Lehrstuhl für Industrielogistik – Montanuniversität Leoben

Optimizing the flow

Applied material flow management

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I. Eidesstaatliche Erklärung

Ich erkläre hiermit an Eides Statt, dass ich die vorliegende Diplomarbeit selbständig angefertigt habe. Die aus fremden Quellen direkt oder indirekt übernommenen Gedanken sind als solche kenntlich gemacht. Die Arbeit wurde bisher weder in gleicher noch in ähnlicher Form einer andern Prüfungsbehörde vorgelegt und auch noch nicht veröffentlicht.

Andre Pura

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II. Danksagung

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III. Abstract

For many companies material flow is a critical but difficult issue. They do not have sufficient information on how their products are flowing through the production and how they can identify bottlenecks and problems. This master thesis deals with the flow of goods through a production system. It is based on a real project, but described in a generic way.

The master thesis starts with the description of planning a material flow project and what the phases of such a project are. It is shown how the system borders of a material flow project are set to guarantee well defined interfaces to the environment. In the next step, it is described how the current situation is analyzed and how it can be visualized. Now, it is possible to define an optimized, theoretical material flow and it is shown how it can be presented. An example is used to demonstrate this and a factory layout is created.

Following some theoretical foundations about flow orientation, some basic facts about storages are discussed. An overview of location and movement strategies is given, the next chapter explains, why it is necessary to set up a controlling and measurement system and how flow objects can be identified. A conclusion and outlook is found in the last chapter.

IV. Kurzfassung

Viele Firmen haben schon die vielfältigen Möglichkeiten des Materialflussmanagements erkannt, vielfach fehlt Ihnen jedoch die Kenntnis und Erfahrung für ein strukturiertes Vorgehen. Diese Diplomarbeit gibt einen Leitfaden über das Thema Materialflussmanagement und Flussoptimierung in der produzierenden Industrie. Sie basiert auf einem realen Projekt, ist allerdings allgemein gehalten.

Im ersten Teil wird die Initialisierung eines Projekts erklärt und welche Phasen ein solches hat. Des Weiteren wird erläutert, wie in einem solchen Projekt die Systemgrenzen gesetzt werden, damit es klar definierte Schnittstellen gibt. Nachdem ein derartiges Projekt beschrieben ist, geht es zur Analyse der Ist-Situation im Unternehmen und zur Visualisierung der aktuellen Situation. Die Ist-Situation wird nun eingeordnet; daraus wird im Folgenden ein Soll-Szenario entwickelt, dieses wird als Materialfluss umgesetzt und entsprechend dargestellt. Die Vorgangsweise wird mit Hilfe eines Beispiels anschaulich beschrieben und ein fertiges Maschinenlayout wird erstellt.

Anschließend wird ein Überblick über innerbetriebliche Lager und deren Bewegungs-, bzw. Belegungsstrategien gegeben. Zu guter Letzt werden verschiedene Materialflusskontrollsysteme vorgestellt und wie mit deren Hilfe Objekte identifiziert werden können. Des Weiteren wird gezeigt, wie die Position des Objektes bestimmt wird um den Materialfluss steuern, analysieren und weiter verbessern zu können.

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1. Introduction

Managing the flow through the production is difficult. It starts from analyzing, followed by optimization and ends with controlling to optimize it again. This master thesis handles with every station between analyzing and controlling the new flow.

Analyzing the stream is important to see what really happens in a production system with the goods and information flowing through it. Total control of a flow is only possible, when a company knows all stations and constraints in their system. They need to identify the critical path through the system and risks which could annihilate the production.

To avoid being disappointed from a production optimization, which should be the target of such a project, planning from the edge is necessary. Therefore the master thesis strips the general project planning and gives an idea of how difficult it could be to plan a project. It shows the risks of failures in the first step of the planning and provides a rough overview. As a result a time table and the steps of the material flow optimization should be clear.

Planning and analyzing the production flow are only two steps to the target. After the analysis has to be interpreted and a feasibility study should be made to clear up if it is possible to gain the given target. This master thesis suggests that it is possible and the next stage could be reached.

Designing a new layout with the given flow and optimize it with a special view on the storage should be done. Now, a new layout was found the flow and layout must be verified and controlled. This is the last step in the circle until a new analysis is done and the next optimization should be done.

On this point maybe the question rises why a company should do such an investment only to organize the flow of a production in a new way. It usually costs a lot to rearrange the machines and buying new information technology equipment for controlling the system. But it is possible to decrease the capital binding costs by reducing the stock level and better planning with the now known resources. Another advantage is to reduce the number of transportation vehicles in the production. This includes a decrease of movements, which means minimizing personal, energy and maintenance costs.

In a sentence: Optimizing the flow through the production means investments to reduce production costs and use all capacities.

This master thesis is based on a real project starts from the edge in an undeveloped plant, from logistics point of view. The company seized the opportunity of changing the landsite to optimize their layout. They tried to find a better layout for their plant with a lot of constraints. These constraints, e.g. given plant size, available data, made it really hard to find an adequate layout for the new site. Especially the storages were uncontrolled and unplanned, which made planning in the past nearly impossible. Now a new layout is set up and the structure is much clearer and easier to control.

The target of this master thesis is to show in general how to find a new layout and what is necessary to bring such a project to success and how to structure it. It additional gives a view over controlling a flow and project management. More precisely this thesis shows:

- The phases of such a material flow project and how they are managed
- The evaluation and analysis of the current situation in a plant
- How to interpret information from the analysis and how it can be visualized
- The design of a new factory layout
- Controlling of the material flow

2. Project Planning and Managing

Before it is possible to start with the project it must be very well planned and a project controlling must be established. In this chapter it is shown why a project management and controlling is necessary for a logistics project and how to establish a management and controlling and which elements are necessary.

2.1 Scope of Project Management

"Project management includes executive, organizational, technical and resource functions to carry out a project" [1]

2.2 Project Phases

For scheduling and calculating a project different phases must be defined. The following steps are common in industry projects. They define the current and expected situation. After running some tests in the pilot phase, the general project can be realized. When it is done, another evaluation should be done to find out how the project meets expectations.

- Define and analysis of the current situation
- Design of expected situation
- Pilot phase
- Evaluation of the pilot phase
- Realization of the project
- Evaluation of the project

The first two phases represent the current and future situation. They are compared to each other and planning work has to be done to convert the current to expected situation. Requirements are analyzed and needed support, such as knowledge or physical items, is organized.

The next stage is the pilot phase. In this phase a representative part is designed in the new way. After all machines or items are reorganized, an evaluation is made. It is necessary to measure the outcome in comparison to the "old" situation or layout for different reasons. Measurable effects could be cost reduction or reduced throughput times. Other tested things are the feasibility after redesign and what side effects appear. When all these values are collected, the responsible project manager or the company must decide, if all requirements are met. In case of a positive decision, the whole project starts, otherwise the project fails and is stopped or it goes back in phase 2 (design of expected situation). [2]

Now it is time to realize the project. When all changes are done, another evaluation starts. It aims on survey data about how the project meets applicant's expectations. Also, collected data gives a review over possible improvements and investments in the future. It is the base for a continues improvement process, which should be set up. [3]

2.3 Project Controlling

"*Controlling is the measurement and correction of performance in order to make sure that enterprise objectives and the plans devised to attain them are accomplished."*

By Harold Koontz [4]

In project management it is the comparison between current and planned values. Values could be time, used resources or money left. If a deviation from the plan is detected, the project manger must act. He has to decide, if more resources are required. When it is necessary, he has to find a way to cover additional resources from another stage of the project or by allocating more. Especially when the deviation is in time and on the critical path, an intervention is necessary, otherwise there is a project delay. Project managers have to be careful, because all these possible solutions to get back in the plan are costing a lot.

2.4 System

"A system is a set of *interrelated components working together towards some kind of process."*

By Michael Pidwirny [5]

The model of a system is necessary for project management because otherwise it is not possible to define project's scope.

In many cases a consultant is required. This could have different reasons. Maybe there is no expert or knowledge of problem given by the project in the company or internal specialists have not enough capacities to manage another project. But in most cases the reason for a consultant is another one. After a long time in a company a lot of people, also internal consultants, get routine-blinded. An external view on a project is required to reach a solution. It is only possible to diagnose a system, if the consultant who diagnose it, is direct outside of the system. Indeed to recognize a system the consultant cannot be a part of it. But maybe the question rises, why should he be direct outside? In this case direct means that he needs a connection to the problem, else he is not able to identify the problem in the project in the right way.

2.5 Borders of the System

Borders are important for defining a project and to establish a controlling and management for it. We need borders to know the scope of our project and what is a part of our project, which means the question if we have to handle with it or not. Usually the company defines more or less rough borders, but in some cases, e.g. it is your company, you must set up them by yourself. [6] To define project borders could be difficult.

When we find a project in the producing part of the industry we start with the physical borders, like a facility or plant borders. But this is not enough. There are many layers in a company.

Two different major layers can be set up in most projects: “Physical Layers” and “Information Layers”.

2.5.1 Physical Layer

Physical layers are found in most projects. They are established in factory designing and other projects where physical objects are existing. A physical layer could be a layout or a sum of different layouts, a map or part of a map, a room or hall, a truck or a whole country.

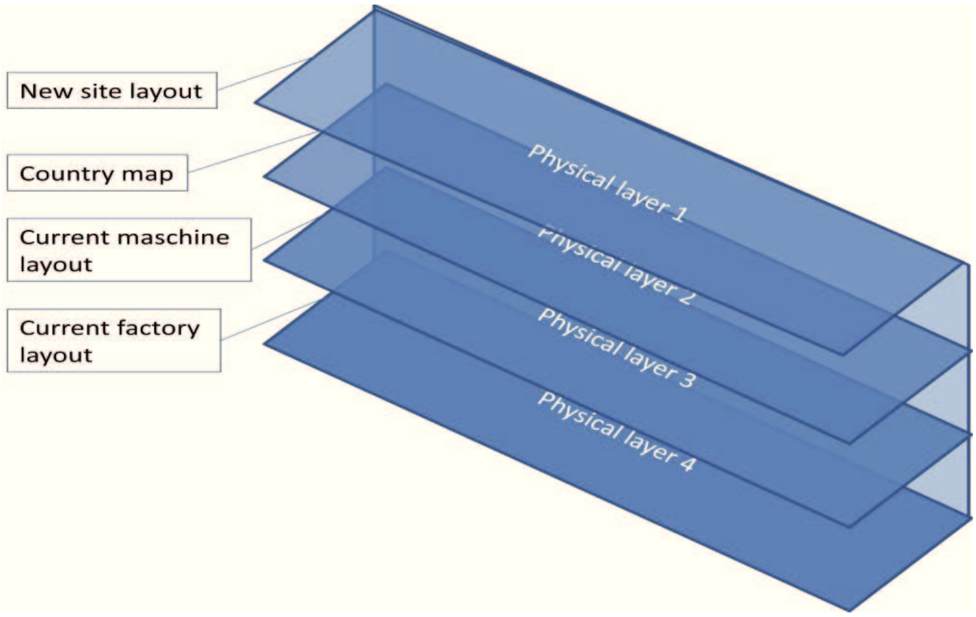

Figure 1 : Example for different physical layers

Physical layers are very easy to define because most people can imagine them. They are able to see or feel them with their own hands. For this reason in most cases there are much more physical then informational layers but this might not reflect the truth. The project manager must be careful that his borders and layers are defined in all layers of the project.

2.5.2 Information Layer

Information layers are very important for each project. They are necessary and they are found in every project. It is not possible to define a project without an information layer. In each project is communication or data flowing through the system and these are typical information layers. But a lot of project managers, responsible for defining the borders and layers, are not able to see the layers or do not know about the different information layers they are handling with. If they do not know the different information layers they are come in trouble with project’s time table because they meet an unknown layer and they do not know in which depth they have to go into this layer. This means that they are not able to define their time for passing the stage.

Table 1 : Some examples for information layers in a production

Name	Description
Adjustment Layer	An adjustment layer is used to connect different machines with a control panel or server. It is used to adjust machines and synchronize them.
Production Layer	In a production layer the actual production table is for each machine is found. It is used for communicate all necessary data about the production to each machine. This data could be for example CAD data for milling.
Tracking Layer	A tracking layer is used tracing a product through all machines. It is used for the connection between the machines and tracking database.
Error Layer	An error layer is an extra layer, because it is only used for sending important information about machines actual state. If there is an error, it is send via this layer to the control panel or server.

In many projects it is not useful or possible to define each layer, but main layers must be defined and borders have to be set up to guarantee a clear project. That means if it is not possible to define all layers and their borders, main layers include all relevant borders and information of the project scope.

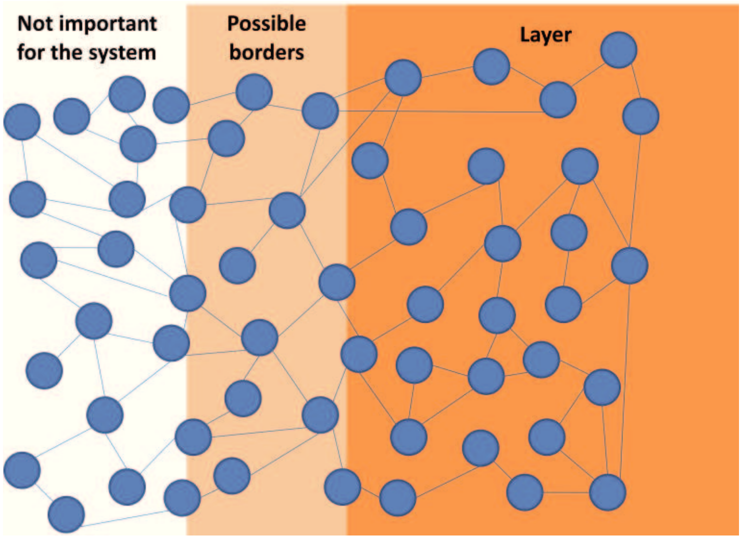

Figure 2 : The picture shows a transportation system with many nodes and edges. Each edge stays for a street between two locations, represented by the nodes. Finding borders is difficult because there are too much possible border nodes.

