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Process analysis and optimization

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INTRODUCTION

The goal of this textbook is to provide a teaching material to the subjects Process Planning and Analysis I. and II. as well as Lean methods. Besides, this book can be useful for every subject, where the topic of design or improvement of any industrial processes emerges. The textbook is based on selected topics of the field of operations management, thus it uses its approach and vocabulary and draw a lot from literatures such as [1-3]. We used the extensive literatures of the field of industrial engineering [4-5] as well as books which focus on narrower topics in detail [6-7]. The limits of this textbook didn't let us to discuss every important topic in detail, instead we would like to provide the big picture about the theory and tools of design and development of industrial processes.

1. THE INPUT-TRANSFORMATION-OUTPUT MODEL

It is beyond doubt, that the ultimate goal of every company is to maximize shareholder value. However, the question arises, what exactly the shareholder value is. Formerly, this value was defined only in terms of monetary profit, but it has been changed over the time. Companies today try to balance profit with social obligations to customers, employees, and partners. Due to this tendency, fulfilling the customer needs has become as important as making profit. The companies have also recognised, that by setting the goal of delighting their customers, they can reach even higher profit, than by focusing merely on the profit.

To fulfil the requirements of their customers companies must create and deliver some type of services and/or products. To be able to do that, an organization in general has three core functions. They are the marketing function, which is responsible for generating customer demands, the development function, which is responsible for the new products, and the operations function, which creates the products or services for the customers. Naturally, besides these functions other supporting functions, such us finance-, technical-, human resource-, and information systems functions, are also necessary. In this textbook we will focus merely on the operations function.

As stated, operation is the activity of creating and delivering products or services. During operation a set of input resources are transformed into the required outputs. In Fig.1. this general transformation model can be seen.

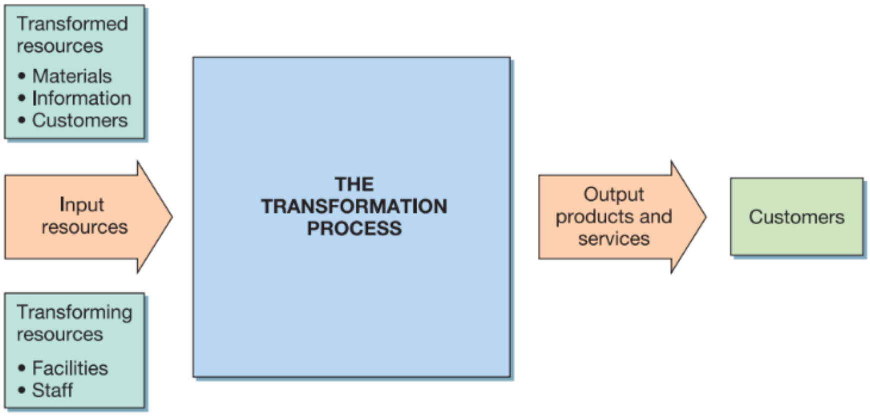


Fig.1. The input-transformation-output model [2]

Based on the nature of inputs and outputs we can distinguish various operation processes. If the output is rather intangible, and created and delivered at the same time, and if the process is highly visible to consumers we talk about services. If the output is tangible, and the transformation process is typically converts one form of material into another form through chemical or mechanical processes, then the output is regarded as a product, and the process itself is called production or manufacturing process. Today the goods and services offered by the companies are often occur jointly, therefore it's getting more difficult and useless to make difference between service and product. However, in this textbook we will focus only on production, knowing, that the general rules and conclusions are valid for both products and services.

Looking at the input resources of a transformation process, we can make difference between transformed and transforming resources. Transformed resources involve material, information, or customers, that is resources which are treated or converted during the process. Transforming resources act on the transformed resources, and include facility (for example: buildings, equipment, technology) and staff (for example: machine operator, maintenance staff, production planner, manager).

The transformation process, that is the production itself is carried out in systems, which are the arrangement of resources designed to achieve the desired objectives. Any system is part of a higher- level system, and, at the same time, can be divided into several subsystems as well. Similarly, all transformation processes consist of a collection of sub-processes, which act together as part of a network. In such a network a process is supplier and customer of other processes at the same time. The sum of these interacting systems and processes is called supply chain, or – as any process can have several suppliers and customers – supply network. Due to this system approach, a hierarchy of systems and processes can be recognised, which helps us to identify, analyse and solve the problems of transformation processes. A level of analysis could be as high as the whole supply chain, or as low as individual process steps.

2. ACTIVITIES OF OPERATIONS MANAGEMENT

In connection with the management of a transformation process there are four main activities to consider. These are according to [2] direct, design, deliver and develop:

- “Directing the overall nature and strategy of the operation. A general understanding of operations and processes and their strategic purpose and performance, together with an appreciation of how strategic purpose is translated into reality, is a prerequisite to the detailed design of operations and process.
- Designing the operation’s services, products and processes. Design is the activity of determining the physical form, shape and composition of operations and processes together with the services and products that they create.
- Planning and control process delivery. After being designed, the delivery of services and products from suppliers and through the total operation to customers must be planned and controlled.
- Developing process performance. Increasingly it is recognized that operations managers, or indeed any process managers, cannot simply routinely deliver services and products in the same way that they always have done. They have a responsibility to develop the capabilities of their processes to improve process performance.”

This textbook focuses on the design and develop of the transformation system, although it’s obvious, that for proper design and develop one must have deep knowledge in planning and control as well.

2.1. Strategy of the operations function

An organization defines the reason of its existence in its mission statement. This mission statement is the basis for determining the organizational goals. Based on the detailed organizational goals the management can develop the organizational strategy, which, in turn, determines the goals and strategies of the certain functions of the company as well. Naturally, the functional strategies should support the organizational strategies, as well as the organizational strategies should support the goals and mission of the organization. According to [3] basically there are three business strategies: low cost, responsiveness (ability to respond to changing demands), and differentiation from competitors (in terms of product features, quality, customer service, etc.).

While the organizational strategy determines the overall direction of the organization, functional strategy is narrower in scope. Operations strategy relates to the operations function, focuses on products, methods, quality, costs, times, etc.., and thus, it determines the role and objectives of the operation. In general, the operations strategy is expected to improve operations performance. The operations performance can be measured based on the performance objectives of operations. According to [3] these objectives are quality (product performance), cost (low price), speed, dependability (reliable, timely delivery) and flexibility (rapid response with new products or changes in volume). In fact, the

improvement of one objective could also improve other objectives:
for example, improving quality has a large effect on all other objectives. Nevertheless, in practice there may be a "trade-off" between these objectives. This is the role of the operations strategy to establish priorities among these objectives to be able to compete on the market.

There are various approaches to plan operations strategies. According to [2] these could be:

- Top-down strategies: the strategy is derived directly from the corporate strategy.
- Bottom-up strategies: the strategy is influenced by the experiences and capabilities of the individual functions.
- Market-requirements-based strategies: the focus is on the competitive factors, which define the requirements of customers. We can distinguish between "order-winning" and "qualifying" factors. "Order-winning" factors significantly contribute to gain more business, while "qualifying" factors are not determinant of success. Improving "qualifying" factors over a certain level doesn't result in competitive benefit (but reaching that level is a must).
- Resource-based strategy: it involves exploiting the capabilities of operations in chosen
markets.

2.2. Decision areas and design activities

Decision areas of operations strategies include [3]:

1. Product and service design
2. Capacity
3. Process selection
4. Layout
5. Work design
6. Location
7. Quality
8. Inventory
9. Maintenance
10. Scheduling
11. Supply chains

These strategic decision areas can be divided into structural and infrastructural decisions. Infrastructural decisions have influence mainly on the organization of the workforce, the planning and control activities, and thus, they involve job design, planning, control, inventory, improvement, etc.. Structural decisions involve decisions in connection with new product design, supply network design (capacity, location, etc.), and process technology. The design activities are primarily influenced by the structural decisions. As this textbook focuses on the design, in the following we will concern mainly those topics, which are in connection with these structural decisions.

In the design phase of a transformation process, the activity is carried out in different levels of detail. At the beginning the overall shape and nature of the process is determined, then we consider the fundamental questions of the supply network, location, process layout, etc.. Finally, the details of the workplace and work have to be determined, sometimes as deep as individual motion-elements of the worker. It must be noted, that this design process – similarly to design in general – is not a straight sequential process, it has always loops, corrective steps, in which analysis and synthesis alternate.

In the following chapters we will discuss some of the above-mentioned activities.

3. DESIGN OF THE TRANSFORMATION PROCESS

The design of the transformation processes or the transformation system involves planning for the inputs, conversion process and outputs of production operation. During the design several decisions have to be made, which should be based on as accurate information about the future demand as possible. Since companies want to fulfil the customer requirements, the forecast of these requirements serves as the basic input to planning and management, as well as design of the transformation system. The design decisions need generally long-term forecasts. There are a large variety of qualitative and quantitative forecasting technics, but to get a good result they are usually applied in a combination.

3.1. Product design

However, the limits of this textbook, don't let us to deal with the product design in detail, we have to mention the most important aspects of it, because, without doubt, the product (and service) itself is the essence of a company, and thus, it has a major effect on cost, time-to-market, customer satisfaction, quality, etc.. The most important note here is, that product design mustn't be treated separately form process design. They have a strong effect on each other, therefore in an ideal situation the product and process design carried out parallel. This approach is called simultaneous or concurrent engineering, and it means "bringing design and manufacturing engineering people together early in the design phase to simultaneously develop the product and the processes for creating the product" [3]. Recently, according to this concept other functions, such as marketing and purchasing, as well as customers are involved in the product design process.

The product design is influenced by a lot of factors (for example: product life cycle, environmental considerations, legal constraints, human and cultural factors, etc.). Here we discuss only those, which significantly affect the production process.

3.1.1. Standardization

An important aspect is the degree of standardization, which "refers to the extent to which there is absence of variety in a product, service, or process". With a highly standardized product the quality and the reliability can be increased, while time-to-market and costs (training, job design, inventory handling, scheduling, etc.) can be decreased. While the lack of variety has clear advantages for the companies, due the fact that customers prefer many options to choose from, it entails some risk as well. To overcome this opposition companies introduced mass customization, which means "the ability to produce products or services in high volume, yet vary their specification to the needs of individual customers or types of customer" [2]. Two possible tactics to realize this are delayed differentiation (postponement the completion of the production until customer specifications are known), and modular design ("parts are grouped into modules that are easily replaced or interchanged").

3.1.2. Robust design

An important aspect is, how sensitive a product is to a change in the environment. As a result of the concept of robust design, the product can function without failure over a wide range of conditions. It pertains to the production process as well. In case of an ideal product design, the product quality is resistant to the influences of the production process. It means, that relatively small changes in the technological parameters, or any variation inherent in the manufacturing process won't negatively affect the quality.

3.2. Process selection

Process selection is one of the fundamental decisions of the operations strategy. It basically determines the production, but it has significant effect on the entire organization (equipment, labour requirements, operations cost, capacity range, flexibility, management) as well. Process selection is necessary not only in case of new products, but as reaction for the changes of the technological possibilities or market environment.

In general, the process is designed based on the required volume and variety. Usually these factors are related in a reversed way to each other. Process selection means the positioning of the production system in the volume-variety coordination system. There are five major process types: project, job shop (or jobbing), batch, repetitive (or mass-), and continuous process. According to [1] the main characteristics of the certain process types are the following:

Job-shop production (e.g. tool shop, repair shop):

1. High variety of products and low volume.
2. Use of general purpose machines and facilities.
3. Highly skilled operators who can take up each job as a challenge because of uniqueness.

4. Large inventory of materials, tools, parts.
5. Detailed planning is essential for sequencing the requirements of each product, capacities for each work centre and order priorities.

