, via order execution to order delivery and the second is order promising, due date setting and shortage planning [82].

The SCP-Matrix contains few activities. What is more, some of them are very complex (e.g. the number of alternatives in sequencing jobs on a machine may be combinatorially large) and it is impossible to find an optimal solution by enumeration of all alternatives. For that reason APS systems use the mathematical methods of operations research (e.g. Linear Programming, network flow algorithms) [24].

The APS systems rely on historical demand data to forecast and manage future demand. However, the current market is very dynamic, product life cycles are short and demand history is often not sufficient [43]. For that reason the APS systems may not work well in modern supply chains and in virtual organizations.

7.3.3 ERP II

ERP systems had a great impact on industry during the past decade [74]. However, the main ERP limitation in the global market is the lack of communication and integration between suppliers and customers [57]. At the turn of the 21st century a new standard of computer-based systems for managing an enterprise was shown. It was called **ERP II**. The new standard differs much from the ERP (the most important differences are shown in Table 7.2). Its main idea is collaborative-commerce (c-commerce). In a traditional model companies compete only on cost and quality of their products and services, but in collaborative world they compete also on the quality of information that they share with their partners [12].

ERP II expands the role of ERP. It does not include only resource optimization and transaction processing, it eases collaboration with other enterprises as well. Contrary to ERP, EPR II's domain includes also non-manufacturing industries [12].

The aim of the new architecture is to transfer the ERP system from an inwards solution to an outwards solution. The ERP II combines "front-office" tools such as Customer Relationship Management (CRM), Supply Chain Management (SCM), and collaboration and coordination platforms with the "back-office" represented by the ERP system [57].

Table 7.2: Differences between ERP and ERP II. Source: [12].

	ERP	**ERP II**
Role	Enterprise optimization	Value chain participation/ c-commerce enablement
Domain	Manufacturing and distribution	All sectors/segments
Function	Manufacturing, sales and distribution, and finance processes	Cross-industry, industry sector and specific industry processes
Process	Internal, hidden	Externally connected
Architecture	Web-aware, closed, monolithic	Web-based, open, componentized
Data	Internally generated and consumed	Internally and externally published and subscribed

In [58] a conceptual framework for ERP II was shown. The framework is illustrated in Figure 7.3. It consists of four layers:

- the core components: the foundation layer;
- the central component: the process layer;
- the corporate components: the analytical layer;
- the collaborative components: the e-business layer.

The foundation layer is the core component of ERP II and the basic architecture. It consists of integrated database and application framework.

ERP is the central component in the framework. The traditional ERP modules like finances, sales and distribution, logistics, manufacturing, human resources are still the backbone of ERP along with additional modules like quality management, project management and maintenance.

The analytical layer comprise the corporate components that enhance and extend central ERP functions by providing decision support for the management of relations and corporate issues. It consists of supply chain management (SCM), customer relationship management (CRM), supplier relationship management (SRM), product life cycle management (PLM), employee life cycle management (ELM), corporate performance management (CPM).

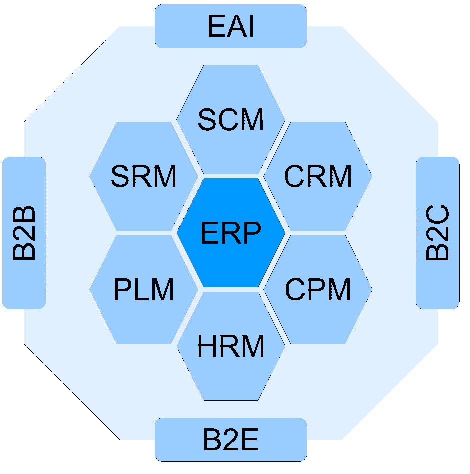

Figure 7.3: The conceptual framework for ERP II. Source [58].

The e-business layer is the portal of ERP II. The collaborative components deal with communication and integration between the ERP II system and external actors: business-to-consumer (B2C), business-to-business (B2B), business-to-employee (B2E), enterprise application integration (EAI).