When no major layers are set up, the project gets in trouble with each following stage of the project because the deviation of the time table and of the main borders is too high. It is also impossible to divide the project in sub projects and work on different ones by the same time, which leads to a long overall time.

2.5.3 Combined Layers

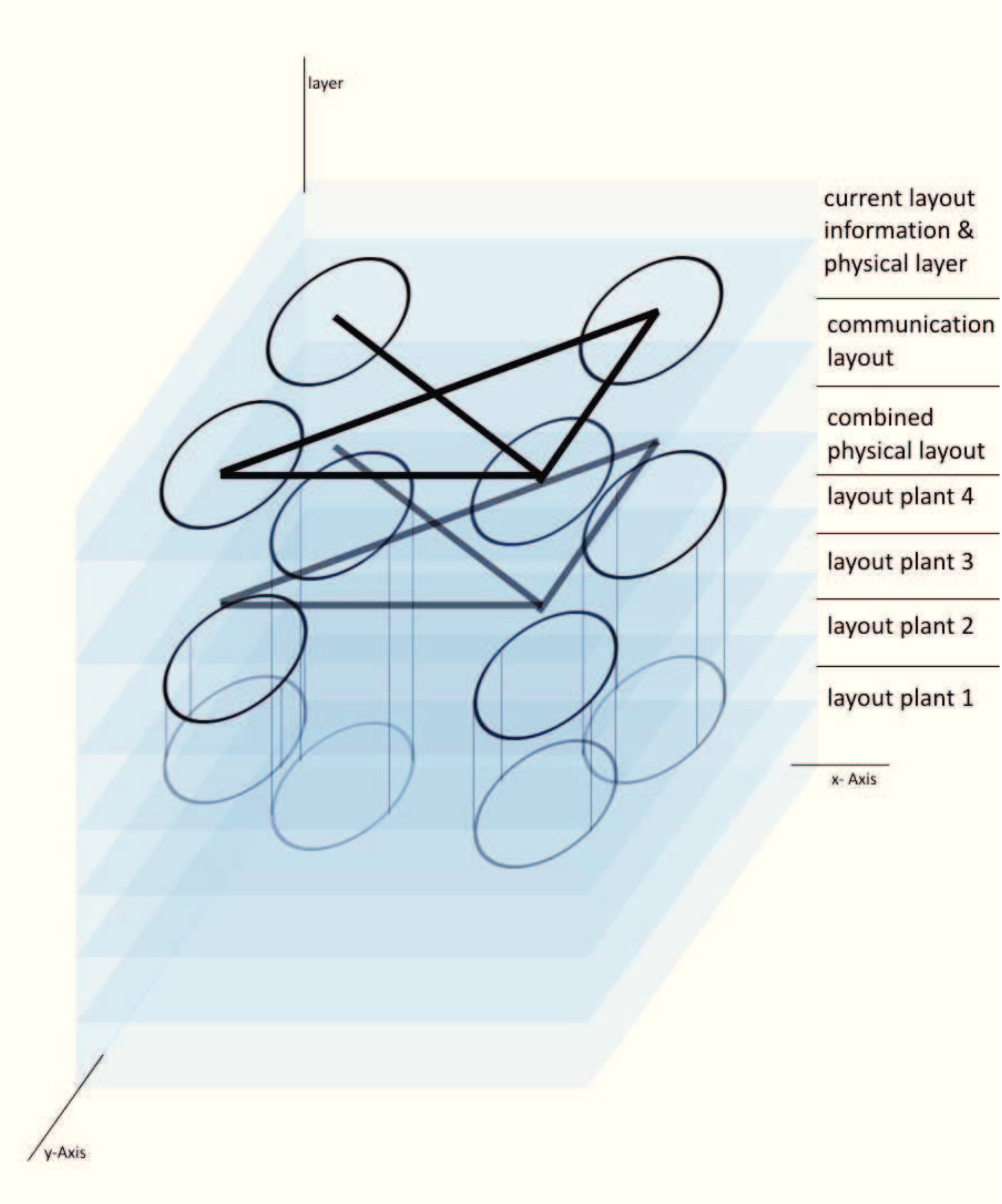

Figure 3 : 3D model of physical, information and combined layer

Graphic No. 3 shows a combined model of different layers. It starts with some physical layers from a layout. The first physical layer could be a layout from the new site where old plants should be combined. X- and y- axis could represent the real size of the area in meter. The layer axis represents the current number of layer, before combination. Physical layer two, three and four named in the graph with layout plant 2, 3 and 4 are showing parts of old plants or sites, which should be combined to a new site (combined physical layout). It includes all physical inventories such as machines, transportation ways, halls, storages offices or server rooms. The network and data which is passing the system is shown in the communication layer. This layer handles all communication and data flow through the system. It is also possible, that there could be an extra communication layer with information about the production plan flow or the production synchronization information.

All these layers are put together in the final layer (current layout information & physical layer). It represents the whole new production site with all aspects of material and information flow. This layer could be the basis for an overall controlling system which covers the whole production site. It is possible to see by a look the production problems and the bottleneck and to focus on it. Another opportunity on this model is that an optimization of the different flows between machine areas can be done. By decartelizing the flows, a clearer structure can be done. It is much easier to control than the old one.

3. Current Situation

The current situation is the "normal" situation in a company. This means that the current situation is the actual facility layout and all known data like throughput per day and/or year and all other production data for the last year. In general when starting analyzing the material flow it goes first in collecting data from the current situation and then in evaluating these data. Summarized the current situation can be defined as the average values from the past, projected of today's date.

This chapter handles with the different stages of analyzing current situation. It starts from collecting data and goes over evaluation and the different analyzing methods.

3.1 Evaluation of the current Situation

To evaluate the current situation there are different methods in the logistics to cover the first step of the logistics analysis. All methods have their advantages and disadvantages. In fact, each method was developed for another specific part branch. But it is also possible to use for example the system analysis, developed for the information technology, for the producing industry with some adoptions. But before going into the different methods there is a very important preparation for all these methods: First of all a target must be defined, which means, what should be the output of its analysis and the borders. Where does system start and where does it end. After these three very important tasks you can go the fourth step, collecting data.

3.2 Collecting Data

In modern companies most people think that it is very easy to collect data leading to knowledge about the system, because global operating companies are using enterprise resource planning systems like SAP and other planning and controlling systems, people are not able to calculate times for reaching their useful data. To find the reason why this happens it is important to know, what data is: data is only the collection of integer, double, string or other values in a database, e.g. Oracle. These collections are based on characters which consist on binary data, collected by sensors or given by employees, the customer or supplier. When we are going in the enterprise resource planning system we find a lot of data collections but first of all we do not know which of these data is useful. Another problem in data from these systems is, that we do not know if these data collections are correct or the reason why it is not correct. So to gain information from such databases is quite difficult, because we have to evaluate the quality of the collections by e.g. comparison to other collections or by benchmarking with approved data. If data is confirmed, it must be compared to the required data and it must be approved that our collection is complete; otherwise it must be completed by repeating the last step or by solving it manually.

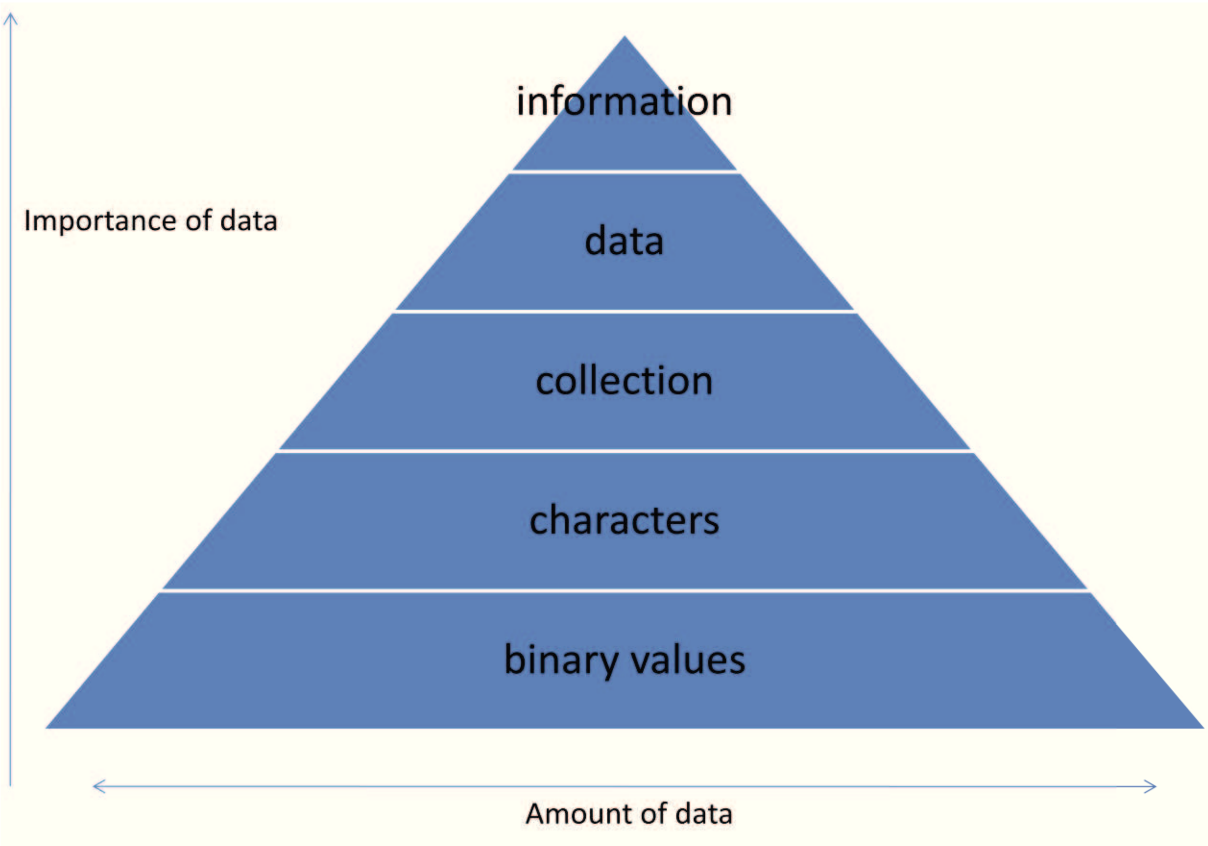

Figure 4 : Importance of data[7]

But we can find companies where no information technology system was introduced or we cannot trust in data and collections from this system. So we have to find another way to evaluate the current situation. If we have to go this way we need to plan much time for this step.

In this project phase we must be careful because if we make a mistake our outcome will not meet the customer satisfaction. After defining the target of the whole project we have to define mile stones, the critical path and small targets for project controlling. Now all small targets have to be collected in a list and define parameters for these targets.

Minimizing througput times	Optimizing the production table	Reduce stock
• In production • Reduce work in progress	• Reduce throughput times in production • Minimize administration work • Minimize change over times • Maximize productivity	• Just in time • Minimize storage area • Maximize productivity in storage

Figure 5 : Example of a list different targets. Targets are in the top and sub targets, small targets, are situated in the list.

After defining the parameters they must be clustered in order to find parameters with the same base data, e.g. throughput times. After clustering and finding the binary data it is possible to start measuring or collecting data from production or by speaking with different employees, like the head of controlling. For the best result there should be at least three measurements for the production or two people should be asked to compare the data with themselves, otherwise there is no guarantee for the quality and correctness of the data. But measure and questioning employees is not the only way to find your data. In most cases it is a good idea to go to the financial department of the company because they have to handle everything with paying incoming goods and getting money from the customer. In most companies these department is very well organized and you can find much information you can trust in about incoming and outgoing goods, prices for raw material or the amount of stored raw material, because they have to document these values by law.

After collecting data we can go to the next stage, analyzing by using different methods.

4. Analyzing and Visualization

There are different analysis methods in logistics. In general, their history is influenced by two different streams. The first influence is software engineering and modeling. The second one is based on military support services and was copied by companies. But both influences had the same background: The systems became too big and complex. The system analyzer had to consider many impacts on their system, such as changing environmental conditions or unexpected inputs (in military systems: new orders, in software engineering: unexpected variable type). To get a view over all the nodes, connections between them and impacts methods and standards were needed. After a short time companies grew and they reached the same problem as the military before. They copied the method and customized them. This was the start up of engineering business processes. This chapter handles with some methods to visualize the material and data flow through the system and how to analyze them.

But all methods are based on process identification. Without this step it isn't possible to go ahead to next methods, because they are all base on a set of known processes.

4.1 Process Identification

The company has to know his know processes starting from the production, going over the storages and also including the management processes. Processes are generally defined as "a set of interdependent tasks transforming input elements into products" (according to the Electronic Industries Alliance standard EIA-632 "Processes for engineering a system"). To find such a procedure, it is necessary to detect the tasks. A task could be a transformation in time, value, geometric form, geographic position or in data. It must be prescribed where a transformation starts and where it ends. It is feasible, that an only transformation could also be a process, if it is important enough. This must be declared by the process owner.