Batch production (e.g. books, bakery, machine parts):

- Shorter production runs.
- Plant and machinery are flexible.
- Plant and machinery set up is used for the production of item in a batch and change of set up is required for processing the next batch.
- Manufacturing lead-time and cost are lower as compared to job order production.
- Better utilisation of plant and machinery.
- Cost per unit is lower as compared to job order production.
- Material handling is complex because of irregular and longer flows.

Repetitive, or mass production (e.g.: automobiles, television):

- Standardisation of product and process sequence.
- Dedicated special purpose machines having higher production capacities and output rates.
- Large volume of products.
- Shorter cycle time of production.
- Lower in process inventory.
- Perfectly balanced production lines.
- Flow of materials, components and parts is continuous and without any back tracking.
- Production planning and control is easy.
- Material handling can be completely automatic.
- Less skilled operators are required.
- Manufacturing cost per unit is low.
- High investment in production facilities.

Continuous production (e.g.: gasoline, steel, sugar, flour):

- Dedicated plant and equipment with zero flexibility.
- Material handling is fully automated.

- Process follows a predetermined sequence of operations.
- Component materials cannot be readily identified with final product.
- Planning and scheduling is a routine action.
- Manpower is not required for material handling as it is completely automatic.
- Person with limited skills can be used on the production line.
- Unit cost is lower due to high volume of production.
- Very high investment for setting flow lines.

Project process (e.g.: ship building, dam building):

- Discrete, usually highly customized products.
- Low volume and high variety.
- Complex process.

In the ideal case, the process is so selected, that the capabilities match the product requirements. The matrix in Fig.2. is the so-called product-process matrix, which shows the ideal choice of the process for the given conditions. According to the matrix all processes should be close to the diagonal: for small volume with high variety the job-shop process, while for high volume with low variety the repetitive-, or mass production is the optimal solution. Combinations falling far from this "line of fit" will have finally higher production costs and therefore they are not competitive. The position of the process has to be regularly checked, because it can suffer a displacement from the optimal area due to a change in the phases of the product life-cycle, changes in product design, etc..

	High variety	Moderate variety	Low variety	Very low variety
Low or very low volume	**Job Shop** repair shop emergency room			
Moderate volume		**Batch** commercial bakery classroom lecture		
High volume			**Repetitive** assembly line automatic car wash	
Very high volume				**Continuous Flow** petroleum refining water treatment

Fig. 2. The product-process matrix [3]

3.3. Facility location

For most of the companies making decisions in connection with location of the facility or plant is not a frequent task. This strategic level decisions have significant impact on the production cost, flexibility as well as the whole supply network. Since it is a long-term commitment and usually means a large investment, the decision should be made carefully, based on long range forecasts, expansion plan of the company, analysis of sources of inputs, and many other factors. According to [2] basically there are two reasons which lead to this kind of decision task:

- Changes in demand:
  - Customer demand is relocated as well,
  - Changes is volume of demand (expand existing, or establishing a new location),
- Changes in supply:
  - Changes in the availability of inputs (For example raw materials),
  - Changes in cost.

From these reasons we can derive the main factors which influence the decision: location of raw materials; labour quality and cost; land, energy, and transportation costs; community-related factors; market considerations; location of customers. In [1] the factors are divided into controllable and uncontrollable factors. Controllable factors: proximity to markets, supply of materials, transportation facilities, infrastructure availability, labour and wages, external economies, and capital. Uncontrollable factors: government policy, climate conditions, supporting industries and services, community and labour attitudes, community infrastructure. For manufacturing plants the decisive factors in the order of importance involve:

- favourable labour climate
- proximity to markets
- quality of life
- proximity to suppliers and resources
- utilities, taxes, and real estate costs.

In the literature [1-4] one can find several quantitative methods which help to evaluate alternatives and identify the ideal location.

3.4. Layout design

“Plant layout refers to the physical arrangement of production facilities. It is the configuration of departments, work centres and equipment in the conversion process.”

According to Moore, “Plant layout is a plan of an optimum arrangement of facilities including personnel, operating equipment, storage space, material handling equipment and all other supporting services along with the design of best structure to contain all these facilities.”” [1] This optimum can be found if the following general principles are kept during the layout design [1]:

“1. Principle of integration: A good layout is one that integrates men, materials, machines and supporting services and others in order to get the optimum utilisation of resources and maximum effectiveness.

2. Principle of minimum distance: This principle is concerned with the minimum travel (or movement) of man and materials. The facilities should be arranged such that, the total distance travelled by the men and materials should be minimum and as far as possible straight-line movement should be preferred.

3. Principle of cubic space utilisation: The good layout is one that utilise both horizontal and vertical space. It is not only enough if only the floor space is utilised optimally but the third dimension, *i.e.*, the height is also to be utilised effectively.

4. Principle of flow: A good layout is one that makes the materials to move in forward direction towards the completion stage, *i.e.*, there should not be any backtracking.

5. Principle of maximum flexibility: The good layout is one that can be altered without much cost and time, *i.e.*, future requirements should be taken into account while designing the present layout.

6. Principle of safety, security and satisfaction: A good layout is one that gives due consideration to workers safety and satisfaction and safeguards the plant and machinery against fire, theft, etc.

7. Principle of minimum handling: A good layout is one that reduces the material handling to the minimum.”

Naturally, additional to these general principles some more detailed information is necessary to design a good layout in the practice. First of all, the type of the layout must be in conformity with the selected process type (project, job shop, batch, mass and continuous process). Accordingly, there are several types of layout possibilities, from which the designer must select the one which fits best to the actual conditions. Although, there is a distinct relationship between process types and layout types, a certain process-type may be realized in different layouts according to Fig. 3. Generally speaking, there are four basic types of layouts: fixed-position layout, functional layout (or process layout), product (line) layout, cell layout (or group layout). However, in practice they often appear in combinations as well.

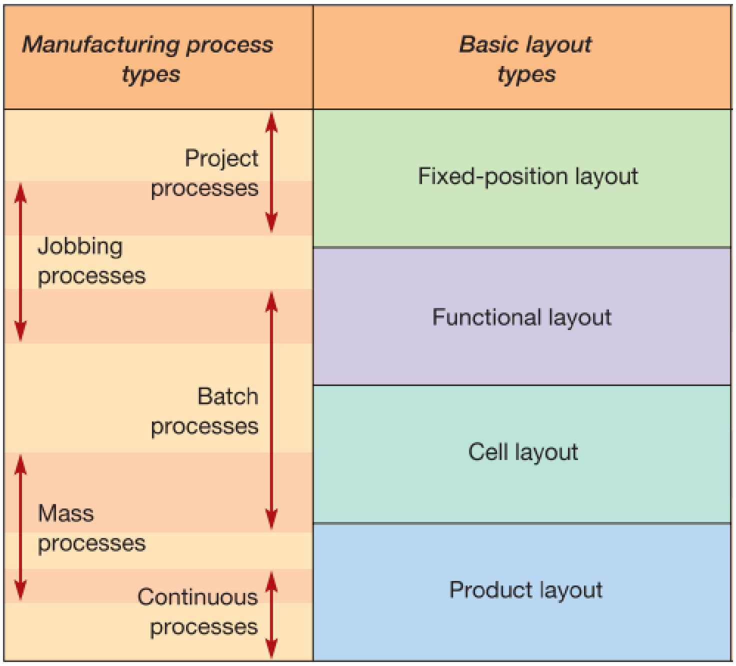


Fig.3 The relationship between process types and basic layout types [2]

In the following we discuss the main characteristics of these layout types.

- Fixed-position layout: applicable for project type or job-shop type processes. The transformed resources (material, customer) are stationary, because they are too large or too sensitive to move. The transforming resources, that is the staff, machines, tools are moving as the process needs it. Examples involve shipbuilding, large machine tools, etc..
- Functional layout or process layout: applicable for job-shop or batch type processes. In this case the similar processes are grouped together in shops or departments, in which similar kinds of activities are carried out. Usually the path of the material-flow is long and complex and varies from product to product. This kind of layout is used when the production volume is not high enough for mass-production, but the variety of products is high: e.g. machine shop, with separate departments for turning, milling, etc.. In a functional layout there are general-purpose machines and equipment, which are commonly cheaper to purchase and to maintain. The interdependence of the successive process steps is low, thus functional layout is not particularly vulnerable to machine failures. Because of the intermittent production and complex process-flow, the material handling is inefficient, and the in-process inventory can be high.

- Product layout: suitable for mass- and continuous processes, where the volume of production justifies the higher investment of a special production line dedicated to one or a few very similar products. These systems are inflexible, so the products as well as the processes must be highly standardized. In these lines the special-purpose machines are arranged to achieve an optimal flow of material for the given product. Due to the lack of variety, fixed-path material-handling equipment (e.g. conveyor system) can be built (often automated), which makes the material flow quick and effective. Because of this, the level of work-in-process inventory, as well as the throughput time can be minimized. Since the machines and workstations are interconnected, the system is very vulnerable to breakdowns. The highly standardized repetitive jobs don't require skilled operators, however it inevitably raises issues in connection with motivation of the workers and ergonomics.
- Cell layout: this layout type can be treated as the combination of the product and the process layouts. The aim is to increase the flexibility while keeping the effectiveness of the mass-production. The cell itself is often formed as a product layout, where the machines are arranged according to the needs of a set of similar products, that is product groups or families. Within the cell the material flow is simple and can be even automatized, work-in-process inventory and lead time can be minimal. The flexibility of the system lies in the collective operation of these cells. An effective cell production presumes a systematic analysis of parts to identify the groups of similar design or manufacturing characteristics. Flexible manufacturing systems can be regarded as special, fully automatized types of cells.

After selecting the right type of the layout or their combination, the detailed design of the arrangement of machines, workstations and equipment is the next step. Each layout type has its special objectives and methods for the detailed design. By designing a process layout, the main issue is the relative arrangement of the machines and equipment in order to reduce the transportation and material handling. Unfortunately, there is no any algorithm to find the right arrangement from the huge number of possibilities, so process layouts are designed on the basis of intuition, common sense, and systematic trial and error. In case of product layouts the design is a more critical issue. Due to the high investment costs, special machines, etc., any later modification would be a difficult and costly action.

According to [2] the main decisions in connection with product layouts are:

- *The needed cycle-time.* The cycle time (the time between completed products) is calculated on the basis of the customer requirement over a period of available time, and it has a significant influence on the design decisions.
- *The number of stages.* It is calculated based on the required cycle time and the total work content, that is the quantity of work necessary to complete the product.

If the work content is high, the number of stages will be accordingly high to reach small cycle time.

- *Task-time variation.* Due to various influences a time needed to carry out a repetitive task is always fluctuating. This causes irregularities in the material flow within the production line, which has to be taken into consideration during design.
- *Balance in the work-time.* The aim of line balancing is to equally allocate the work content to the stages, thus to ensure smooth material flow. With proper balancing the idle time of stages can be minimized, thus the utilization will be increased. A widely spread tool for line balancing is the precedence diagram, which "visually portrays the tasks that are to be performed along with the sequential requirements, that is, the order in which tasks must be performed" [2]. The literature [3] describe the process as: "… tasks are assigned one at a time to the line, starting at the first workstation. At each step, the unassigned tasks are checked to determine which are eligible for assignment. Next, the eligible tasks are checked to see which of them will fit in the workstation being loaded. A heuristic is used to select one of the tasks that will fit, and the task is assigned. This process is repeated until there are no eligible tasks that will fit. Then the next workstation can be loaded. This continues until all tasks are assigned." It is important to note, that the heuristic rules don't guarantee an optimal solution, therefore it is useful to develop several alternatives, then choose the one with the highest efficiency. In practice other technical considerations are also have to be considered, such as skill requirements, incompatible tasks, space limitations, equipment constraints, human factors, etc..