Nowadays, when enterprises are driven to pursue extended-enterprise, collaborative relationships with customers, suppliers and partners, ERP II seems to be the best business application strategy while ERP is obsolete [12].

7.3.4 Multi-agent systems

Another concept of decision-making system for VE or SCM is a **Multi-Agent System** (MAS) which is a part of the domain of Distributed Artificial Intelligence. In this approach, every action is a result of interactivity between autonomous and relatively independent entities called Agents [51].

MAS is analogous to a digital ecosystem. It is a society of cognitive agents having knowledge and skills. Agents have also their own goals, plans, intentions and beliefs and communicate with each other by asynchronous messages. What is more, they can learn and cooperate in order to reach their goals, even with remote agents in other companies [51].

Figure 7.4 shows an exemplary agent-based SCM. The system receives orders from the customers and generate plans based on availability of raw materials,

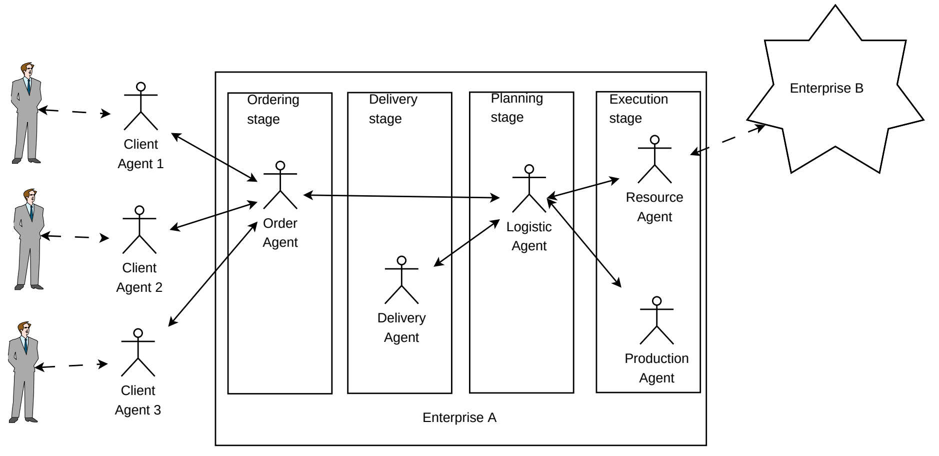

Figure 7.4: Agent-based SCM. According to [5].

storage capacity and delivery due-dates specified by the clients. The logistic agent consults with other agents and determine the best way to deliver the final product to the customer. If meeting clients' demands is not possible because of some constraints in the company collaboration may be extended to other units in the VE [5].

7.3.5 Electronic Data Interchange

Firms within a supply chain routinely communicate with each other. This interorganizational communication can occur in many ways. A very common form of transferring data between companies is **Electronic Data Interchange** (EDI) [35].

EDI is computer-to-computer transmission of standardized business transactions. It allows organizations to seamlessly receive and send business documents to/from their trading partners and update their internal systems automatically. Electronic Data Interchange can be divided into three basic processes [66]:

- directing data to and gathering data from different application programs;
- converting data from proprietary formats (as used by application programs) to standard formats (as transmitted by the communication network) and reversing this process at the other end; and

- actual transmission of data between trading partners over a communication network.

Benefits of EDI include [66]:

- a faster trading cycle – electronic transmission of business data compresses time;
- the ability to adopt new business processes such as Just-In-Time (JIT) manufacturing techniques;
- enhanced competitiveness through a win-win partnership;
- increased productivity;
- improved customer service;
- faster communication between trading partners leading to reduce inventory and inventory carrying costs;
- improved accuracy of information and error reduction through the elimination of the need to rekey data;
- reduced operating costs.

Therefore, EDI's influence on changes in supply chain structures and relationships is immense [97].

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