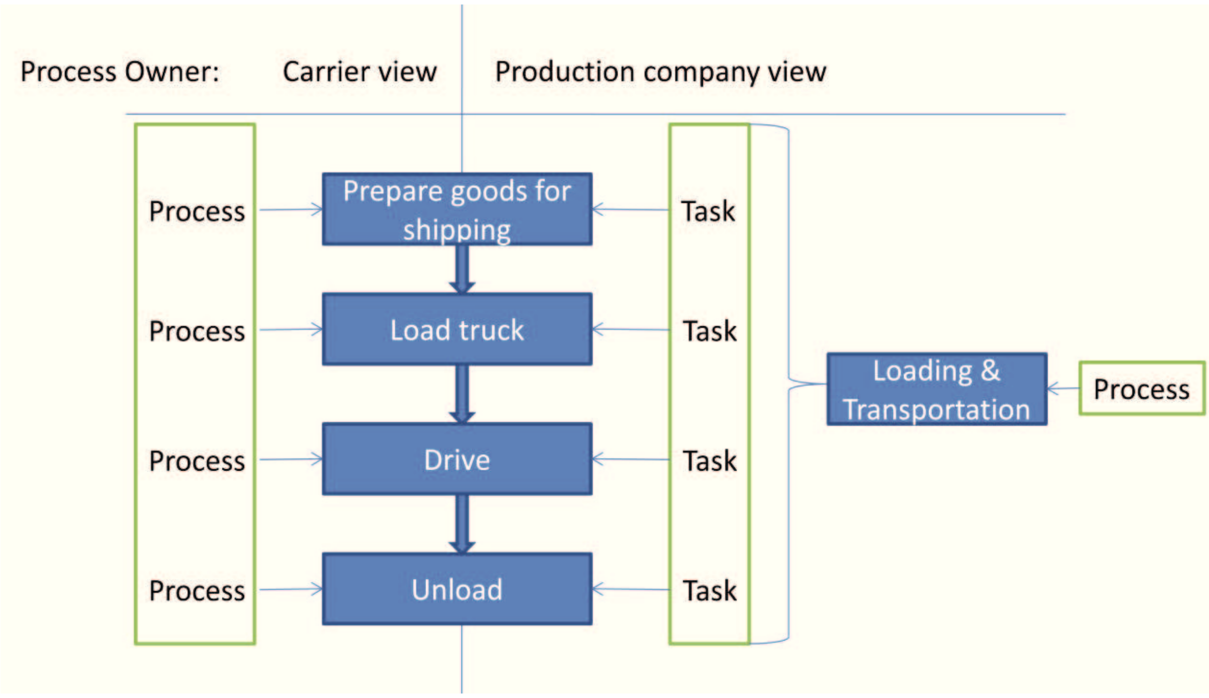

Figure 6 : This Graphic shows, that it depends on the process owner, if it is a task or a process.

After all processes were found, the next step can be made: the construction and analyze of process chains and clustering different goods.

4.2 Clustering

After identifying the processes the next step is the range of products. If there are many different products, to reduce complexity, conduction is necessary. Clustering is used, when products with equal attributes are existing. To minimize complexity and gain a better overview they are clustered into different groups and instead of handling with each product only the group is used in the system. Typical cluster attributes are the value, mechanical characteristics, color, elements used in it, quality, size or weight.

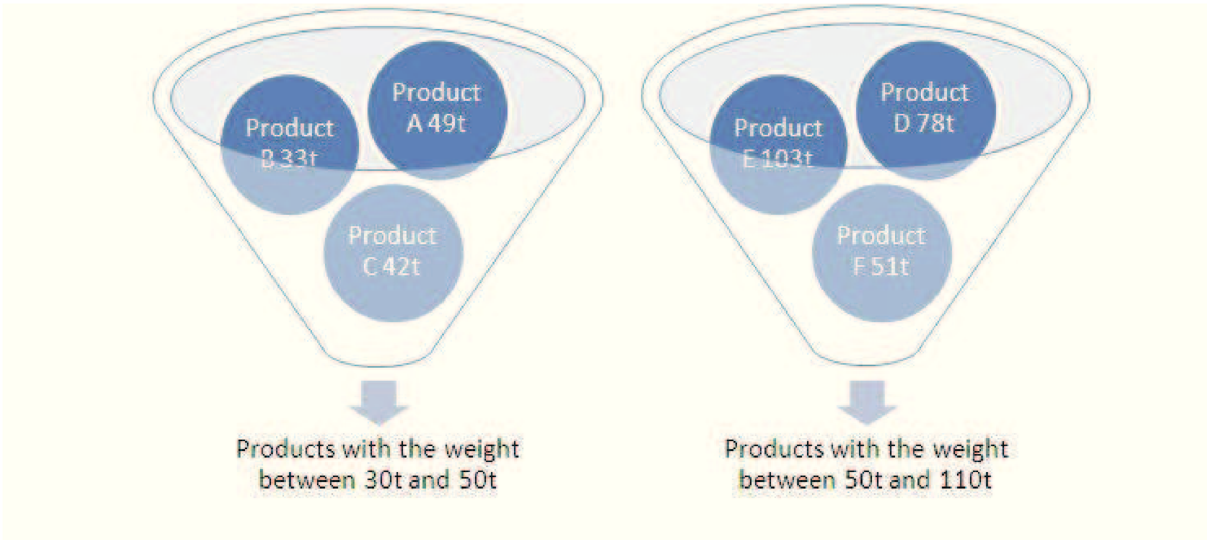

Figure 7 : Clustering six products into two different groups

Next the process chain must be analyzed and visualized. As in the introduction is mentioned, there are two unequal appendages: a technical and a business way. The next part of this chapter handles with the technical way of visualization.

4.3 System Analysis and Unified Modeling Language

Unified **M**odeling **L**anguage (UML) is a standard not a method from the **O**bject **M**anagement **G**roup (OMG), which defines a notation and semantic to visualize, construct and document business processes. The biggest advantage of UML is that it is a standard. Many people are able to read it and a misunderstanding is quietly not possible. For managing the flow not all diagrams are necessary and useful, but there are three diagrams that should be done at all:

- Use-Case Diagram
- Activity Diagram
- Sequence Diagram

4.3.1 Use-Case Diagram

This diagram shows connections between actors (stakeholders) and use-cases from actor's point of view. It is a tool to get a better view over what happen when an actor influences a system. An actor specifies a role played by a user or any other system that interacts with the subject.[8] A use-case is the specification of a set of actions performed by a system, which yields an observable result that is, typically, of value for one or more actors or other stakeholders of the system.[9] This means, that the processes or a sum of them are represented by use-cases and impacts, for example a customer or an employee, are described by actors. Diagram No. 7 shows an example for a Use-Case-Diagram. It pictured the system as a rectangle and outside the system the actors, which interact with the use-cases insert the system represented by circles.

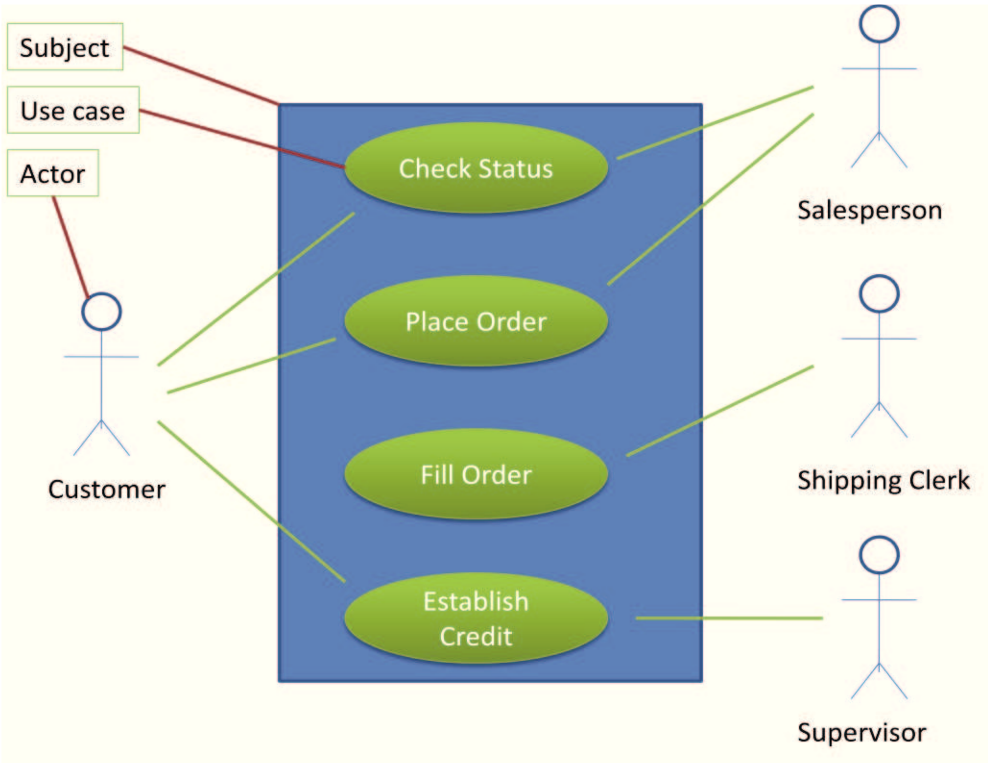

Figure 8 : UML Use-Case-Diagram [UMLS.600]

These diagrams are used for interpreting different influences on a system and where, what consequence is expected.

4.3.2 Activity Diagram

Activity-Diagrams describe possible action sequences through a system. There could be decisions, splits and synchronizations between activities. It must start and end with a specialized node.

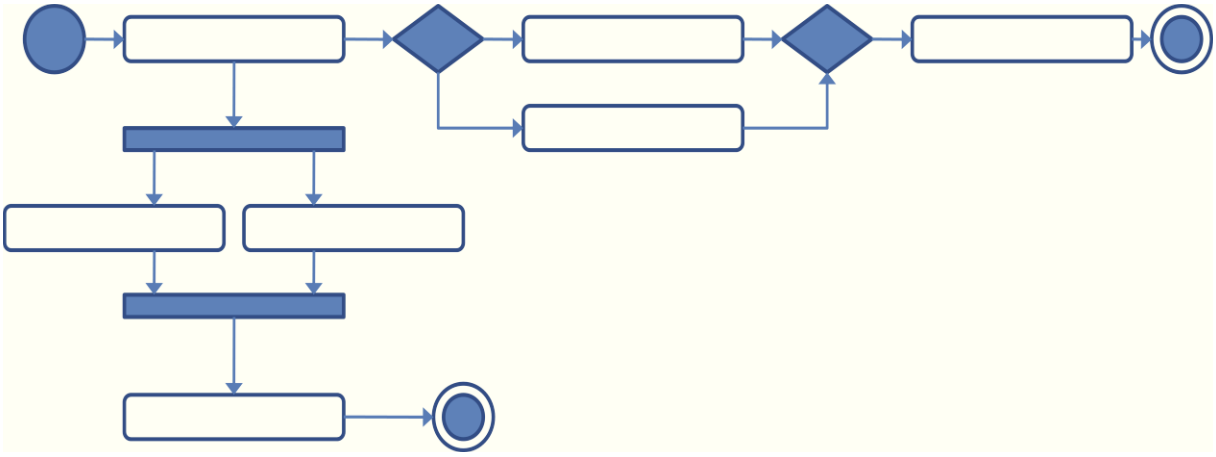

Figure 9 : Left-top node: Start node; Right and bottom node: end; diamond: decision; rectangle with rounded corners: activities; black balk: splitting or synchronization[10]

The graphic above describe a theoretical run from the start to an ending node crossing different nodes. In business models activities are equal to processes. These diagrams are necessary to pursuit the entity, which could be physical goods or information in a production rule system. The trace of entity is required to find bugs and unnecessary steps in a system.

4.3.3 Sequence Diagram

A sequence diagram shows the interaction between classes over a time. The time is represented by a time line starting at the top and going down.

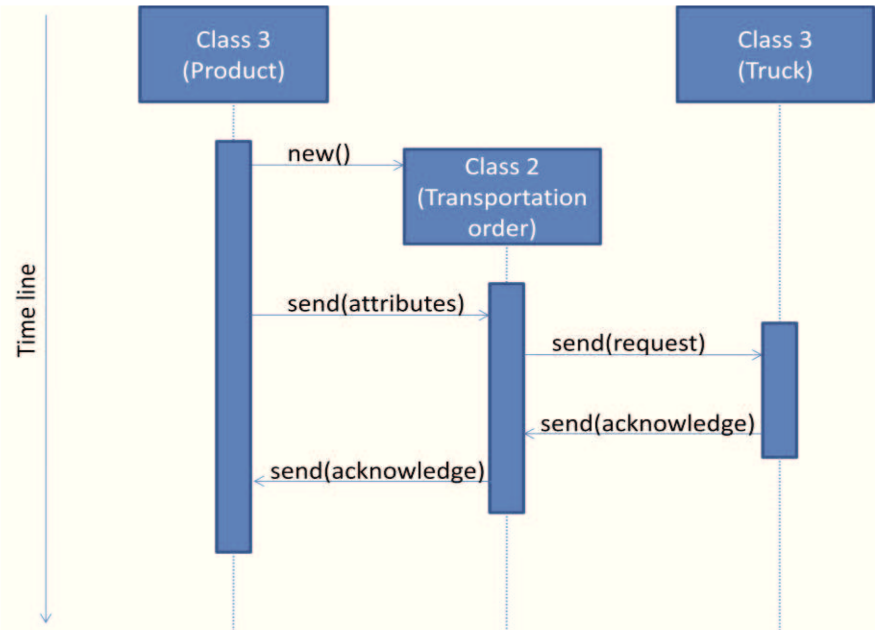

Figure 10 : Sequence diagram from a transportation request

Figure no. 10 describes such a diagram. It shows how different classes could interact with each other and how the information is flowing between each other. The classes can represent a lot of different subjects in business cases. Subjects could be responsiveness, a product, an information technology system, a data base, a machine or much more. These graphics are used for controlling interactions and the connections between them. Identifying key classes is also possible by searching classes with many impacts to others.

Additional to the technical methods of system analysis, there is a business appendage.

4.3.4 Event-driven Process Chains

"Event-driven Process Chains (EPC) is a method developed by Scheer, Keller and Nüttgens within the framework of Architecture of Integrated Information System (ARIS) to model business processes."[11]

It shows a company their business processes from a control view, which means that it can start from a view over the whole structure and how decisions go through the system and end by the direct view on a process or data flow diagrams. It is possible to show the whole structure beginning from the top level.

The EPC is standardized and therefore many rules must be obeyed. It is necessary to follow the rules because in most cases we found standardized diagrams. If this is not the case, not everybody who is able to read EPC diagrams would be able to read this specific one.

Rules to obey:

- An event can only be followed by a function.
- A function has always a following event.
- In a single EPC graph without process paths, the graph must have at least one start event and one end event. In other words, a graph must be started and ended with events, not with functions.
- If the graphs have process paths that link them, in the source graph the process path should be put at the end of the graph after the end event, and in the target graph the process path should be put at the beginning of the graph before the start event.