3.5. Work design

Under the term work design, we understand three main topics: job design, allocation of work times and the design of the work environment. These topics are discussed together, because they are based on similar concepts and frameworks as illustrated in Fig.4., and they are in a very close connection with the topic of human resources. In this phase of the design of the transformation process the human perspective has a particular importance.

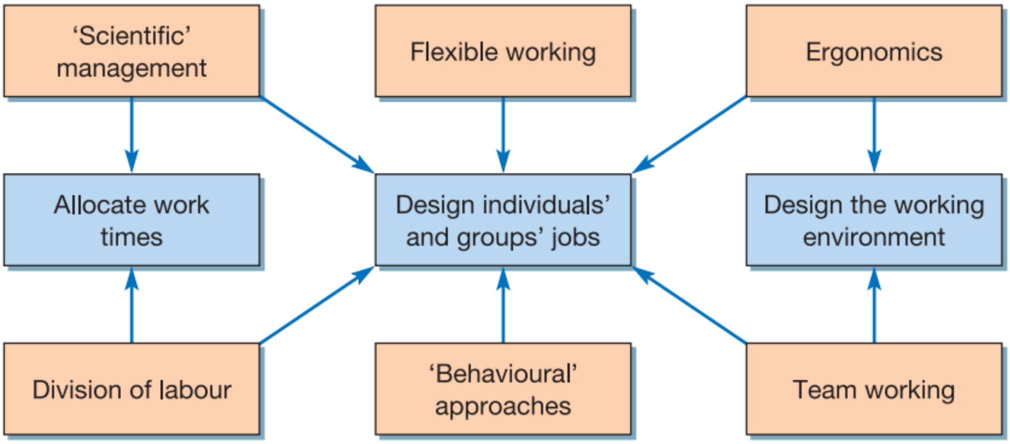


Fig.4 The main influences on job design, work time allocation and the design of the working environment [2]

3.5.1 Job design

Job design involves the determination of the content of workers' jobs, the method they do the job and interact with the equipment, and their workplace. There are two basic approaches to job design. Formerly a systematic, logical way of thinking was dominant, in which the decision making is based on numbers, time-data, and results of various analysis. On the contrary of this scientific approach, the behavioural school consider the fulfilment of human needs as the precondition of efficient processes. The behavioural approach involves techniques such as job enlargement, job rotation and job enrichment to make the work more interesting, it focuses on motivation of the employees, and it prefers teamwork.

To find the best method to do the job a systematic approach called methods study is used. This tool helps to determine and standardize the activities and methods of work for a job. In Chapter 5 we will discuss this tool in detail.

Ergonomic considerations are very important to avoid fatigue, injuries and thus low productivity. The anthropometric aspects have a fundamental role in the workplace design. The decisions in connection with work areas, tools, position of equipment, work content, speed, weights to move, etc. are all based on anthropometric data of the human body (Fig. 5., 6.).

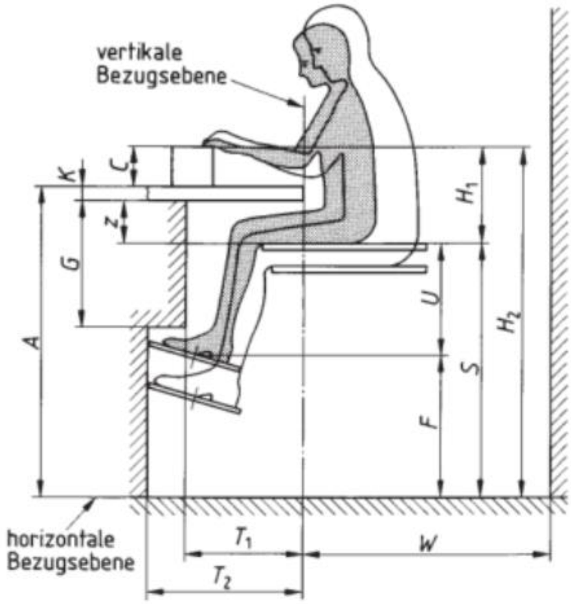


Fig.5. Data for workplace design based on anthropometric data. [11]

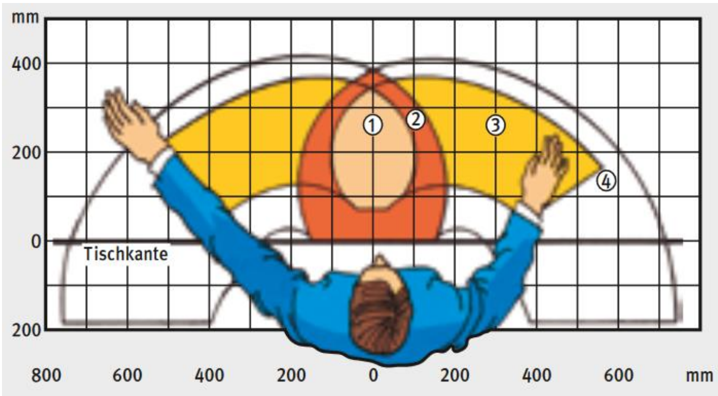


Fig.6. Reach zones for workplace design based on anthropometric data [10]

3.5.2 Work environment

The work environment, where the work is carried out, has a significant effect on the work performance. In a long term, poor working conditions can lead to health problems as well. In design we have to consider not only physical factors such as illumination, noise, vibrations, ventilation, humidity and temperature, but other factors such as leadership style, compensation, worktime and breaks, safety, etc.. Most of these factors are covered by government regulations or standards.

3.5.3 Allocation of work times

To be able to allocate the work, first we have to know, how much time the work takes to complete it. This information is important from other aspects as well, such as cost, scheduling, compensation system, control of production, management. Unfortunately, the determination of this time can't be very accurate, because there is always a fluctuation due to the skill, experience, motivation of the worker, actual environmental conditions, variation in the raw material or tool quality. Anyway, there is a lot of experience and knowledge collected over the decades, which offers proven methods to estimate the work time. The commonly used approaches are:

- Quick and cheap but inaccurate methods: historical records, ask expert, time logs, and work (occurrence) sampling.
- More accurate engineering estimates preceded by methods analysis: stopwatch time study and standard data.

The field of work measurement deals with these tasks. By definition, work measurement is "the process of establishing the time for a qualified worker, at a defined level of performance, to carry out a specified job". In chapter 5 we will discuss the methods of work measurement in detail.

4. PROCESS DEVELOPMENT

Even if the transformation process of a company is well designed and realized, and is functioning properly, there is always a possibility for improving. Moreover, according to the dominant approach of recent times, improving processes is a basic principle of operations management. There are various improvement approaches, but there are several elements, which are commonly found in them. These elements involve [2]:

- Thinking in continuously repeated improvement cycles. An improvement cycle should consist of a problem definition phase, followed by measuring and analysing the actual situation. Than new ideas or solutions are worked out, tested, and finally implemented. The final phase is always some kind of checking or control if the improvement reached the goal, and is sustainable. See PDCA cycle, or DMAIC cycle.
- Thinking in processes. Improvements should focus on the whole process which add value to the customer, not individual workplaces, or departments.
- Evidence-based problem solving. Improvement activity should be based on quantitative data. That means, data collecting and analysis is an important part of developments.
- Customer centricity.
- Waste identification. Waste is any activity that does not add value, the goal is to eliminate these activities.

- Including everybody and educating. The experience and knowledge of all the staff is a very good source of development. To be able to use this opportunity, employees must know the improvement methods, as well as understand the organizational context of it. For this, structured training, and supporting system is necessary.

Among the widely used improvement approaches we mention here the following approaches:

- Total quality management (TQM): this philosophy consider quality as basis of everything done by an operation. It emphasis totality of this idea. The philosophy is not focusing merely on improvement, but it plays an important role. Its main elements are customer focus, designing-in quality rather than inspecting it, and the idea that improvement covers the whole organization and includes every person.
- Lean management: this approach has a huge literature, therefore here we mention only the key elements from point of view of improvements: customer-centricity; internal customer–supplier relationships; perfection is the goal; synchronized flow; reduce variation; include all people; waste elimination.
- Business process re-engineering (BPR): "the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service and speed". The main principles of BPR:
    - "Rethink business processes in a cross-functional manner which organizes work around the natural flow of information (or materials or customers).
    - Strive for dramatic improvements in performance by radically rethinking and redesigning the process.
    - Have those who use the output from a process perform the process. Check to see if all internal customers can be their own supplier rather than depending on another function in the business to supply them (which takes longer and separates out the stages in the process).
    - Put decision points where the work is performed. Do not separate those who do the work from those who control and manage the work."
- Six Sigma: „A disciplined methodology of defining, measuring, analysing, improving, and controlling the quality in every one of the

company's products, processes, and transactions – with the ultimate goal of virtually eliminating all defects". Its main elements are:

- Customer-driven objectives.
- Use of evidence.
- Structured improvement cycle: the DMAIC cycle.
- Process capability and control.
- Process design.
- Structured training and organization of improvement.

We note, that in the practice these approaches often can't be clearly distinguished, and they can appear in a combination as well. The reason for this is the clear overlap between the approaches as illustrated in Fig. 7..

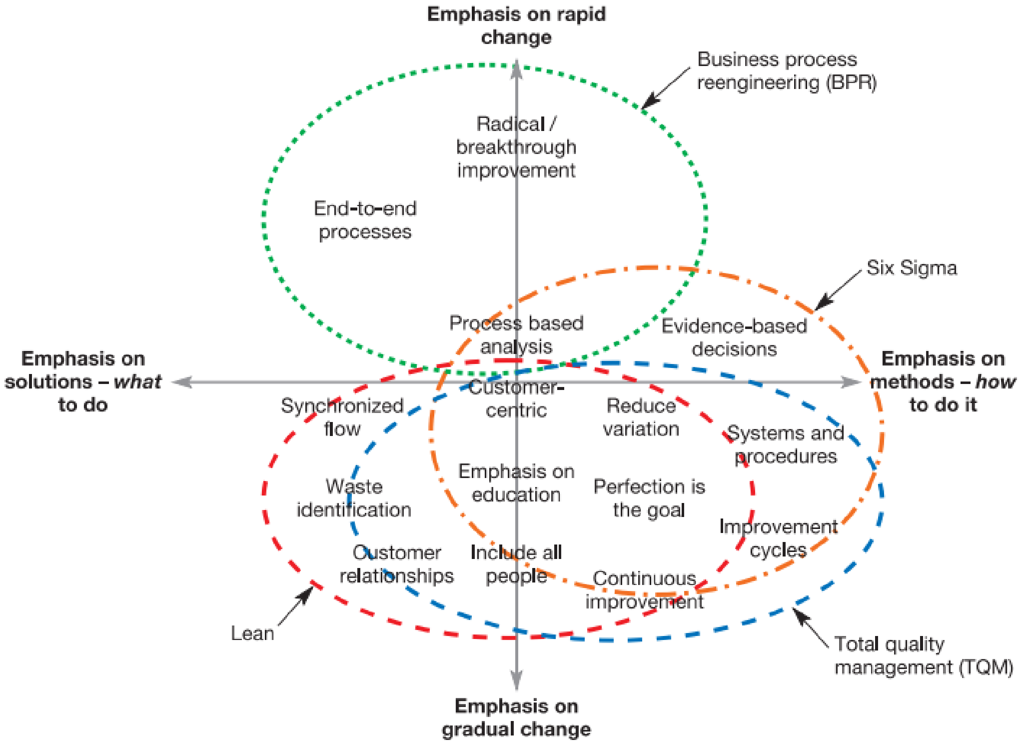


Fig.7. Differences and similarities of development approaches [2]

5. WORK STUDY

As formerly discussed, a common element of the process development approaches is the process analysis step. This step includes an examination of the current method, collecting

and analysing data, and carrying out measurements to understand
what is happening. An efficient tool called methods study covers most of these activities. Methods study is applied in the process design phase as well to define the most effective way of work. In the design phase methods study is applied together with work measurement, which aims to determine the time of a work. Together, these complementary studies are often referred to as work study. The relationship between methods study and work measurement is shown in Fig. 8.