- A combination of functions and events can be achieved using logical connectors.
- Logical connectors can be placed between functions on the one hand and events on the other hand, but the alternation of functions and events must always be maintained.
- An event is a passive element. This means that it cannot be used to make decisions, but it can be used to trigger parallel activities. Therefore an event can be followed only by an 'AND' connector, not an 'OR' or 'XOR' connectors.

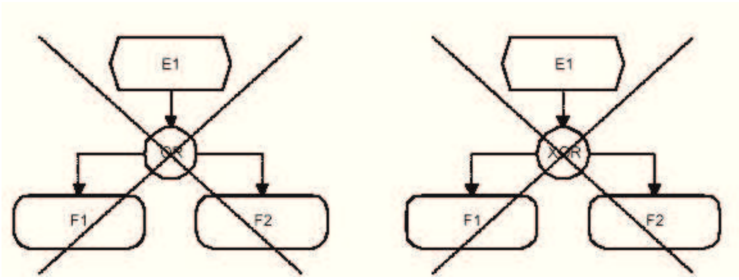

Figure 11 : Forbidden connections

- A function is an active element. This means that it can be used to make decisions and to trigger parallel activities. Therefore any of the logical connectors can follow a function.
- Logical connectors should match, meaning that an opening 'XOR' serving as a branch should be closed by another 'XOR' connector. The same rule applies to fork/join using 'AND' connector and 'OR' connector.
- All elements must be connected to the control flow, because an isolated element would have no meaning or contribution to the whole process.[12]

After the restrictions are known, an EPC can be drawn.

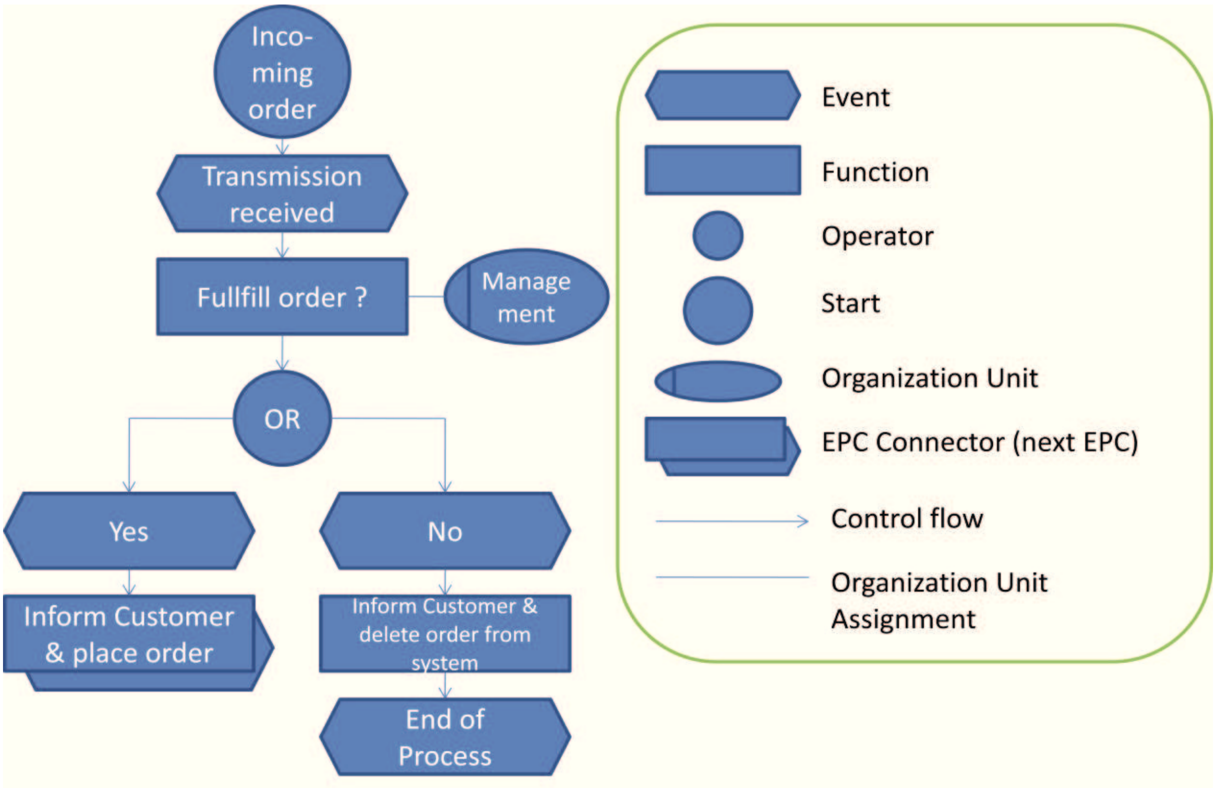

Figure 12 : EPC from a business process in the management

Graph No. 12 represents a typical EPC on a management level. It shows responsiveness of the management for the decision, if the company will fulfill the order or not. In this example a huge order is the input, because otherwise management would not be involved. After a negative decision, the customer gets the information and the process ends. On the other side, if there is a positive call for the order, another process with an EPC diagram starts.

This is a typical usage for an EPC diagram in management or administrative businesses, instead of using an EPC diagram to show a material flow, what is more common. The syntax for flowing material is the same, but there is an additional sign for the information stream (two arrows in opposite direction).

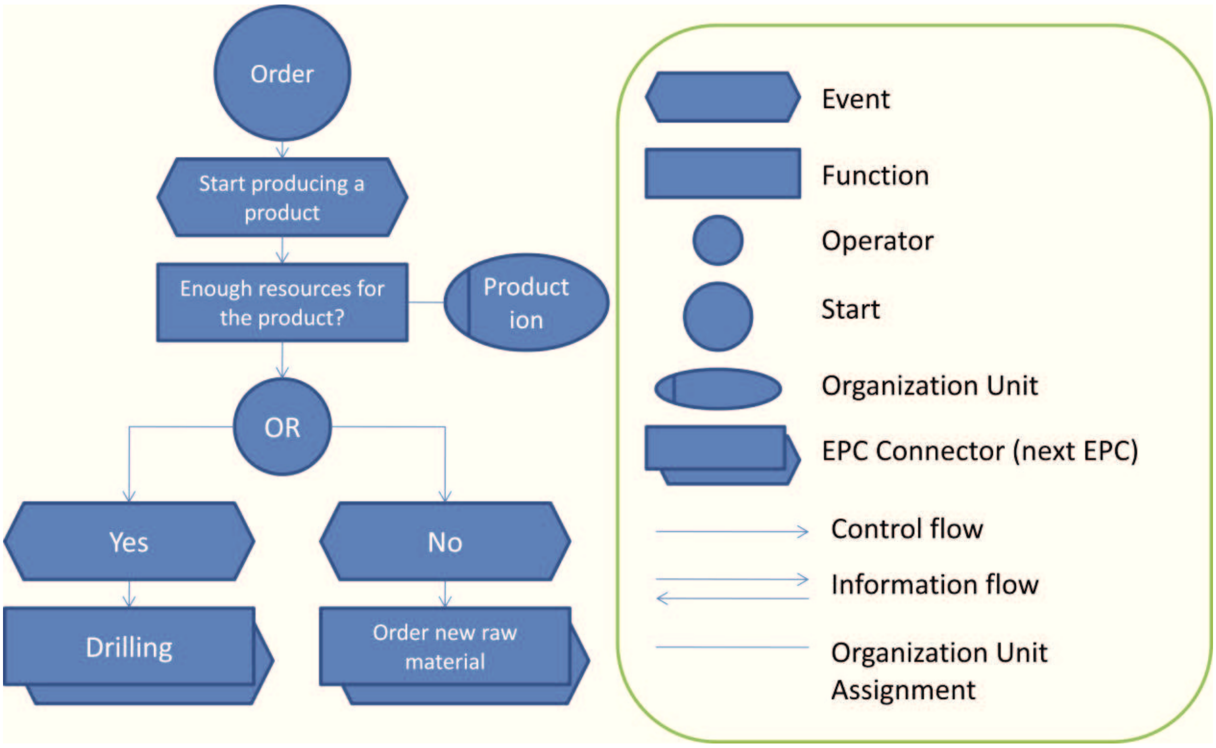

Figure 13 : Material flow EPC

The diagram displays a material flow EPC diagram. At the moment there is no database query, represented by the information flow, in the system. The control flow represents in this stage of the flow only information and no physical good.

In the next stage the entity, which is passing the system, got material (Figure No.14). Now there is a physical good, raw material, going through the production. It is possible to follow the entity from the order income to the shipment as the case maybe until the system's border is reached. In another case, diagram no. 13 represents the connection between an entity and a database. The entity passes a station where information about the order is required and it is found in the database. So, the entity waits until the information is given back and saved as an attribute in the object.[11]

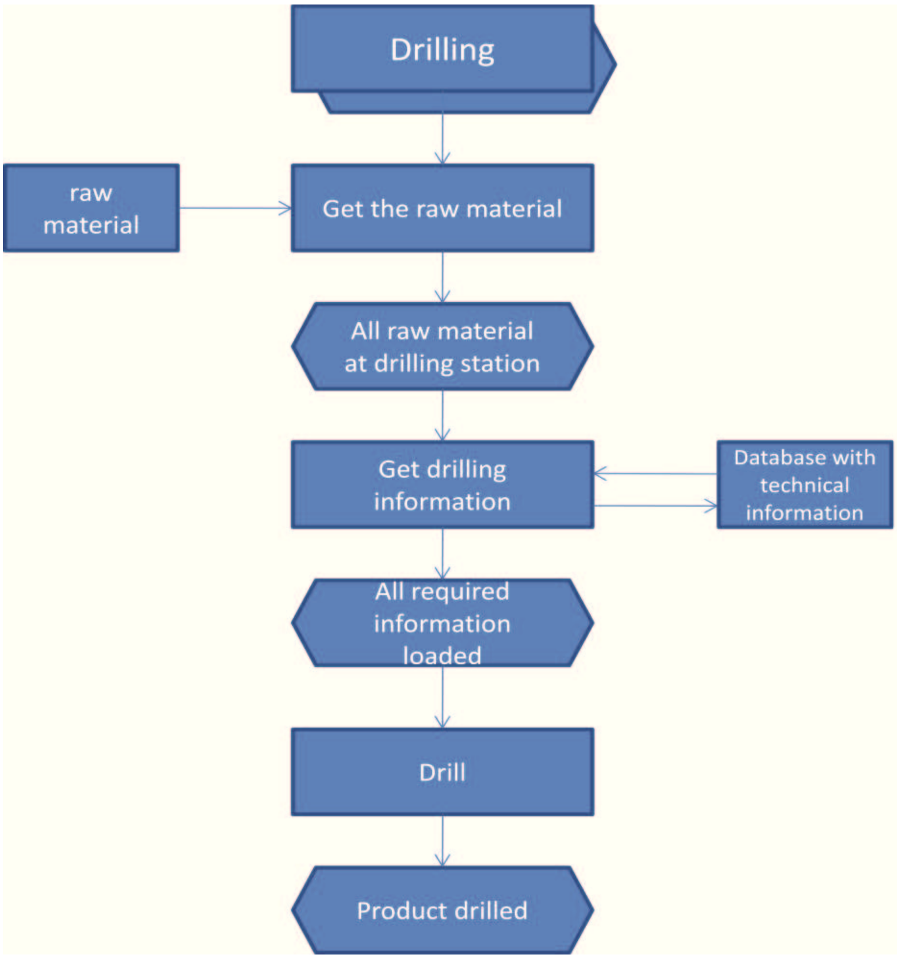

Figure 14 : EPC with a database connection and adding raw material as entity's attribute.

4.3.5 Value added Chain Diagram (VAD)

The VAD describes an abstract model of value added processes in a company. In most cases it gives a view over the organization and positions of relevance processes in the company. A relevance process attribute is marked by direct increasing product's value. This means that all key processes must be included in a VAD. Support processes must be included only if they are useful for diagram's understanding.

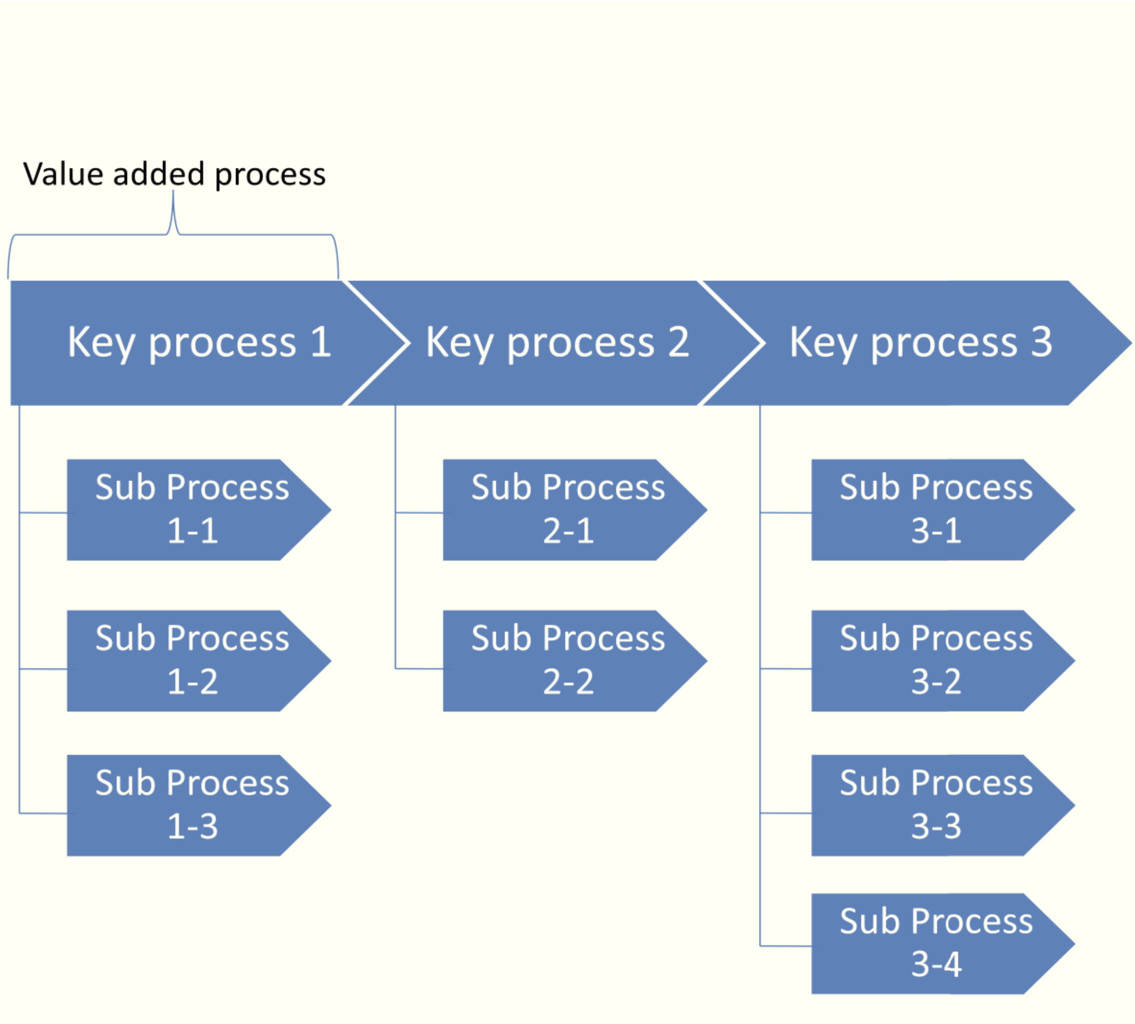

Figure 15 : Value added chain diagram with key and sub processes

This diagram can be combined with an event driven process diagram. A key process could be used for a summary of the sub processes in an overview. A sub process can be designed with an EPC or an activity diagram.

4.3.6 Comparison between EPC and UML Activity Diagram

Due to the fact that UML activity diagrams and EPC diagrams are showing quiet the same, there are some differences between them. Most discrepancies are coming from their development state. At the beginning, UML was designed to visualize object orientated processes in the information technology, based on military visualization systems. By contrast to UML, EPC was developed by business companies to design their complex production processes.

Table 2 : Difference between EPC and UML Activity diagram

	EPC	UML Activity diagram
Context	Process-Oriented modeling (business oriented)	Object-Oriented modeling (IT oriented)
Notation/Terminology:		
Active element	Function	Activity / Action state
Passive element	Event	-
Process chain	Control flow	Transition
Logical connectors:		
Branch / Merge	"XOR" connector	Decision diamond
Fork / Join	"AND" connector	Synchronization
"inclusive" or	"OR" connector	-
Iteration	-	" * " (multiplicity sign)

The table above (Table No.2) shows the formal differences between UML activity diagram and EPC modeling. The biggest difference between both models regards the context. EPC was developed to design business processes and UML for visualization of object oriented models. This is also found in the logical connectors. An "inclusive OR" operator is in most programming languages not really included. Therefore it is not necessary to implement them.

But both models are useful to design a material flow through a production. The physical stream could be designed with an EPC diagram, because it is faster and easier. Big process diagrams can be made in a short time. Instead of using EPC for the information flow, UML activity diagrams would be better. Their advantage is that iterations, which we can possible find in an information flow, can be modeled.

Finally, a combination of both diagrams will show the whole information and physical flow in a plant or company.

4.4 Sankey Diagram (Evaluation Tool)

The Sankey diagram is a visual interpretation of a data collection. It tries to make a lot of data much more readable. But in some cases, e.g. when you have many connections between different nodes, it could be hard to read. Sankey diagrams want to show main routes through the system and the connections between these nodes. As in a typical operation research system nodes and edges could be found. For starting painting the diagram data must be prepared. Preparing data starts with a table where all nodes are found on both axes. In the cells are set up goods travelling between the x-axis node and the y-axis node. This table is called cost matrix. It sounds easy but in most cases it is very difficult to find out, how many goods are going through this path. To find out which goods are travelling where, there is basic way to gather this information.

1. Defining all products in system

   Products must be defined with a unique name.

2. Defining process stations

   A process station is every location in the system where we have value- and non value-added services. It could be a machine, storage or transportation system.
3. Choose a unit to compare flows

   Choosing the right unit is very important because if the wrong one is chosen maybe diagram do not show expected values and it is impossible to find the best layout
4. Defining routes

   In the next step speaking with employees is very important because they have to define routes through your system, which means that they have to fill out a check list with the different process stations to find out which stations are passed.
5. Translate checklists to a cost matrix

   After all product routes are defined by checklists they must be converted in cost matrix. After this step there must be the same amount of cost matrix as of products.
6. Combine the matrixes to a cost matrix

   By adding every path in each value to unique cost matrix you got your final one, it is possible to work with. This matrix consists of all flowing data through your system. In the diagonal only nulls can be found because there the flow from on node to itself is defined as null. If it is necessary to translate this matrix to program code, in some cases it must be defined as unlimited or un-defined otherwise the algorithms are not working in the right way.

node nr \ node nr	1	2	3	4	5
1	0	0	0	0	0
2	22	0	0	0	0
3	12	109	0	0	0
4	13	1	1	0	0
5	2	32	54	32	0

in t/day

Figure 16 : Cost matrix

After creating a cost matrix it is possible to start painting the diagram. Each node and edge should be painted. The strength of the edge depends on cost matrix's value. It shows where main routes through the system are.

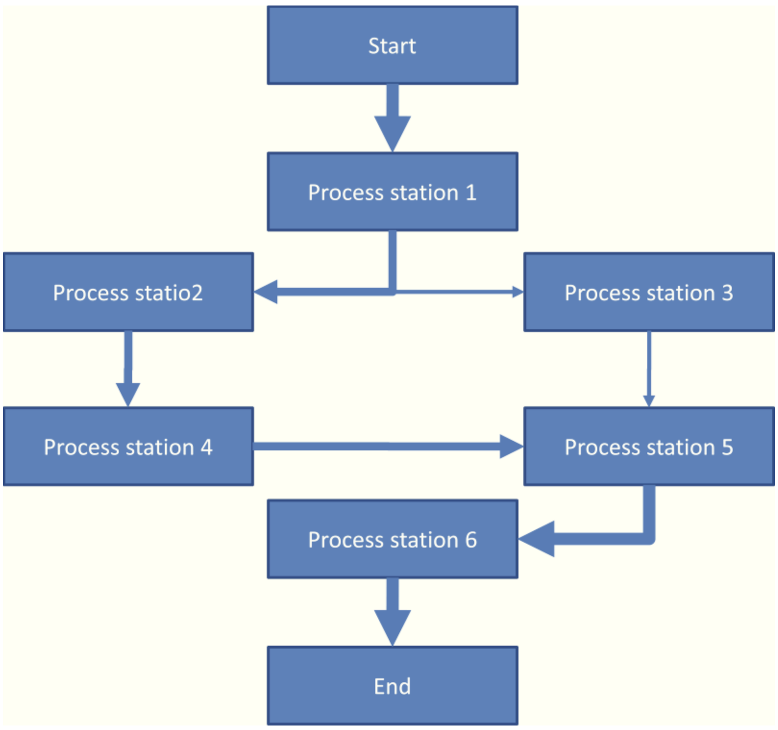

Figure 17 : A typical Sankey diagram with different weighted routes.

In many cases Sankey diagrams are based on an EPC or Activity diagram. They try to interpret and combine the given system with a real flow. Usually first a EPC or Activity diagram is painted, because they are only showing the structure without any interpretation or weighting of the routes.

5. Material Flow Processes

All described methods handle with different classes of processes. But in a material flow analysis the same basic processes can be defined in every method. It is possible that they have different names, but their function is equal to the following processes.

Transport

Transport means the movement of goods from one place to another location. There are different modes of transportation. In some cases the good travels by itself, e.g. if the good is a finished car, or it needs a transportation device for travelling between sink and source. Transportation could also be the physical movement of data between a server and a client.

Movement of goods

Is the physical movement of goods from one work equipment to another in order to supply the good at the right time.

Store

Storing goods is used, when the production is not synchronic with the supplier or customer demand. This means that goods are stocked to release them, when they are required.

Puffer

Is the temporary storage of goods, which could not be processed on the next station. This could happen, when we have different pace on stations next to each other.

Order Picking

Is the combination of spread goods in a location after defined constraints to provide a huge assortment there.

Distribute

Is the division of grouped goods to provide them in little pieces on other stations.

Sort

Sorting divides goods, concentrated on a location, with different attributes in defined groups. This must be done to find equal goods.

Building loading Units

Building loading units is defined as combining different goods to a unit. This process is necessary to simplify the system by adding a new object which combines a number of other objects.

Packaging

This includes everything which should prevent the product from damage.

Quality Inspection

Testing includes everything to ensure the quality of the product and it proofs the functions of the product.

At this point question rises, what are these definitions used for, or why should they be defined. And the answer is simple. If they are not defined many people forgot these processes, because they think, that the processes are included in other processes. So they must be defined to guarantee that every activity and station in our system is mapped in the system and to represent these processes by their selves instead of including them to other processes.[13] [14]

6. Evaluation and Interpretation of the Material Flow Analysis

After all current situation analyses are finished, results must be interpreted to find new solutions and methods to optimize the flow. Analyze flow diagrams and connected matrices are not as easy as it seems. It needs many experience and knowledge about logistics and logical thinking about the system. The interpreter should be able to look over the system borders and to find influences on it. These could be a change in the whole market, which is an impact on given system, or the loss of a key customer because the analyzed company isn't competitive anymore.

Usually the interpreter starts with the flow diagram. He has a rough look over it and tries to find out basic routes through the system. If a Sankey diagram is accessible he uses this diagram to find the main routes. This is very easy if a Sankey diagram is present, because the paths are represented by arrows and the amount of value going over it is represented by the strength of the arrow. He only need to seek the big arrows and has main routes through the system, so he knows where to orient on for the next steps and the future layout.

After looking over the Sankey he goes into the data and matrices of the diagram. There he can evaluate the exact amount of every route and the value of the goods going over it. Prioritizations of the routes are the followed stage of his evaluation and now it is possible to compare the values with the Sankey diagram to confirm the prioritized routes.

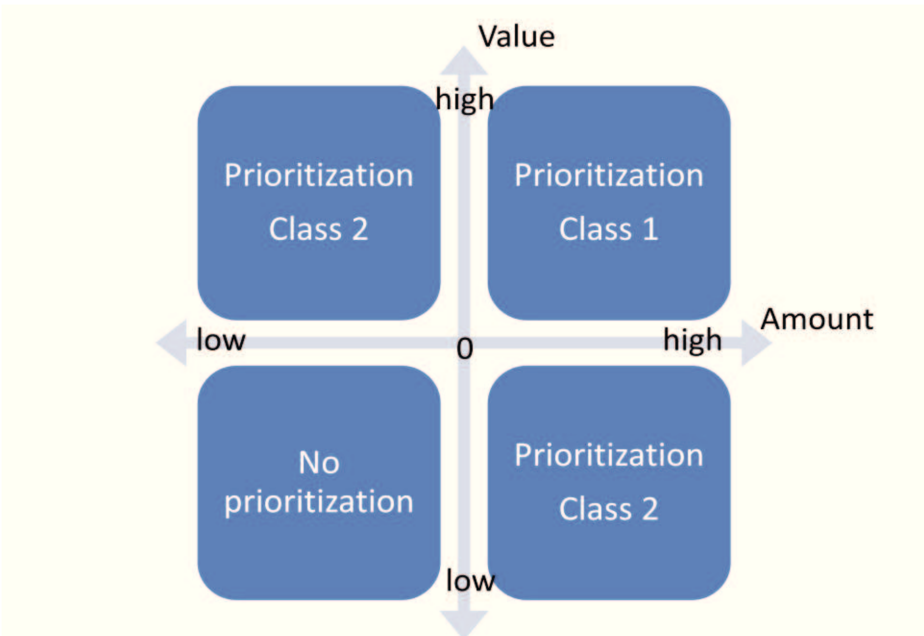

Figure 18 : The highest prioritization is on Class1 Products. Class 2 Goods must be downgraded under Class 1

The result should be a few routes, which include our main product route, but also routes with high value and low amount of goods must be focused, because cost of working capital is very high on these routes.

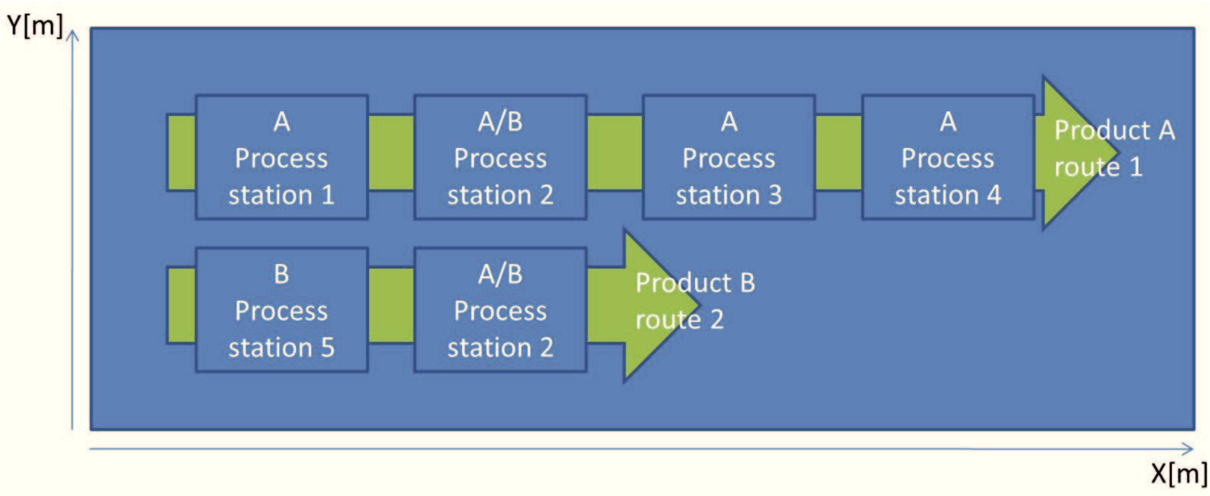

Figure 19 : Two routes through the production with difference physical length

In a well-planned system all station or the routes are found next to each other in a line or circle. Every station should be directly situated next to the followed and prior process station to minimize the transportation costs and time. Other optimization possibilities could be the synchronization of different stations and the calculation of the best lot size. This is found in the literature, e.g. “Produktionswirtschaft” by Theodor Nebl or “Logistics Systems: Design and Optimization” by André Langevin, Diane Riopel.