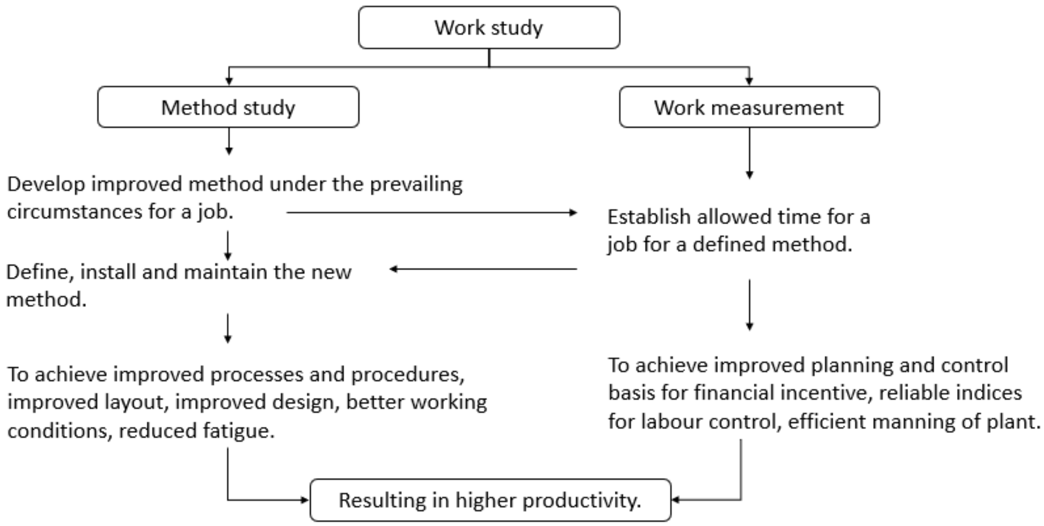


Fig.8. The relationship between methods study and work measurement [5]

5.1. Method study

Method study is a systematic approach to finding the optimal method of a work. It can be done for new jobs to establish a method as well as for existing jobs to observe how the job is currently being performed. There are six steps in method study:

- Select the work to be studied.
- Record all the relevant facts of the present method.
- Analyse the job, examine the facts critically and in sequence.
- Develop the most practical, economic and effective method.
- Install the new method.
- Follow up implementation to assure that improvements have been achieved and maintain the method by periodically checking it in use.

For analysis and development of solutions various charts such as flow process charts and worker-machine charts are used.

Flow process chart: "Chart used to examine the overall sequence of an operation by focusing on movements of the operator or flow of materials." [3] These charts are used to identify the non-value-adding process steps. The commonly applied symbols can be seen Fig.9..

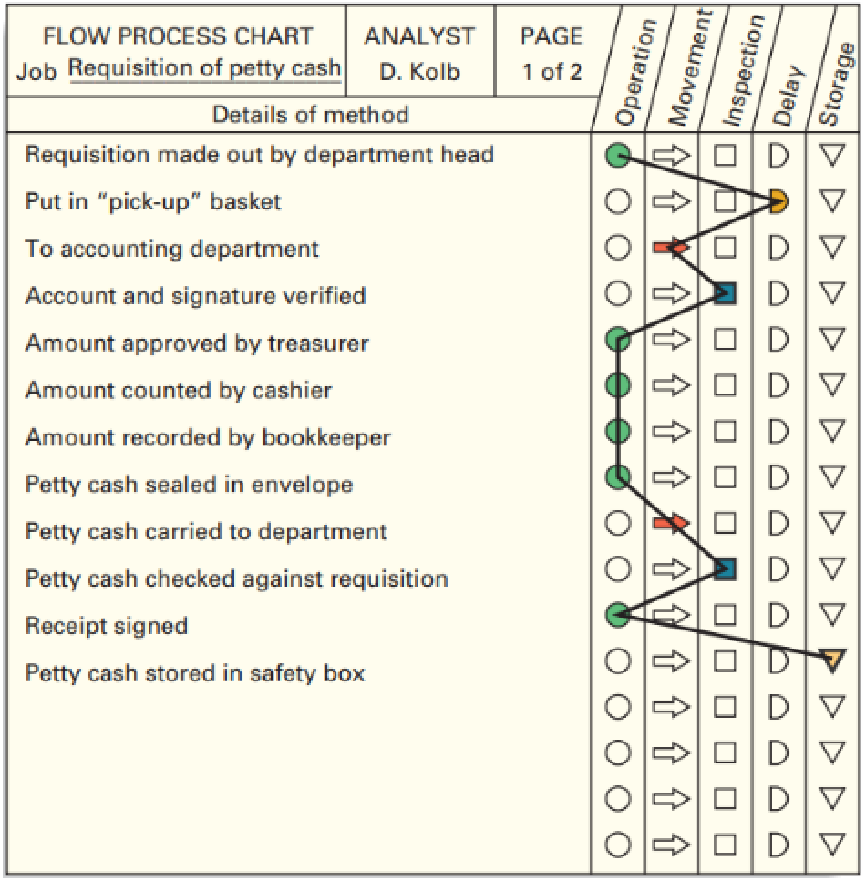


Fig.9 Process flow chart [3]

Worker-machine chart (man-machine chart): the chart visualizes the utilization of the worker and the machine at the same time. The goal of the chart is to analyse how the activity of the man and the machine overlap, thus to identify idle times, and to reach better utilization. An example of worker-machine chart is illustrated in Fig. 10.

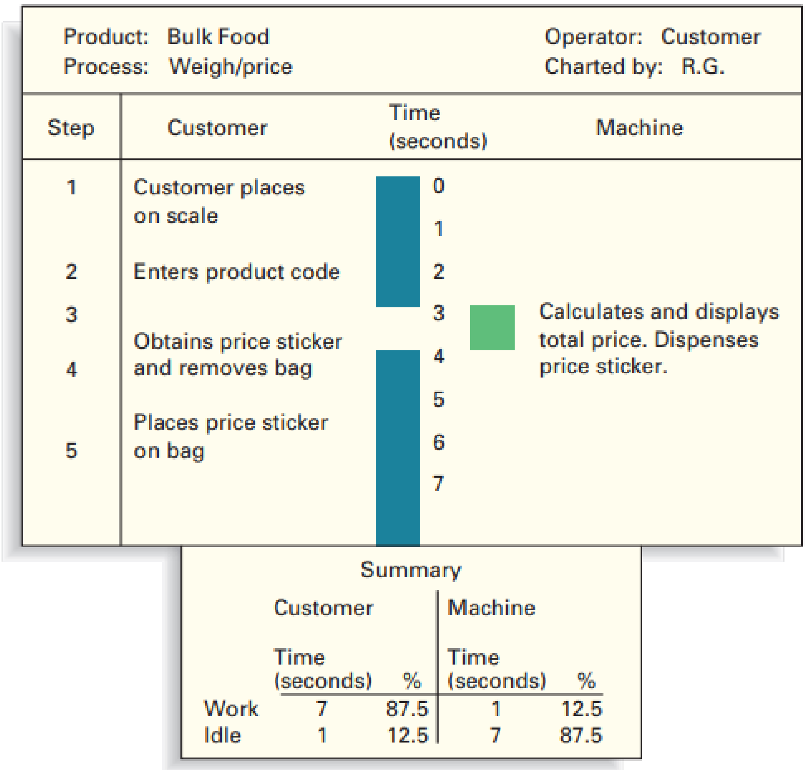


Fig.10. Multiple activity chart (worker-machine chart) [3]

To find the optimal work method sometimes it is useful to analyse the motion of the worker in detail. Motion study offers a systematic way to study the human motions. There are several techniques applied to identify the best sequence of motion and to eliminate wastes. One efficient method is called micromotion study, which uses motion-picture camera to record the human motion. With this technique rapid motions can be also analysed by slowing down the record.

5.2. Work measurement

As defined in Chapter 3. work measurement deals with the establishment of the standard time necessary to carry out a certain job. In general, the measurement methods involve the detailed analysis of the certain job, therefore, the measurement has an important role in recognising the potentials in processes and defining the direction of improvement as well. There are four basic techniques for work measurement, all of which has its own advantages and thus optimal conditions of application: time study, work sampling, predetermined time standards, and standard data.

5.2.1. *Stopwatch time study*

"Technique for recording the times of performing a certain job or its elements carried out under specified conditions and for analyzing the data so as to obtain the time necessary for an operator to carry it out at a defined rate of performance." Advantages and disadvantages [4]:

- "Enables analysts to observe the complete cycle, providing an opportunity to suggest and initiate methods improvement.
- The only method that actually measures and records the actual time taken by an operator.
- More likely to provide coverage of those elements that occur less than one per cycle.
- Quickly provides accurate values for machine-controlled elements.
- Relatively simple to learn and explain.
- Requires the performance rating of a worker's skill and effort.
- Requires continuous observation of the worker over repeated work cycles.
- May not provide accurate evaluation of noncyclic elements.
- Requires work to be performed by an operator."

Fig.11. illustrates an example of a time observation sheet. The origin of the time study is dated back to the beginning of the 20. century, thus it has been discussed thoroughly in the literature (e.g.: [5-8]).

Job Pack 20 x pt # 73/2A Location Packing Dept. Observer FWT

Element		Observation 1	2	3	4	5	6	7	8	9	10	Average basic time	Allowances	Element standard time
Make box	Observed time	0.71	0.71	0.71	0.69	0.75	0.68	0.70	0.72	0.70	0.68			
	Rating	90	90	90	90	80	90	90	90	90	90			
	Basic time	0.64	0.64	0.63	0.62	0.60	0.61	0.63	0.65	0.63	0.61	0.626	10%	0.689
Pack x 20	Observed time	1.30	1.32	1.25	1.33	1.33	1.28	1.32	1.32	1.30	1.30			
	Rating	90	90	100	90	90	90	90	90	90	90			
	Basic time	1.17	1.19	1.25	1.20	1.20	1.15	1.19	1.19	1.17	1.17	1.168	12%	1.308
Seal and secure	Observed time	0.53	0.55	0.55	0.56	0.53	0.53	0.60	0.56	0.49	0.51			
	Rating	90	90	90	90	90	90	85	90	100	100			
	Basic time	0.48	0.50	0.50	0.50	0.48	0.48	0.51	0.50	0.49	0.51	0.495	10%	0.545
Assemble outer,	Observed time	1.12	1.21	1.20	1.25	1.41	1.27	1.11	1.15	1.20	1.23			
fix and label	Rating	100	90	90	90	90	90	100	100	90	90			
	Basic time	1.12	1.09	1.08	1.13	1.27	1.14	1.11	1.15	1.08	1.21	1.138	12%	1.275

Raw standard time		3.817
Allowances for total job	5%	0.191
Standard time for job		4.01 SM

Fig.11. Time observation sheet [3]

5.2.2. Predetermined data

In case of the technique of predetermined time standards there is no direct time measurement of the activity. Instead, the job is built up from basic human motions (e.g.: reach, move, turn, grasp, position, disengage, release), for which motions there are established time standards. These standards are based on detailed studies of large samples and are widely accepted. Depending on the level and scope of application, there are several systems to choose from, such as MTM-1, MTM-2, UAS, MOST, etc.. These systems differ in the classification method, detail, time units of the basic motions. The application of this technique requires the accurate and complete description of the work method, thus, it helps in work simplification and encourages the optimization of workplace layout as well. A big advantage of this technique, that it can be used in advance of the actual production. Fig. 12. shows an example of an MTM-1 time-table.

TABLE I—REACH—R

Distance Moved Inches	Time TMU A	Time TMU B	Time TMU C or D	Time TMU E	Hand In Motion A	Hand In Motion B	CASE AND DESCRIPTION
¾ or less	2.0	2.0	2.0	2.0	1.6	1.6	**A** Reach to object in fixed location, or to object in other hand or on which other hand rests.
1	2.5	2.5	3.6	2.4	2.3	2.3	
2	4.0	4.0	5.9	3.8	3.5	2.7	
3	5.3	5.3	7.3	5.3	4.5	3.6	**B** Reach to single object in location which may vary slightly from cycle to cycle.
4	6.1	6.4	8.4	6.8	4.9	4.3	
5	6.5	7.8	9.4	7.4	5.3	5.0	
6	7.0	8.6	10.1	8.0	5.7	5.7	**C** Reach to object jumbled with other objects in a group so that search and select occur.
7	7.4	9.3	10.8	8.7	6.1	6.5	
8	7.9	10.1	11.5	9.3	6.5	7.2	
9	8.3	10.8	12.2	9.9	6.9	7.9	
10	8.7	11.5	12.9	10.5	7.3	8.6	
12	9.6	12.9	14.2	11.8	8.1	10.1	**D** Reach to a very small object or where accurate grasp is required.
14	10.5	14.4	15.6	13.0	8.9	11.5	
16	11.4	15.8	17.0	14.2	9.7	12.9	
18	12.3	17.2	18.4	15.5	10.5	14.4	
20	13.1	18.6	19.8	16.7	11.3	15.8	
22	14.0	20.1	21.2	18.0	12.1	17.3	**E** Reach to indefinite location to get hand in position for body balance or next motion or out of way.
24	14.9	21.5	22.5	19.2	12.9	18.8	
26	15.8	22.9	23.9	20.4	13.7	20.2	
28	16.7	24.4	25.3	21.7	14.5	21.7	
30	17.5	25.8	26.7	22.9	15.3	23.2	

Fig.12. Part of an MTM-1 time-table. [4]

5.2.3. Work sampling

"Work sampling is a method of finding the proportions of total time devoted to various activities that constitute a job or work situation by random sampling" [4]. It means, that the aim is not to determine accurate time data, but rather to determine machine and worker utilization, frequency of certain activities or events, or causes of delays. This technique is useful for analysing nonrepetitive or irregularly occurring events, such as machine failures, or other problem of the system (missing personnel, waiting times, etc.). The reliability of the result depends on the sample size, and the represented conditions, that is the sampling period, therefore, normally, a work sampling takes several weeks and hundreds of observations. The steps of work sampling in general based on [4]:

1. Determine the scope of the study: objective, area, method of measuring output!
2. Brief personnel involved in the study: explanation of the objectives, methodology, deliverables and the possible effects!
3. Classify the activity into work categories!
4. Carefully plan the frequency and interval of sampling!
5. Take a short test study!
6. Make and record observations!
7. Process the results and reevaluate the precision of estimates!

6. VALUE STREAM MAPPING

The Value Stream Mapping (VSM) and the Value Stream Design (VSD) are an important lean management method for analyzing the current state of the factory or the processes and it is useful to design the future state of the processes, products or services. This method or tool can show the beginning of the products until the customers. The VSM can helps to implement other lean tools and techniques. The Value Stream Mapping focuses on areas of a plant or company which can add value to a products or services (for example: the quality checking is a non add values process). The Toyota Motor Company uses two types of mapping [27]:

- Material flow mapping
- Information flow mapping.

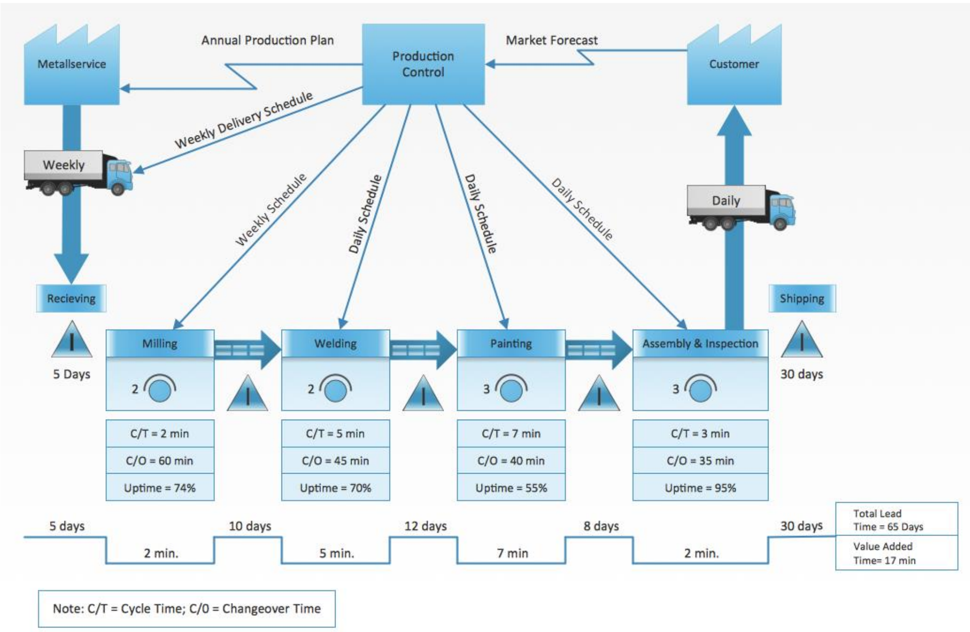
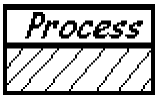
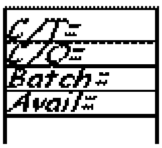
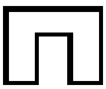
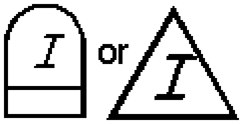
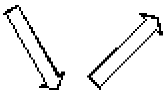
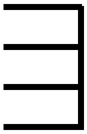
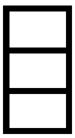


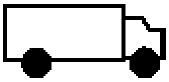
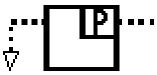
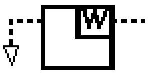
Figure 13.: Value Stream Map [7]

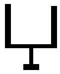
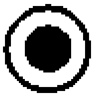
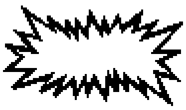
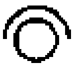
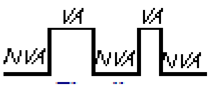
The Value Stream Map uses amount of standard symbols which help to design the VSM and the VSD maps. The purpose of this technique to identify and remove or try to reduce the wastes in the value stream. The knowledge and understand of these symbols is essential to correctly investigate the production system problems. The wastes removal can helps to increase the efficiency of the processes and improve the product quality. [8] [27]

Table 1.: Value Stream Map Symbols [1]

Symbol	Name	Description
	Customer/ Supplier	*"The supplier is represented at the upper left of the icon (placed at the starting point of the material flow), and the customer is shown as the upper right (placed at the end point of the material flow)." [1]*
	Dedicated Process	*"It shows a process, machine or an operation through which the flow of material takes place." [1]*
	Shared Process	*"When the process operation or department is shared by other value stream families, it is shown using shared process icon." [1]*
	Data box	*"The data box is used with other icons and signifies the need for the analysis of the significant information and data." [1]*
	Work-cell	*"It shows that multiple processes are integrated in the manufacturing work-cell." [1]*

	Customer/ Supplier	*"This symbol helps to show inventory between two processes. It is also used to show the storage of raw materials or finished products." [1]*
	Shipments	*"The movements of raw materials between suppliers and receiving docks and finished products between factory to customers are shown using this icon." [1]*
	Push Arrow	*"The pushing of material between different processes, when the need from the downstream process has not occurred is shown using push arrow." [1]*
	Supermarket	*"It is the symbol used for kanban stock-point. It is generally used to reduce overproduction and put a limit on the total inventory, when the production takes place in batches." [1]*
	Material Pull	*"This symbol shows physical removal and connects the supermarkets with the downstream processes." [1]*
	FIFO Lane	*"When the inputs are limited using a First- In-First- Out inventory system, this symbol is used." [1]*
	Safety Stock	*"The hedging of inventory against downtime, demand fluctuations or system failures is shown using the safety stock icon." [1]*

	External Shipments	*"When external transport is used to ship raw materials from suppliers or finished goods to the customers, this symbol is used." [1]*
	Production Control	*"The central production scheduling or control department is shown using this symbol." [1]*
	Manual Information	*"General flow of information from reports, memos or conversation is shown using this symbol." [1]*
	Electronic Info	*"The electronic transmission of information like electronic data interchange, local area network, wide area network are shown using this symbol." [1]*
	Production Kanban	*"When parts are provided to the downstream process, the supplying process is captured using the production Kanban." [1]*
	Withdrawal Kanban	*"Withdrawal Kanban" [1]*
	Signal Kanban	*"It is used when the amount of inventory in supermarket falls below the trigger level or minimum point." [1]*

	Kanban Post	*"It shows a location where Kanban signals reside for pickup." [1]*
	Sequenced Pull	*"Signaling to sub-assembly to produce predetermined product without the use of supermarket is shown using this symbol." [1]*
	MRP/ ERP	*"It shows scheduling using material resource planning or enterprise resource planning." [1]*
	Kaizen Burst	*"It shows the need for improvement at the particular process to attain future state map of the value stream." [1]*
	Operator	*"The need for an operator at a particular workstation is shown using this symbol." [1]*
	Timeline	*"It shows value added times and non-value added times. These are used to calculate the total cycle and lead times." [1]*

6.1. Types of Wastes

In 1995 Daniel T. Jones defined seven independent wastes what you can find in the daily production life or in services. These wastes are based on the Toyota Production system (TPS) principles. [14]

- Overproduction: creating too much finished products or services, it is a waste (time and money), the finished products need a warehouse, storages and logistic equipments.

- Waiting: products are not being transported, operators are waiting for each other, services are waiting for each other.
- Transport: unnecessary product moves around.
- Processing: complex solution for a single process, unsafe production.
- Inventory: storage costs and equipments, sometimes it is not a waste.
- Unnecessary motion: it is a type of the ergonomic waste, in this case the employees have to make plus energy to picking up objects or move something or somewhere.
- Rework: scrap rework, the company can lose time and money in the production.