6.1 Production Structure

Before planning and designing the new layout the structure must be declared and planned. In logistics we can find different typical production structures. There are four basic forms with different advantages and disadvantages: job-shop production, batch production, fixed-site production and continuous flow production.

6.1.1 Job-Shop Production

A job-shop is characterized by small batches of a variety of custom products. Most products require an individual process station set up, which means, that the machines must be set up for the manufacturing process for each small batch. Examples are factory machining centers, paint shops and all other factories that manufacture individual products in small lot sizes.

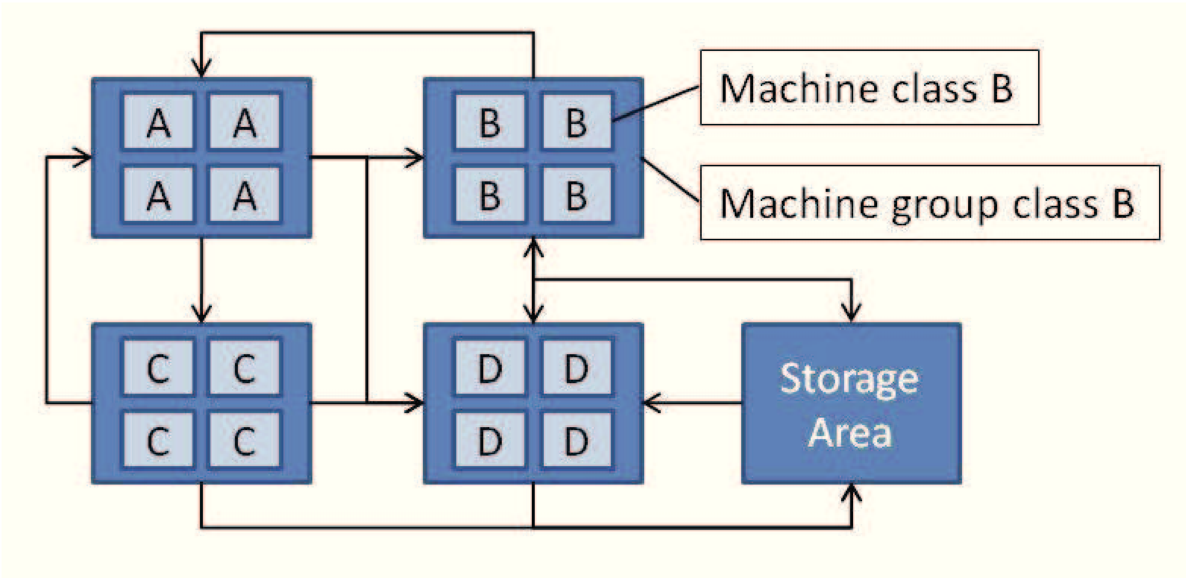

Figure 20 : Typical Jop-Shop production layout

In a job-shop all similar equipment is grouped together, e.g. grinding machines or dryers. It is possible that a good must pass a process station twice or more times. The system isn't very fluent, but very variable in producing different goods, because there could be long ways from one to the next process station, material handling times are very high between the different stations. The machines must be designed for a quick change of their set up to minimize changeover times. The synchronization of two machines of different kinds is not possible as long as there is a small batch and a high variety of products. The flow is not directed in the system and the storage area is placed next to the machines or in separated areas.[15]

6.1.2 Batch Production

A batch production is characterized by small groups of manufacturing machines or stations, which are necessary for one production step. This means that product parts similar in production have their own production site. These grouped stations must not consist of the same machine class. The grouped machines are set up to a specific good and it is not necessary that they have low changeover times. Batch sizes should not be too low and products variation is not too high. If there are any variations of goods, the difference could be a combination of different parts, but the parts themselves have no variation in type.

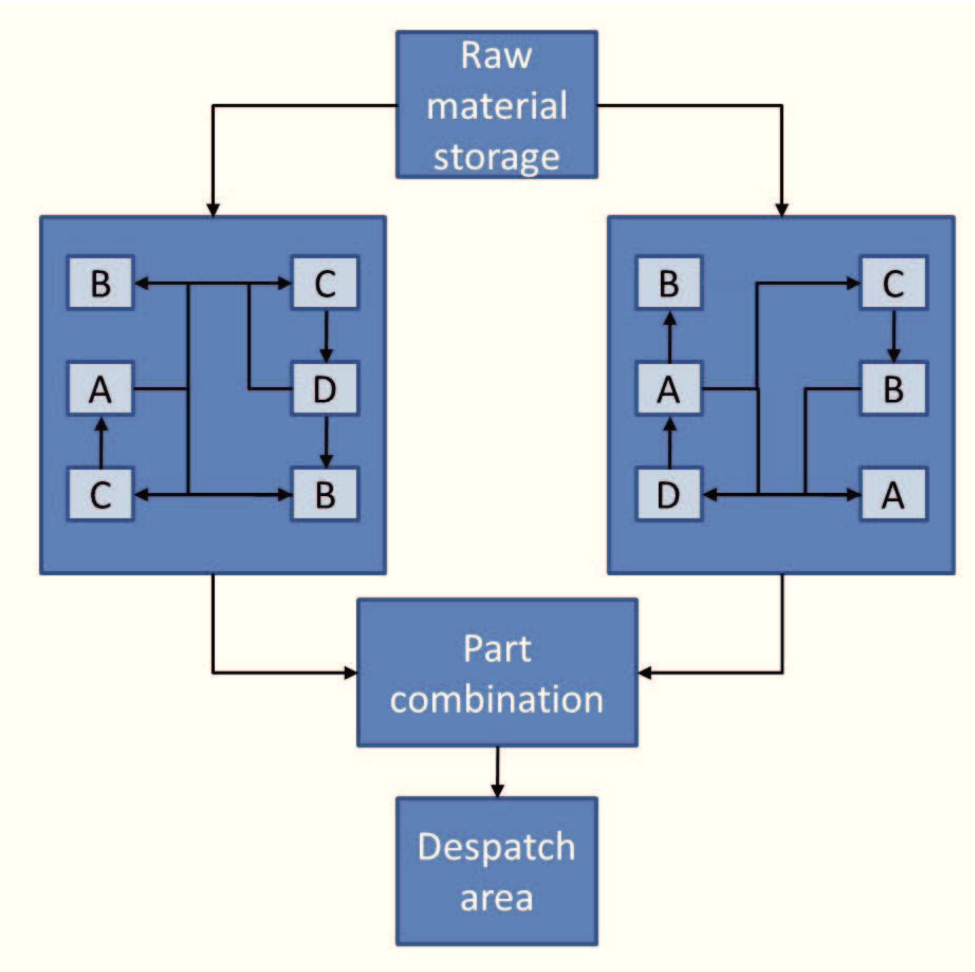

Figure 21 : A batch production layout with grouped machines and a part combination area

Batch production can be found in many different parts of the industry. The biggest industry where batch production could be found, is the production of electric devices. The different electric components are combined in the designated area to specified devices.

6.1.3 Fixed-site Production

A fixed-site production is characterized by materials, tools, and personnel are brought to the location where the product is fabricated. The reason for organizing a production that way is, that in some cases it is impossible or too expensive to produce a product in the factory. Therefore the factory is "moving" to place where the product is required. Fixed-site productions are typical for building streets or power plants. It is also used in building huge sites or other buildings. In some cases parts are prepared in factories off site transported to their destination and combined with the other parts on site. [16]

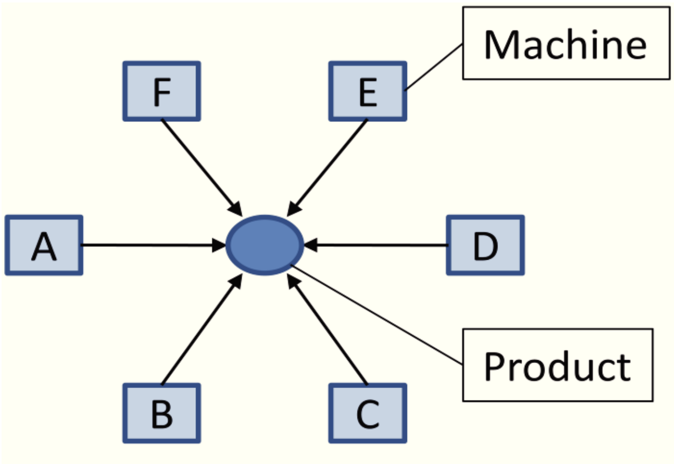

Figure 21 : Fixed-site layout

6.1.4 Continuous Flow Production

A continuous flow production is very fluent and clear designed. Its biggest target is a continuous flow through the system without waiting times or other non value added operations. It is based on the batch production structure but more specialized. When a process station is passed, there is usually no opportunity to go over this station again. All machines belonging to the production of a good are placed in a line and are synchronized. The good passes the system with a given speed and a constant throughput time. Managing such a system is very complicated because the production plan must be very well planned. If maintenance for a machine is necessary, the whole line must be stopped. For this reason maintenance work should also be included in the production table.

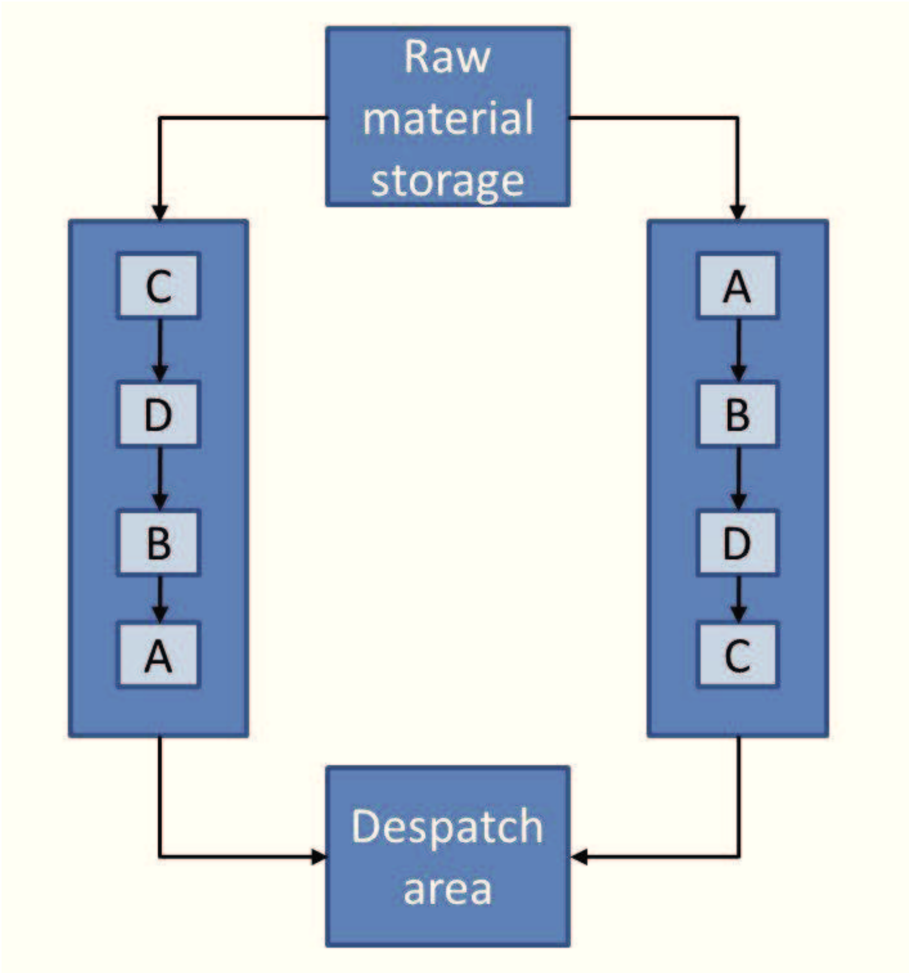

Figure 22 : Continuous flow production layout

This production is typical for mass and bulk products. It is also used in the automotive industry. For using such a system a high developed IT system is required. The complexity of the system is too high for managing them manual. If there are variations of the good in the line, e.g. in the automotive industry, the variation must be realized in the last step or if only a few products must be customized, it should be done after finishing the product (Rebulding). [17]

7. Development of a new Layout

After the system was evaluated, now it is necessary to develop a new better layout. But before starting some constraints must be found. In the prior step the main routes were found and defined and it is known on which routes we have to focus on. This is one of the constraints. Another constraint is the dimension of the new plant site. It must be evaluated which sizes the new hall, if this is not feasible, planning is impossible, because these data is necessary for the layout planning. Other constraints could be e.g. the position of a machine or the maximum impact on a specific plant area.

The constraints are set up and the next stage in designing the layout could be reached. Stations connected to both routes must be found. They are connecting the different routes to each other and they are building the angles of the first rough layout. These angles are called connectors and they are used to design the rest of the layout. Figure No. 24 shows the process of converting different types of process stations to a flow layout for the new design. This is the basic to adopt the next stages. It starts with graphic No. 24, which displays two different routes through the system and has one connector. This is very simple to include into a layout because only one station is used for both lines.