6.1.1 The Waste of Transportation

The transportation is a movement of materials, documents or in some cases humans from point to point (or to from point 'A' to point 'B'). It can be a waste (usually) if it adds zero value to the finished goods or services. The transport can be a necessary point of technological processes, for example: cement factory, heat treatment process etc. It is an unnecessary step from the view of your customer. In the most cases the transport adds no value to the products. But you can not avoid the movement in a production or service centers, just think about conveyors or fork lifts or when we have to move products and raw materials between production lines or factories or when you have to print documents for signature. The waste of the transport can make a lot of extra costs for your company. You need people who can work with the logistic equipments, you have to buy expensive equipments and you have to pay for the other additional costs of this kind of machines and equipments. [12] [16] [17] [19] [20] [21] [33]

6.1.2 The Waste of Inventory

You have to use different types of inventory and logistic systems in your production and service center, that costs money, but you can optimize it from the cost side and from the process side too. The inventory is very important - in some cases you have to use a high level of stocks if your business requires it, for example: you can guarantee the delivery in 36 hours for all over the world. It is an extra service from your side and you can use a high inventory limit. In the practice the companies would like to eliminate the inventories in the production, also from the area of raw material and finish goods and they try to minimize them in the field of work in process (WIP) stock. The inventory costs can generate many further costs: you have to use logistic operators and other logistic equipment, the warehouses need a new building, you have to use shelves, you have to design logistic roads and motions etc. All of the equipments need space and maintenance background and other technical supporter areas. The big warehouses and inventories can generate the waste of transportation. [12] [16] [17] [19] [20] [21] [33]

6.1.3 The Waste of Motion

The unnecessary motion is the next important waste. These motions can be movements of people, machines, documents, products etc. These motions are not as small or easy to perform, for example: bending down to pick up heavy object from the floor. On a long term it causes stress and it can generate a lot of unhealthy changes in the human body. The next example is to ship the products between two workshops or machines. It is a similar property to the waste of transport. The waste of motion costs a lot of time, money and causes a high stress for the operators. [12] [16] [17] [19] [20] [21] [33]

6.1.4 The Waste of Waiting

The waste of waiting is what everybody can feel in his or her daily life or daily routine. Peoples are do not want to wait or stand in a wrong line in the shops or post offices. We can find the similar waiting problems in production areas too. The waste of waiting is very important for the production-, maintenance teams and service centers as well. If the machines stop the maintenance team have to repair it. The production does not have time to wait for maintenance or quality inspection etc. They have to make the products or the company can lose customers. [12] [16] [17] [19] [20] [21] [33]

6.1.5 The Waste of Overproduction

The overproduction can be a dangerous waste. In this case your customer demands are not clear, and your processes are bad. The overproduction can generate another waste, the high level of inventory. It is very easy to understand. You have to put your products somewhere if you cannot sell them. Another dangerous point of the overproduction is the

cost of the production processes. If you would like to get a finished
product you have to put a lot of energy, human resource and money into it. If you can find overproduction in your company, that means that your just in time system and supply management do not work. [12] [16] [17] [19] [20] [21] [33]

6.1.6 The Waste of Over processing

The waste of Over processing is where we use unsuitable techniques or oversized equipments and machines. During this waste we perform a lot of processes that are not important by the customers or by the management level. In this situation we can lose time and money. The basic lean principles suggest having small appropriate machines instead, and if possible do not buy the most expensive huge machines. [12] [16] [17] [19] [20] [21] [33]

6.1.7 The Waste of Defects

The definitions and the explanations of these wastes are clear, but not easy to find them in a real process. The wastes and defects can reach your customer and it can generate a quality complaint. Important to know, the number of the quality complaints are an important KPI number of the factories. It means that most critical failures or mistakes are the quality errors. The not incorrect maintenance has an effect on the quality of products and the lifetime of the machines or machine elements. To avoid this waste, you have to use Poka Yoke tools, automation and improve your machines and maintenance program and you have to develop the skill and knowledge of the human resources. [12] [16] [17] [19] [20] [21] [33]

6.1.8 Seven plus one more waste

In the daily life we always speak about seven wastes, but a lot of companies forget the main principle of lean. This principle can be the key for the success. It is the waste of the human talent. The machine operators, technicians, engineers and other employees have big knowledge and experience in their work and they have an important daily routine in their workdays. If you would like to improve your processes and your organization, you have to use your employee’s experiences and knowledge. You have to involve all of these people to develop your company and build a better future and vision for your company. These people live in the processes and they know what the weakest points of your production or service system are. This is the 8th waste. Honestly, we know eight wastes in practice. In the practice the management have to use different types of Kaizen or idea management systems to get this knowledge and experience. [12] [16] [17] [19] [20] [21] [33]

After the muda safari you have to eliminate the wastes from your value stream. You can use a variety of tools, lean tools, techniques or methods. During the waste investigation you have to use the lean principles and put the product quality improvement into your focus. Another important aspect is the customer demand. You have to define the value in your system. If you can define the value in your system well, you can improve your processes and start to eliminate the negative effects in your company. These redesigned processes will help you to make processes with a higher efficiency. [12] [16] [17] [19] [20] [21] [33]

Important to make the development continuously, the lean principles will help to you in this work (for example: PDCA circle). In a company you always have to know the followings: the customer demand and the external and internal processes are always changing. If you would like to save your company money or improve your department competitiveness, you have to eliminate the seven plus one wastes and always use continuous improvement techniques. [12] [16] [17] [19] [20] [21] [33]

6.2 The Toyota 3M model: Muda, Muri and Mura

In the practice we know other types of wastes not only the basic seven. The basic idea comes from Toyota Motor Company where they developed their system in order to eliminate the three main groups of wastes, which are the following: Muda (waste), Muri (overburden) and Mura (unevenness). The seven wastes are not other like Muda. We know eight different types of wastes, these are the following: transport, inventory, motion, waiting, overproduction, over processing, defects and the waste of talent. [12] [16] [17] [19] [20] [21] [33]

Simply taking out the Muda sometimes does not work in the practice. Usually, there is a simple reason why the Muda is there, and this reason often has to do something with the other two types of wastes: Muri and Mura. This three sets of wastes have a relationship between each other. [12] [16] [17] [19] [20] [21] [33]

"The three waste sets can be found at production areas and at office areas and processes too. The office processes can hide a lot of wastes. The production wastes are easy to see - you can see the unnecessary motions, the high stock etc. In the offices the processes are often hidden inside the computers, servers, mailboxes and IT systems." [12] [16] [17] [19] [20] [21] [33]

The target in the practice to eliminate the three groups of wastes. In a lot of cases it is impossible to eliminate all of them from the processes or services, for example: you cannot build up your factory without quality inspection points or without unnecessary motions, you can just minimize the numbers of these types of wastes. If you have to deliver your product and your services, you just try to reduce the time of transportation as you can, but you cannot reduce it to zero. [12] [16] [17] [19] [20] [21] [33]

There can always be an opportunity where machines or community have to give that an extra effort or time to make sure the customer demand is effectuated. There is no question with this activity if you get extra orders or reach a new customer or buyer. The question starts when you are wait these from your employees all the time, until the step where a machine will burn down, or a colleague burns out and leaves the corporation. The last group is the Mura. The Mura cannot be eliminating in 100%, but we can find excellent examples in practice which are helpful to reduce the Mura. If you have a big product mix, you have to use other raw materials and you have to use a new technology and process times. [12] [16] [17] [19] [20] [21] [33]

The following three paragraphs describe the most important properties of the three waste groups. [12] [16] [17] [19] [20] [21] [33]

"Muda, waste, can be defined in eight types, 7 defined by Toyota and 'non-utilized skills'. These are (again): transport, inventory, motion, waiting, overproduction, over processing, defects and waste of talent. As Mnemonic device, the first letters of these

wastes form the acronym downtime. There are numerous tools available to identify and remove waste from your process, which include Poka Yoke, Kanban, Takt Time, SMED and One-Piece flow. In the article each of the types of waste are described and linked to tools which can be used to eliminate them systematically.” [33]

“Muri, overburden, can result from Mura, and from removing too much Muda (waste) from the process. When operators or machines are utilized for more than 100% to finish their task, they are overburdened. This means breakdowns when it comes to machines and absenteeism when it comes to employees. To optimize the use of machines and make sure they function properly, preventative- and autonomous maintenance can be implemented. To prevent overworked employees, safety should be the focus of all process designs and all standard work initiatives.” [33]

“Mura, unevenness, can be found in fluctuation in customer demand, process times per product or variation of cycle times for different operators. In production environments with low-volume, high product variation, flexibility is more important than in high-volume, low-product variation environments. When Mura is not reduced, one increases the possibility for Muri and therefore Muda. Mura can be reduced by creating openness in the supply chain, change product design and create standard work for all operators.“ [33]

In the practice we have to eliminate or remove the wastes from the life of the company. In books and literature, we can find three main types of waste removal operations [14] [29]:

- Non value adding operation
- Necessary but non value adding
- Value adding

The value stream mapping is an important lean tool which helps to analyze, design flows, measure cycle times, calculate inventories etc. in the company. The values stream mapping is often uses in production areas, but a lot of companies forget the following: in a modern factory which is following the lean philosophy uses value stream mapping in

other areas, like in logistics, supply chain management, service
related industries, healthcare, software engineering, product development, quality field, and office processes etc. [6] [10] [11] [18] [23] [24] [28] [30]

The base of value stream mapping made by Shigeo Shingo. His standard looks like the following: the value-adding steps be drawn across the center of the map and the non–value adding steps be represented in vertical strains at proper angles to the value circulate. With this approach the processes can see easily and the wastes can come to the up. In his idea or concept, the value stream the process(es) and the non-values streams the operations. The idea here is that the non–value adding steps are frequently preparatory or tidying as much as the value-adding steps and are intently related to the person or machine/computer that executes that values-adding process. Consequently, every vertical line is the 'story' of someone or workstation while the horizontal line represents the 'story' of the product being created. The value stream mapping is a vital part of the six sigma method. [6] [10] [11] [18] [23] [24] [28] [30]

6.3 Value stream mapping in software developing

Nowadays the software solutions get a higher prior than ever. This fact is part of the Industry 4.0, which is the new industrial revolution. We can find dozens of software solutions on the market which helps for the engineers and users to make better systems and processes. Important to speak about lean in software development. The software developing process also contains a lot of wastes. The value stream mapping is supported by the pioneer authors of the field James P. Womack and Daniel T. Jones. [2] [3] [13] [26] [27] [31]

The value stream map can help to analyze the material (artifact) and the information flow in a software. The following examples can show the use of VSM to software process improvement in industrial field [2] [3] [13] [26] [27] [31]:

- Artifact analysis
- Information flow analysis

In the work of Hines and Rich defined seven different value stream mapping tools. These are the followings [2] [3] [13] [26] [27] [31]:

- Process activity mapping
- Supply chain response matrix
- Production variety funnel
- Quality filter mapping
- Demand amplification mapping
- Decision point analysis
- Physical structure mapping

7. FLOWCHART

The flow chart is a special diagram which is very popular in software development, in production areas, quality field, analyzing, designing, documenting etc. The flowchart can represent an algorithm, workflow or a process. The flowchart has some basic elements. It shows the steps with different types of boxes and shows the connection between the boxes with arrows. The special diagrammatic representation can show a solution mode to a given model. [21]

The flowcharts can help to design and document processes, programs, standard work instructions or computer softwares etc. They help visualize what goes on and thereby assist recognize a system, and possibly also discover less-obvious functions in the technique, like flaws and bottlenecks. There are different forms of flowcharts: each type has its personal symbol system and notations. In the practice we can find two types of boxes in the flow chart [1-21]:

- Processing step (activity – rectangular box)
- Decision (diamond)

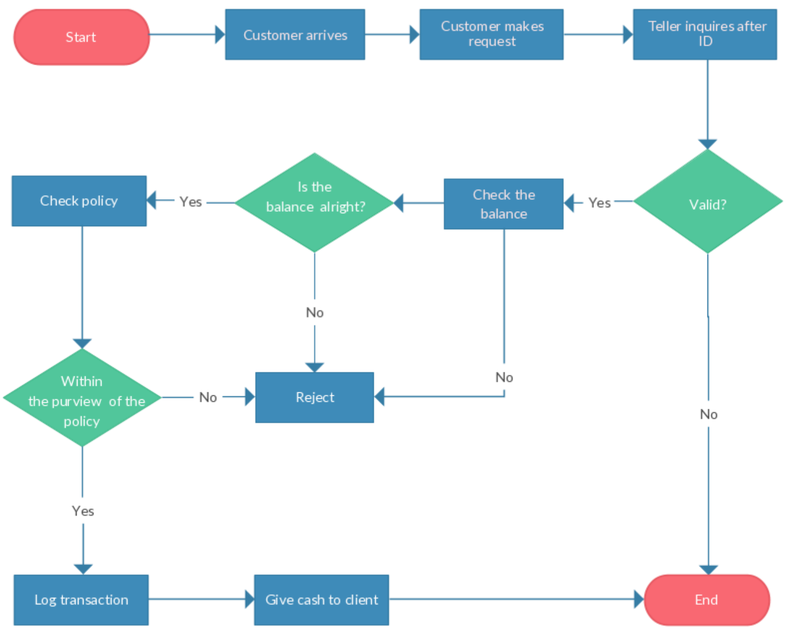


Figure 14.: Flow chart example [6]

The flow chart works as a cross functional method when the chart is divided into different horizontal or vertical parts. The cross functional flowcharts can give a chance for the authors to show the responsibility of the members of the process, make decisions and shows the connection between the process members. [1-21]

The flow chart is very important tool in process developing field. Kaoru Ishikawa defined the flowchart as one of the basic seven quality tools. These tools can be find in all of the quality systems. The seven basic quality tools are the following [1-21]:

- Histogram
- Pareto chart
- Check sheet
- Control chart
- Cause and Effect diagram
- Scatter diagram
- Flowchart

In software developing we are using a special type of flowchart, it is the activity diagram, but important to know we can find a lot of variants of flow charts in the practice. Two alternative diagrams can be the Nassi – Shneiderman diagram and the Drakon chart. In the practice we know a lot of other or alternative names of flowchart, some examples: flow chart, process flowchart, functional flowchart, process map, process chart, functional process chart, business process model, swimlane process model, process flow diagram, work flow diagram, business flow diagram, etc. The terms "flowchart" and "flow chart" appellations are correct. [1-21]

7.1 History of Flowcharts

The origins of flow chart made by Frank and Lillian Gilbret who developed the flow process chart. The title of their work was: “Process Charts: First Steps in Finding the One Best Way to do Work. They were members of the American Society of Mechanical Engineers (ASME) in 1921. The Gilbreth couple found their possibility into different industrial fields very quickly. Another pioneer of process development was Allan H. Mogensen who started to train business people in the use of the tool of industrial

engineering int 1930s. In 1944 Art Springer used the tools and he
developed the Delibrate Methods Change Program. In this year another student made a big step with this tool. Ben S. Graham who was the director of Format Engineering at Standard Register Industrial applied the flow process chart too. He used the chart to present multiple documents and the relationship between these documents, we call his “new” tool for multi flow process chart. The American Society of Mechanical Engineers adopted a standard symbol system which derived from Gilbreth's original work as the "ASME Standard: Operation and Flow Process Charts.” [2] [4] [5] [8] [10] [11] [13] [22]

Herman Goldstine and Janos Neumann (John von Neumann) also developed a special flowchart to design computer program. The origins of this kind of flowchart can be find in Goldstein and Neumann’s unpublished work. The following work contains Neumann’s works: "Planning and coding of problems for an electronic computing instrument, Part II, Volume 1" from 1947. [2] [4] [5] [8] [10] [11] [13] [22]

The flowchart gets a high prior to develop computer program, but the popularity of the flowchart showed a negative trend in the 1970s. At this time, pseudo codes came to the foreground because it uses the common language such languages without strictly parts. The flowcharts are still very popular tools to describe computer programs. The modern tools what the reader found in the previous chapters (like UML activity diagram or Drakon chart) are extensions of the flowchart.

The flowcharts can be put into different types of user groups and we know four general types [1] [3] [17] [18]:

- Document flowcharts
- Data flowcharts
- System flowcharts
- Program flowchart

The focus of the different flowcharts the control not the particular flow itself. We know some different classifications in the practice. In 1978 Andrea Veronis defined three basic types of flowcharts [1] [3] [17] [18]:

- System flowchart

- General flowchart
- Detailed flowchart.

But in the same another researcher made another point of view of the flow charts (Marilyn Bohl, 1978) [1] [3] [17] [18]:

- System flowcharts
- Program flowcharts.

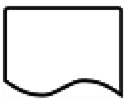
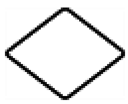
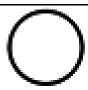
In 2001 Mark A. Fryman defined more types [1] [3] [17] [18]:

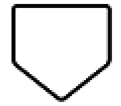
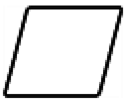
- Systems flowcharts
- Product flowcharts
- Process flowcharts
- Decision flowcharts
- Logistic flowcharts
- etc.

7.2 Symbol Systems

The flowchart standard developed by the American National Standards Institute (ANSI) in 1960s. The ANSI symbols adopted by the International Organization for Standardization (ISO) in 1970. The current standard was revised in 1985. The flowcharts flro from the top to the bottom and left to the right. [7] [9] [12] [14] [15] [16] [20] [23]

Table 2.: Common flowchart symbols [16]

Flowchart Symbol	Name	Description
	Process Symbol	*"Also known as an "Action Symbol," this shape represents a process, action, or function. It's the most widely-used symbol in flowcharting." [16]*
	Start/End symbol	*"Also known as the "Terminator Symbol," this symbol represents the start points, end points, and potential outcomes of a path. Often contains "Start" or "End" within the shape." [16]*
	Document symbol	*"Represents the input or output of a document, specifically. Examples of and input are receiving a report, email, or order. Examples of an output using a document symbol include generating a presentation, memo, or letter." [16]*
	Decision symbol	*"Indicates a question to be answered — usually yes/no or true/false. The flowchart path may then split off into different branches depending on the answer or consequences thereafter." [16]*
	Connector symbol	*"Usually used within more complex charts, this symbol connects separate*

		elements across one page." [16]
	Off-Page Connector/Link symbol	*"Frequently used within complex charts, this symbol connects separate elements across multiple pages with the page number usually placed on or within the shape for easy reference." [16]*
	Input/Output symbol	*"Also referred to as the "Data Symbol," this shape represents data that is available for input or output as well as representing resources used or generated. While the paper tape symbol also represents input/output, it is outdated and no longer in common use for flowchart diagramming." [16]*
	Comment/Note symbol	*"Placed along with context, this symbol adds needed explanation or comments within the specified range. It may be connected by a dashed line to the relevant section of the flowchart as well." [16]*

The ANSI/ISO standards contains other symbols not just the basic shapes. Some example [7] [9] [12] [14] [15] [16] [20] [23]:

- Data File or Database: cylinder (disk drive)
- Document: rectangle with a wavy base
- Manual input: quadrilateral, with the top irregularly sloping up from left to right, like the side view of a keyboard

- Manual operation: trapezoid with the longest parallel side at the top, to represent an operation or adjustment to process that can only be made manually
- Parallel Mode: two horizontal lines at the beginning or ending of simultaneous operations
- Preparation or Initialization: elongated hexagon, originally used for steps like setting a switch or initializing a routine

For parallel and concurrent processing the Parallel Mode horizontal lines or a horizontal bar indicate the start or end of a section of processes that can be done independently [7] [9] [12] [14] [15] [16] [20] [23]:

- *"At a fork, the process creates one or more additional processes, indicated by a bar with one incoming path and two or more outgoing paths."*
- *"At a join, two or more processes continue as a single process, indicated by a bar with several incoming paths and one outgoing path. All processes must complete before the single process continues."*

In the practice we know a lot of type to draw or make flowcharts. We can use whiteboards with "postit" paper, we can use simple papers, or we can use computes softwares. The most popular softwares [21]:

- yEd
- Inkspace
- Microsoft Visio
- etc.

These softwares are very easy to use and contains a lot of other management tools which are very helpful during any type of project management. [21]

8. SWIMLANE

The swim lane is a special process flow diagram or a flowchart. This tool can visualize the job sharing, the responsibilities of sub processes and/or business processes and the documents. In the practice we can use swim lane on horizontal and in vertical view, but the horizontal view is most popular than the vertical. [1-5]

The origins of the swim lane can be find in the 1940s. It these times it was a variation of the flow process chart called multi column chart. Geary Rummler and Alan Brache were the first researchers who were call the chart as a swim lane. We can find a lot of extra information about this definition in their book: Improving Processes (1990). The alternative name of the swim lane is the Rummler – Brache Diagram. [1-5]

We know an alternative origin of the swim lane. The swim lane is a port of the JBoss jBPM jPDL (Process Definition Language) graphical process designer a part of the JBoss jBPM framework for process languages. Swim lane graph was developed by Prof. Dr.-Ing. Binner in 1980s. The swim lane was a part of his doctoral thesis on the requirements of the IT and CIM concept at the Institute for Factory Facilities at Prof. Wiendahl at TU-Hannover. [1-5]

The swim lane flow chart shows a lot of differences from other flow charts. The swim lane grouped the process members and visualized them in “lanes” or “swim lanes”. Each member has an own lane, these parallel lanes labelled to show the chart is organized into one system. The vertical view or direction can show the sequence of the events in the full process. The horizontal view or direction can show what the subprocess is performing. The arrows between the lanes and boxes can represent the information and/or material flow between the subprocesses and members. [1-5]

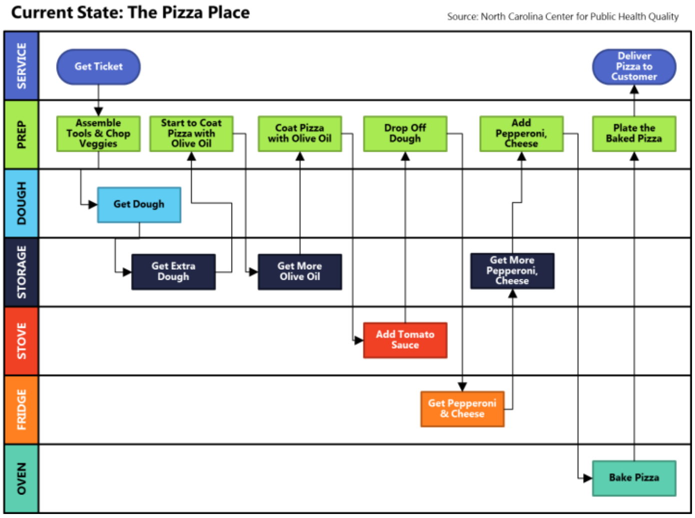


Figure 15.: Swim lane example [4]

Good to know: the flow can be rotated. We can read the sequence horizontally from left to the right. In this case the roles and members are on the left edge of the chart. This version is very easy to use, read and design. Nowadays the computer screens are wider than ever, so this property can provide a good view of the chart. Swim lane has an own standard symbol set. In some case it is different from the simple flow chart symbol set. [1-5]

The swim lane is very important process, quality or business development field. This tool can contain all of the departments who are member of an organization or the analyzed process. With this tool we can identify the failures and cheats in our organization or process. With swim lane we can illustrate different functional capabilities and/or responsibilities in an organization. We can illustrate the documentation and material flow and we can put the cycle times next to the each subprocess steps. The swim lane is a very important tool of the Business Process Modeling Notation (BPMN) and in the Unified Modeling Language activity diagram. [1-5]

The most popular computer software to design swim lane chart is the Microsoft Visio. The software contains a lot of useful tools to make a good design for the chart. [1-5]

9. KEY PERFORMANCE INDICATORS – KPI SYSTEM

In the industrial life or in our daily routine it is very important to monitor, measure and check our activities or our health. Enough to think about the blood pressure, weight or blood sugar level etc. These numbers can give information about our health condition. If we have any problem with our blood pressure we have to go to the doctors, get some pills or we have to change something in our lifestyle. This new (healthy) blood pressure will be our target. In industrial field we can find similar numbers. In the practice we call these numbers performance indicators or key performance indicators (KPI). These indicators are a special number of a performance measurement. The KPI numbers can evaluate the success of the organization. We can define KPI numbers for programs and projects. In these cases, the KPI numbers can show the efficiency of the projects. In the most cases success is defined on a long term with strategic goals. Very important to find the right KPI(s). In the first step we have to understand what the target of the company or the project is. The management always measure a lot of independent target in the practice, the full organization must follow these targets and the KPI numbers. In the practice, we can find dozens of techniques which can help us understand and present the state of the business, key figures. [2] [3] [4] [7]

"The performance indicators define the values what the organization has to measure. This is what we can simply call indicators. We can speak about various categories in the field of key performance indicators. These can be the following [2] [3] [4] [7]":

- Quantitative indicators
- Qualitative indicators
- Main key performance indicators that can describe the outcome of a process
- Key Performance Indicators which can show the success and the failures of a process and developments
- Input indicators, important to measure the quantity of the resources during the process
- Process indicators that represent the efficiency and/or the productivity of the process

- Output indicators that show the outcome of the process and developments
- New indicators which can connect to the company processes
- etc.