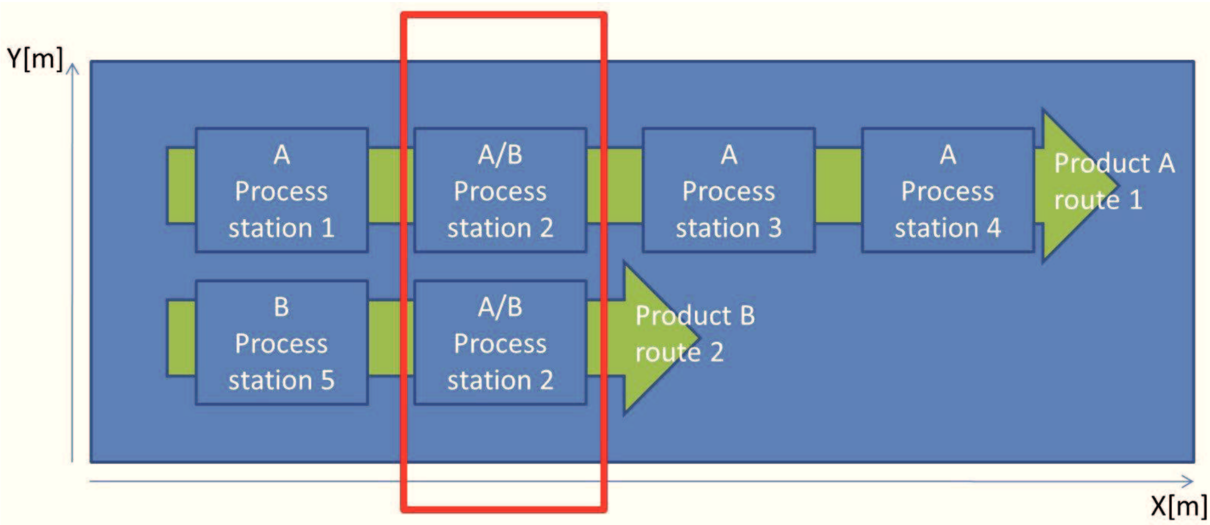

Figure 23 : Two Routes through the system. Station2 in included in both routes

If there is more than one connector it is quite difficult to find a clear layout. Figure No. 26 shows a system with three connectors. This is a bigger challenge because handling with three points is much harder than handle with only one connector.

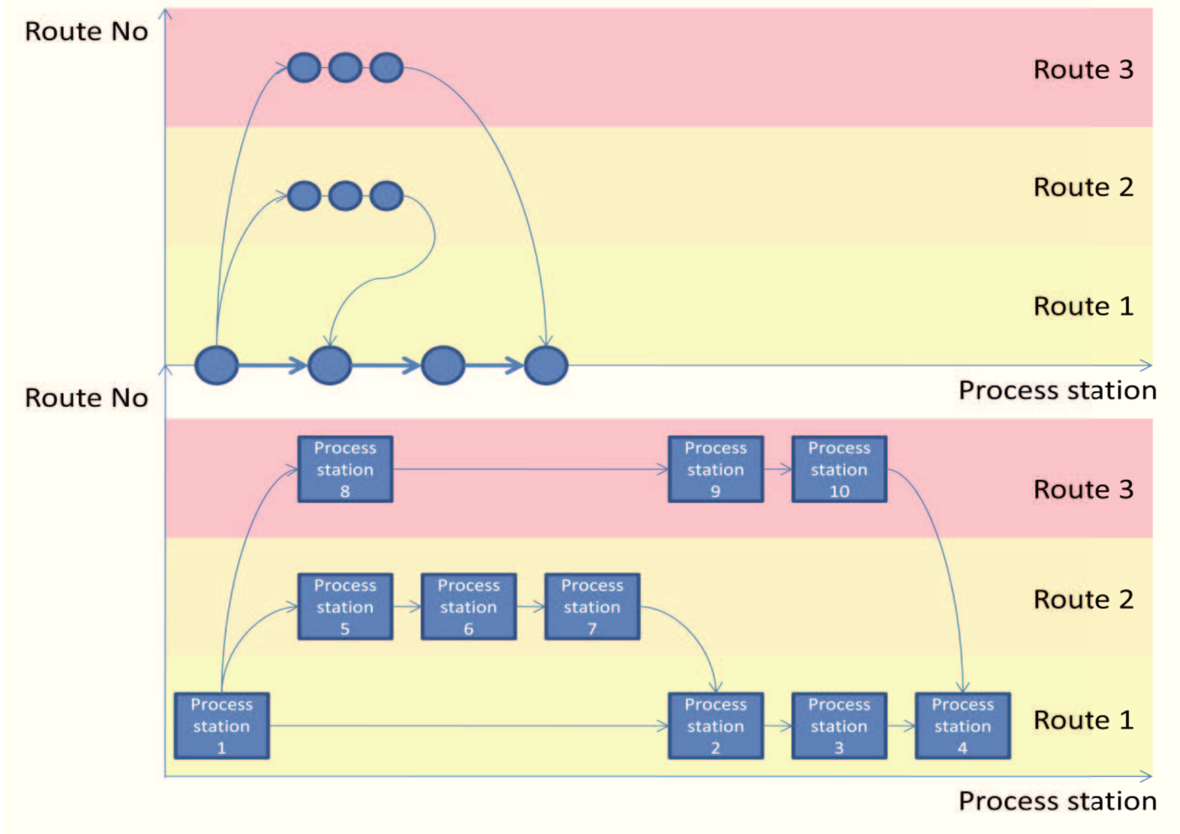

Figure 24 : Shows three routes through the system with three connectors

After defining all connectors in the system, a rough layout must be found. This layout is based on the dimensional restrictions given by the constraints. But also the sizes of the machines and transport devices are necessary for the first layout. If the machine sizes are unknown, it is possible to measure them from the old layout. Therefore an exact layout from the old site, if there is an old one, must be given. Now it is time to place the machine areas in the layout. This means, that every machine has a specific dimension and the machine area includes the machine itself, puffer and working range of the machine.

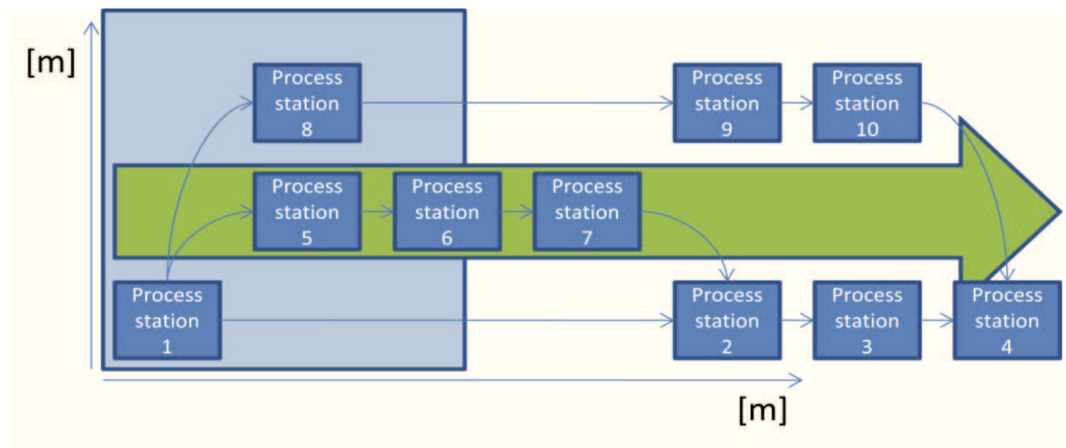

Figure 25 : The direct import from the given connector graphic to the new plant side (in light blue)

But only including the stations brings it not to a favorable layout as graphic No. 26 shows. The rough layout with the machine areas is too big for the given plant size. So the machines must be arranged in a new way. Because of the different physical route length it is not optimal to place the areas in rows.

After a rough searching in geometric figures, it is found, that a circle has the minimum spanning route around a given area. But there is a constraint. The available site area is not round. It is a rectangle. The rough layout (figure No. 26) consists of one main route and two side routes. This means, that a geometric figure must be found, which can be placed in a rectangle, has a main route directly from one to the other point and includes two side routes. Because it consists of the start and the end station of the system, it must be the shortest path from the entry of the system and the end.

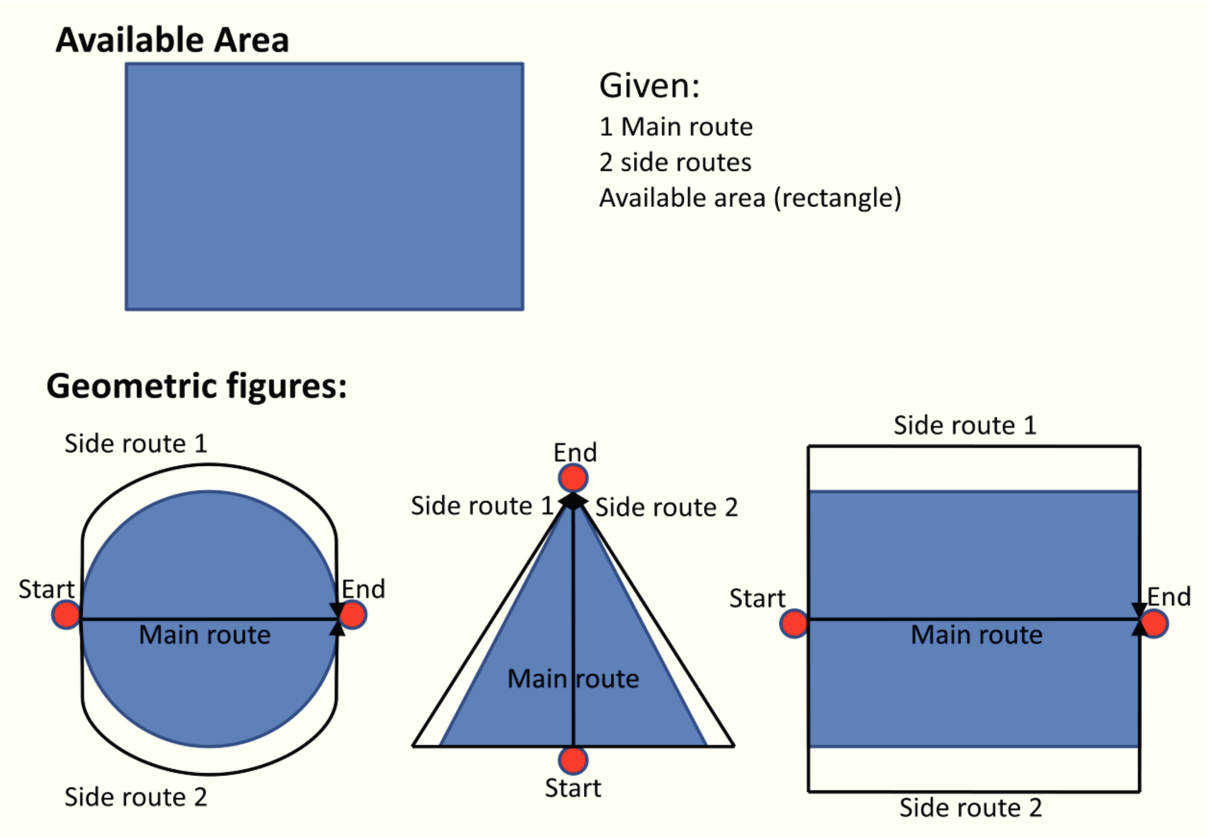

Figure 26 : Samples of geometric figures with one main and two side routes through the system

Another problem must be solved. The side routes are not symmetric to each other. They have different physical length. This makes it impossible to find a standard geometric figure for the given stations. But as Figure No. 27 shows, the best solution, ignoring the different length, would be a combination from a rectangle and a circle. A figure quiet similar to this is an ellipse. It is based on a circle but looks in some configurations like a rectangle as the graphic below shows.

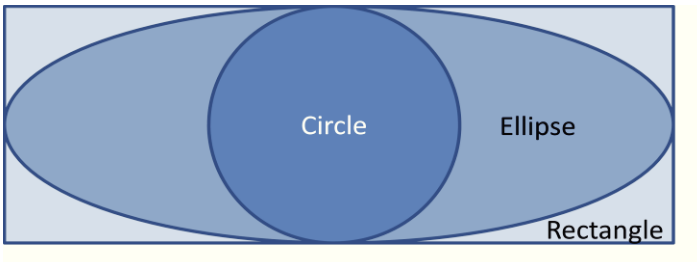

Figure 27 : From a Circle to a rectangle. The Ellipse

Now the start- and endpoint, main route and side routes must be defined. The start point can be found on the left, the end point on the right apex of the ellipse. The main route is defined as the shortest connection between these two points, the symmetric axis. Side routes are the upper and lower boundary of the ellipse. The side routes must be fitted to the layout. This should consider the different physical length of the ride routes. Therefore one side route must be shortened to the end station of this route. This contains also the destroying of the symmetric ellipse form. That is the reason for finding another form, similar to our problem. The first starting position from the ellipse was not too bad, because only one constraint did not fit. Hence, it is worthwhile to start again from this point, but including the different physical side route lengths.

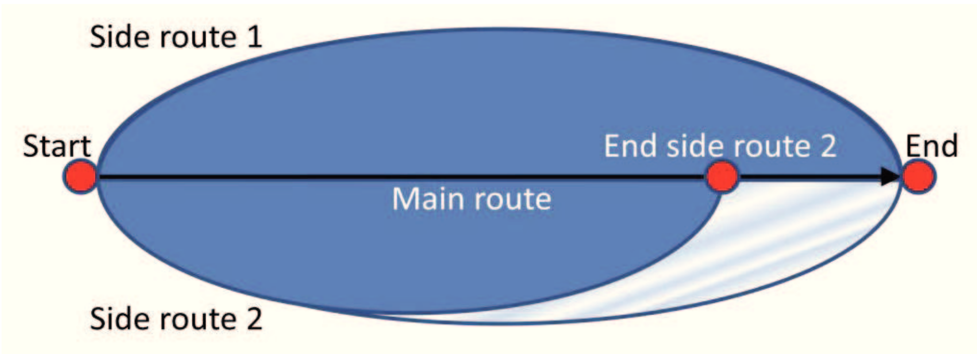

Figure 28 : Ellipse with a shorten boundary

The graphic above shows the cut side route 2 with the new endpoint. The geometric form is a combination of two different ellipses. The first one in the upper and the second smaller one in the lower part. This makes it possible to combine all constraints with the layout. Three routes with different length are included and based on this route layout it is possible to place the different process stations along the route.