9.1 Overall Equipment Effectiveness (OEE)

The most important KPI number in industrial life is the OEE or in other name: Overall Equipment Effectiveness. The OEE can show the availability of the company, machines or production areas or we can use it for only one machine. It contains three main factors: the efficiency, performance and quality. It helps to identify areas where the production has to improve. We can calculate it with the following formula [1] [2] [5] [6] [8]:

$$Overall\ Equiomeny\ Effetiveness = availability \times performance \times quality \quad (1)$$

- Availability
- Performance
- Quality

The big advantages of OEE is that it is calculating with the planned shutdowns, like holidays or scheduled maintenance etc. The planned production time what is needed to calculate overall equipment effectiveness. We can get a lot of information from these numbers, the best of the world factory looks like the following: it is one that produces the best product (the quality is perfect), as quickly as possible (we do not have to wait), with no unscheduled down time (without any problems or failures). This is the 100% OEE, but it is impossible to get. For certain manufacturing plants, world class OEE is generally considered being 85% or better. The average OEE score is just only 60%. [1] [2] [5] [6] [8]

Important to know: we can find big differences between the industrial fields (automotive, electric, food etc.). The OEE can be the best indicators in the daily production routine. OEE also provides a way of measuring the success of production or lean activities like TPM or SMED. Important to know: the OEE formula is used in a general form in this

book. We can find a lot of versions of OEE in the practice. It means
that the companies use a little modification in the formula, the three main factors will not change but the deeper meaning of each factor cannot be the same.

[1] [2] [5] [6] [8]

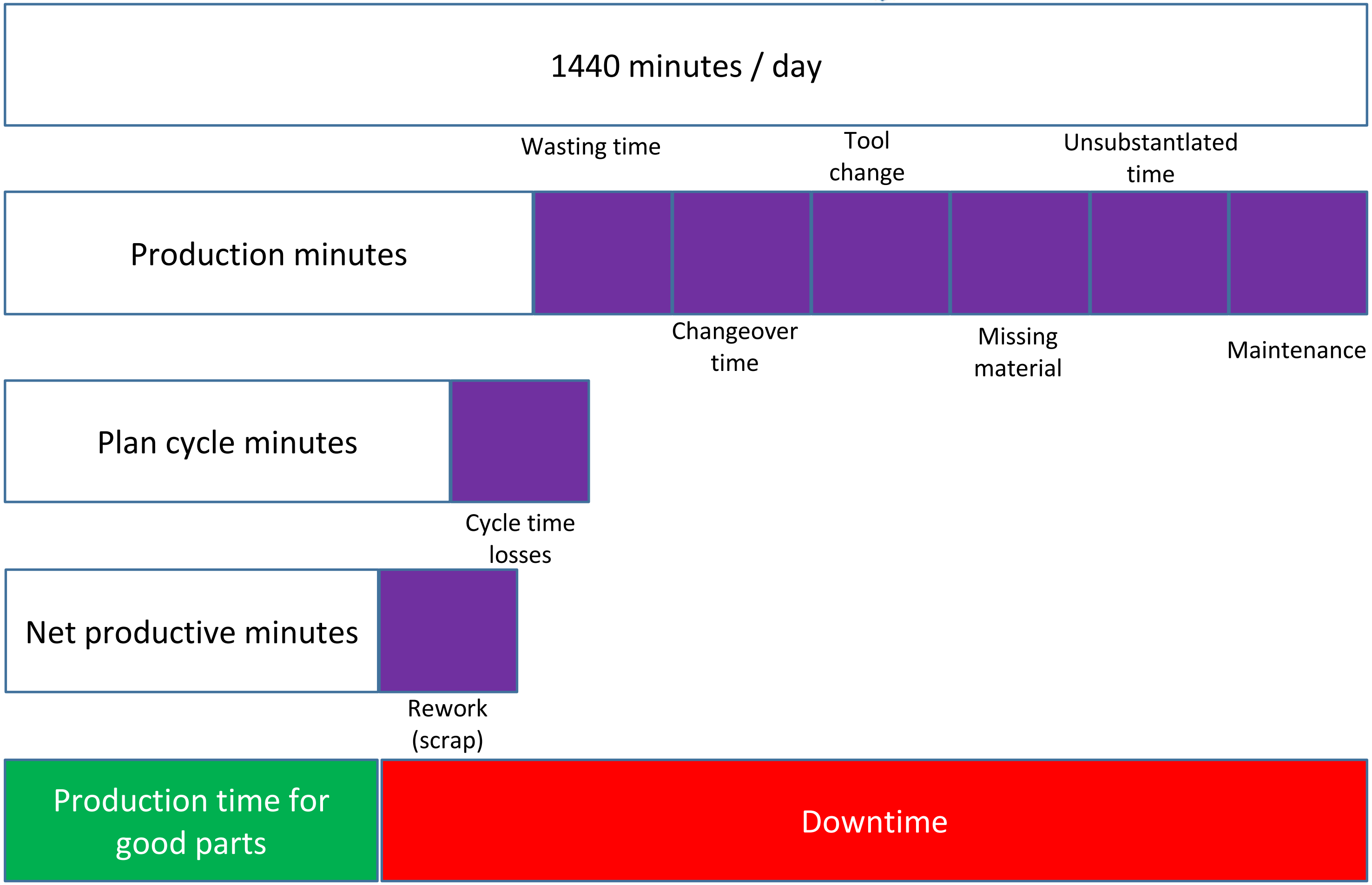


Figure 16.: Example about 1 production day [2]

The overall Equipment Effectiveness is influenced by various losses and is made up of availability (A), output (O) and quality factor (Q). We can calculate them with the following formulas [1] [2] [5] [6] [8]:

$$AF = \frac{total\ availibility - unplanned\ downtime}{total\ availibility} \quad (2)$$

$$PF = \frac{production\ minutes - cycletime}{production\ minutes} \quad (3)$$

$$QF = \frac{plan\ cycle\ minutes - scrap\ minutes/rework\ minutes}{plan\ cycle\ minutes} \quad (4)$$

Let's see two examples:

1. Example [1] [2] [5] [6] [8]:

$$AF = \frac{production\ minutes \times 100\%}{planned\ minutes} = \frac{510 \times 100\%}{1440} = 35.4\% \quad (5)$$

$$PF = \frac{planned\ piece\ minutes \times 100\%}{production\ minutes} = \frac{435 \times 100\%}{510} = 85.3\% \quad (6)$$

$$QF = \frac{net\ production\ minutes \times 100\%}{planned\ piece\ minutes} = \frac{426 \times 100\%}{435} = 97.9\% \quad (7)$$

$$OEE = AF \times PF \times QF \quad (8)$$

$$OEE = 0.354 \times 0.853 \times 0.979 \times 100\% = 29.6\% \quad (9)$$

2. Example [1] [2] [5] [6] [8]:

Basic data:

Shift length: 8 hours = 480 min.

Short Breaks: $2 \times 15min.$ = 30 min.

Meal Break: 30 min.

Down time: 47 min.

Ideal Run Rate: 60 pieces / minute

Total Pieces: 18371 pieces

Rejected Pieces: 523 pieces

$$Planned\ Production\ Time = Shift\ Lenght - Breaks \tag{10}$$

$$Planned\ ProductionT\ ime = 480 - 60 = 420\ minutes \tag{11}$$

$$OperatingT\ ime = Planned\ Production\ Time - Down\ Time \tag{12}$$

$$Operating\ Time = 420 - 47 = 373\ minutes \tag{13}$$

$$Good\ Pieces = Total\ Pieces - Reject\ Pieces \tag{14}$$

$$Good\ Pieces = 18371 - 223 = 17848\ pieces \tag{15}$$

$$Availability = \frac{Operating\ Time}{Planned\ Production\ Time} \tag{16}$$

$$Availability = \frac{373}{420} = 0.8881 = 88.81\ \% \tag{17}$$

$$Performance = \left(\frac{Good\ Pieces}{TotalPieces}\right) \div IdealRunrate \tag{18}$$

$$Performance = \left(\frac{17848\ pieces}{373\ minutes}\right) \div 60\ \frac{pieces}{minute} = 0.7974 = 79.74\% \tag{19}$$

$$Quality = \frac{Good\ Pieces}{Total\ Pieces} \tag{20}$$

$$Quality = \frac{17848}{18371} = 0.9715 = 97.15\% \tag{21}$$

$$OEE = Availability \times Performance \times Quality \tag{22}$$

$$OEE = 0.8881 \times 0.7974 \times 0.9715 = 0.6879 = 68.79\% \tag{23}$$

10. SWOT ANALYSIS

SWOT analysis is a framework to analyze of Strengths, Weaknesses, Opportunities & threats of a process, persons or products. It is used to identify and analyze the different factors (internal, external) that create an impact on projects, places or persons. [1] [2]

It is a simple & effective planning tool which consists of multiple factors which evaluate the following [1] [2]:

- Strength,
- Weakness,
- Opportunity.
- Threat.

It gives us knowledge which is required to understand the situation more clearly so we can make more productive decisions. [1] [2]

SWOT analysis can be applied to the following [1] [2]:

- The whole organization
- To a particular department or a unit of business
- One single project
- To a single person development or progression of career.

It is usually utilized during the start of a strategically planned exercise.

Its framework is determined as an important support of making decisions as it enables entities to expose opportunities of achievements that were previously just considered threats before they developed into burdens. [1] [2]

It is also used for the following opportunities [1] [2]:

- To review the position & health of the organization
- It is a basis for performance evaluation
- Strategic options are assessed using this method which contain any investment opportunities or a potential partnership
- SWOT is used before a new strategic plan is developed
- It is used as to prevent crisis management

The following benefits of SWOT analysis are given below [1] [2]:

- It helps to make decisions by developing a visual representation of different factors that impact the business or project
- It helps encourage strategic thinking between the employees
- Discloses the direction in which change is taking place
- As it is very simple to understand all the employees easily take part in the development of SWOT
- Helps us to answer how to maintain and highlight our strengths
- It shows us how to compensate for our weakness
- It allows us to exploit new opportunities
- It helps us anticipate & identify any future threats which can be prevented using SWOT.

The following methods are used to develop a SWOT analysis [1] [2]:

- First step is to clearly explain your team why the analysis is important and the process to do it
- Hang four charts, one for each category
- Then tell your team to brainstorm ideas so as each chart is filled
- Time must be taken to make sure that the charts completed are appropriate & complete with the information gathered
- As soon as the analysis is done & charts completed the information must then be recorded into matrix forms
- The following analysis then should be presented in front of key decision takers in the company
- Develop a plan to take action against each of the four charts.

The following are the steps to completely utilize SWOT analysis and integrate it into the system [1] [2]:

- The first step to utilize SWOT analysis is to convert the weaknesses into the strengths also to convert the threats into the opportunities
- Next step is to be self-critical during the SWOT analysis & excuses should not be made

- There will always be weaknesses with everyone, in this step we have to accept them and realize the normality of weaknesses
- Separating the involved groups into smaller teams which will allow all the voices in the organization be heard.

Tables

Figures

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