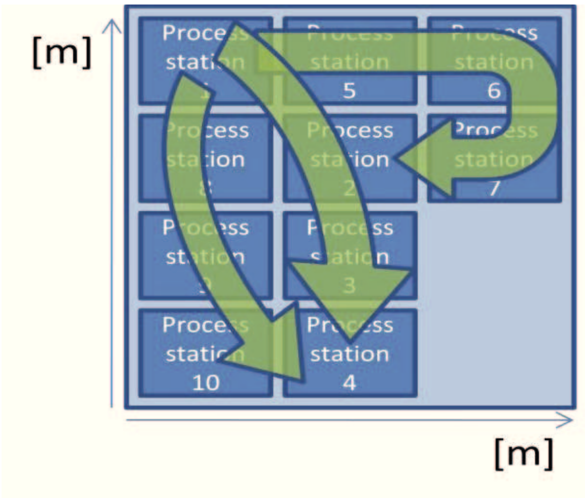

Figure 29 : Factory layout after optimizing the routes through the system

The result (figure No. 30) shows the new factory layout with the different routes through the system. It is placed in the given space and meets all criteria set. Side routes are found left and right of the main route, which goes diagonal from the left top to the right bottom of the layout. It is not necessary for each route to cross another route. This makes it very clear and simple. After placing the machines in the designated areas and marking them the layout is finished. But it must be remembered, that this layout optimization is not the only thing which must be done to optimize the flow through the production. The layout with the given stations is fine, but there are other decisions to be done to minimize production costs.

7.1 Flow Orientation [18] [19] [20]

To reduce costs in production it is very important to orient on the flow through the system. In literature 8 basics for a flow could be found. They guarantee that the designed layout would be work.

1. Process Governing

The process owner must trust in the process. This means, a high controlled quality and a constant availability and capacity of the process.

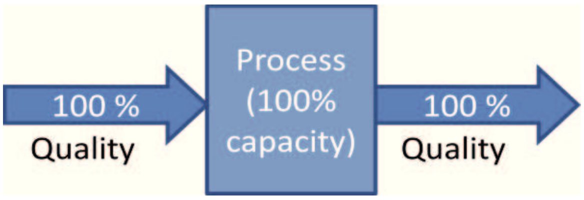

Figure 30 : Process governing

2. Known Process Capacities

To afford a continuous flow the capacities of the process stations must be known and coordinated. As a result a constant production speed is ensured.

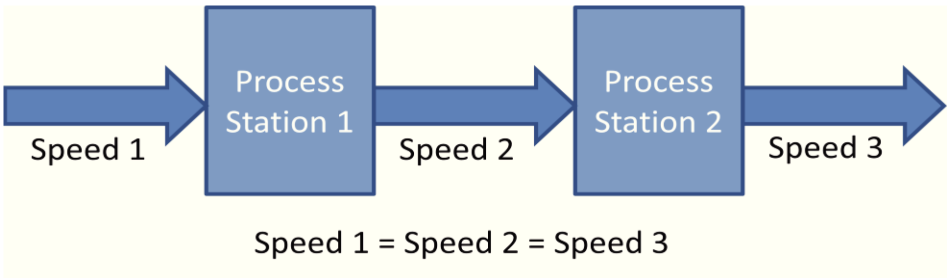

Figure 31 : Known process capacities

3. Flexibility

A flexibility must be given to react on unexpected fluctuation of inputs. This could be a buffer for example to guarantee the constant flow.

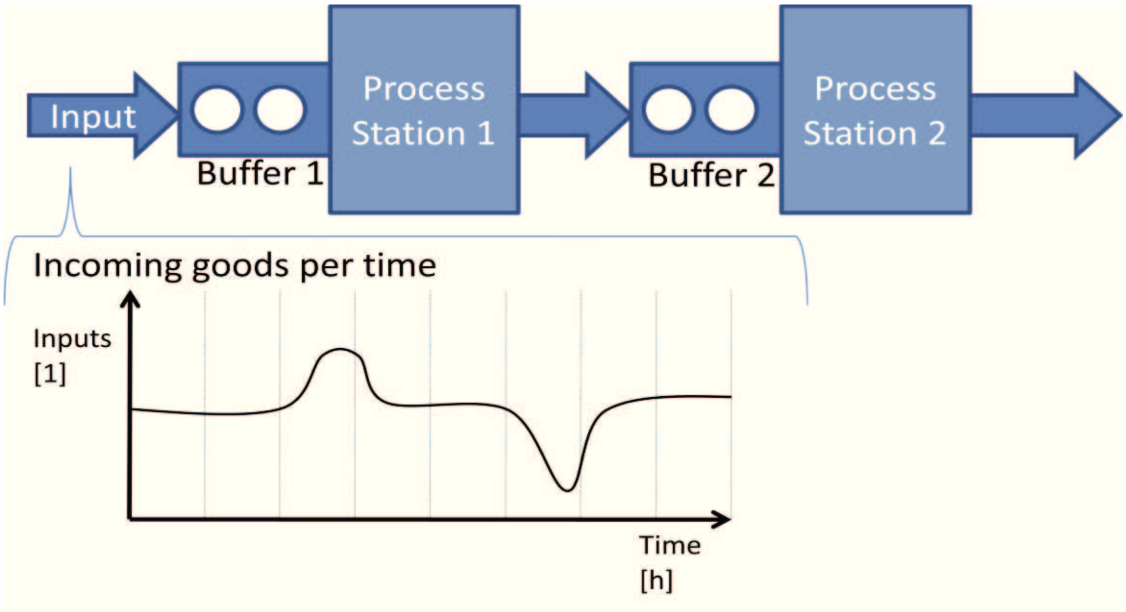

Figure 32 : A flexible system with two process stations and two buffers.

4. Equal working Structures

Working times should be equal or a multiple number of the shortest working time from station to station to optimize the flow through the stations.

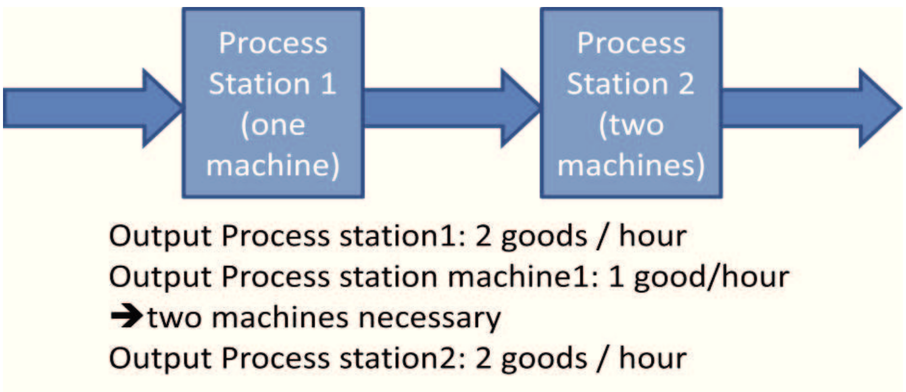

Figure 33 : Process station2 requires two machines. Otherwise there would be a gap and bottleneck in the flow

5. Continuous Input and equal lot size

A constant charge input is necessary to ensure a continuous flow. It is better to plan many small jobs instead of a job with big charges. Big discontinues charges are hard to forecast, because forecasts are planning with a continuous input and forecast quality depends on deviation. When many such charges arrive, deviation increase and forecast's quality decrease.

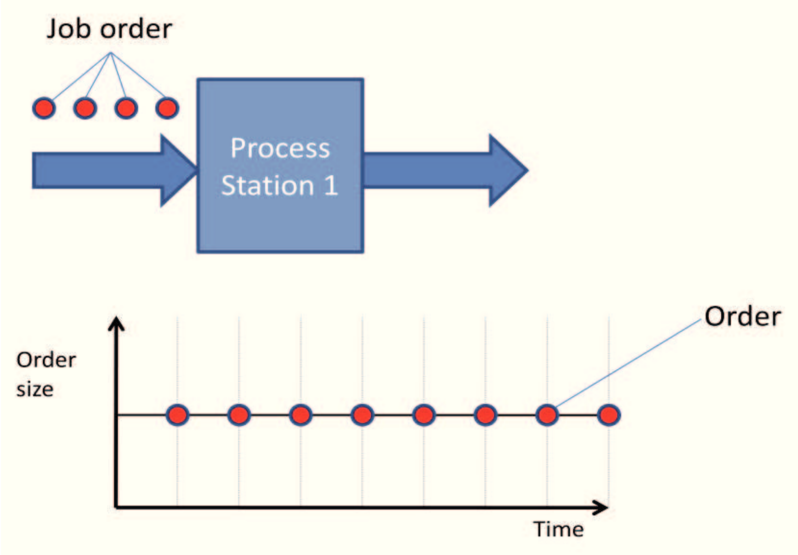

Figure 34 : Continuous charge input

6. Synchronization

The process stations and parallel production flows must be synchronized to minimize buffers, not finished products and goods in storages.

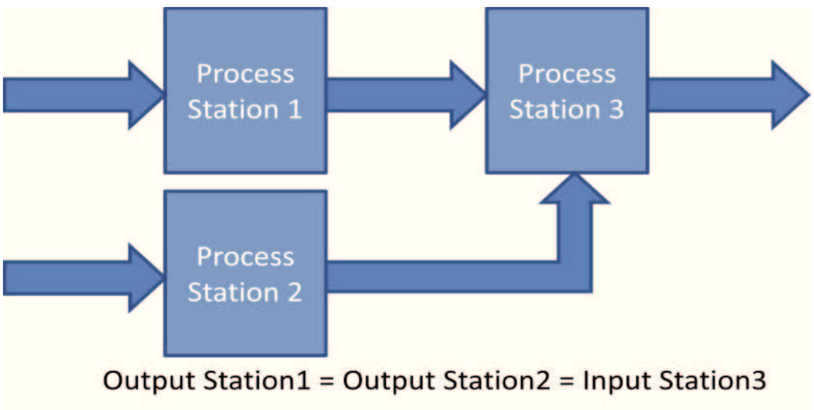

Figure 35 : Synchronization of the outputs from Process station 1 and 2 and the input of Process station 3 to gain the best flow through the production (A product from station 1 as well as from station 2 is necessary to produce in process station 3)

7. Prevention of Prioritization

Prevention of prioritization is necessary because a prioritized product blocks the flow of all other products with a lower classification. This means in case of restricted capacity that the other products and the whole system come in trouble.

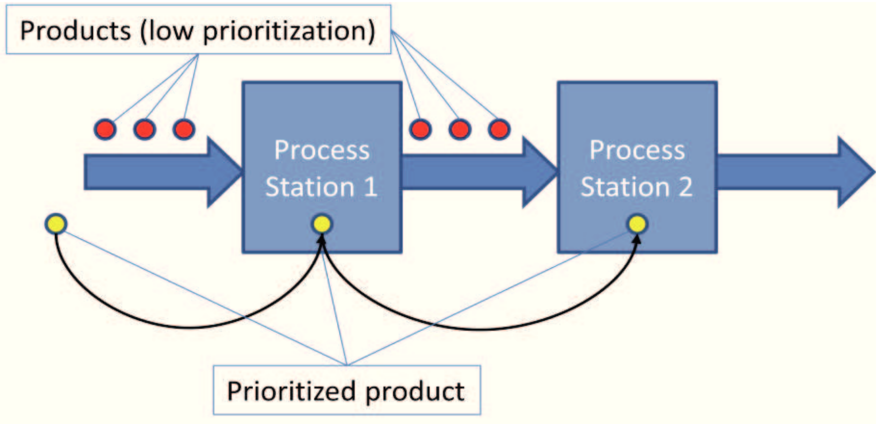

Figure 36 : All products with a low prioritization must wait until the prioritized product crosses the station

8. Controlled and defined Buffers

To define a buffer size is very important and it shows that the whole flow is under control. If there is a dynamic buffer without any restrictions, it blocks the flow because too much products are waiting and it could not be calculated when a specific product passes a station.

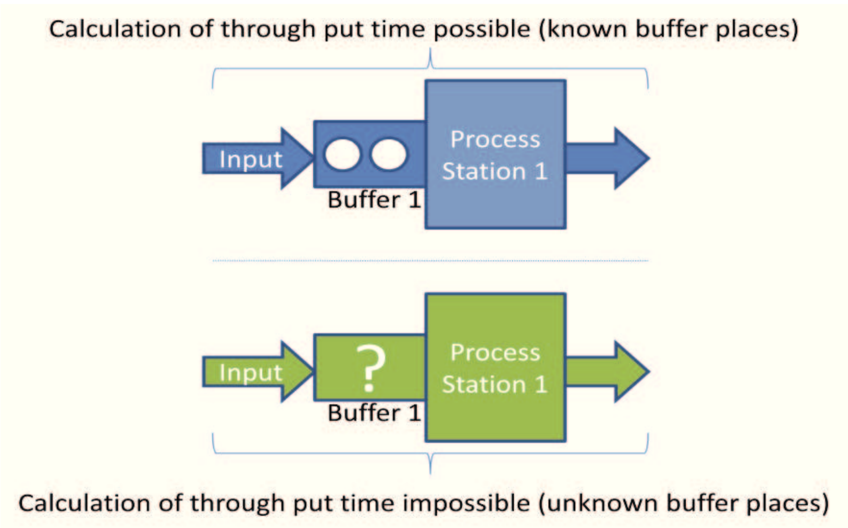

Figure 37 : Only known puffer sizes guarantee an exact calculation of the throughput time

8. Storages

In material flow systems we find different stations as listed in a chapter before. This chapter handles with a specific station, the storage area. It is important to have an extra look on the storage areas because in most systems we can find many different products in storage at the same time. This means that there is a lot of capital bounded at this station. Another reason why it is necessary to think about storage is that a typical storage has no value added service to the product. The product is waiting until it is required.

8.1 Storage Concepts

A storage system is a subsystem of the whole material flow through the production. The difference between a normal material flow system and the flow through a storage are the customized stations. In a normal system the process stations are value added. A product cross a station to increase its own value. In warehouse systems the value add service is not really found, but the product is also transformed in a way of bridging time. The good enters the warehouse to "wait" in best case a specific in the worst case an unspecific time.

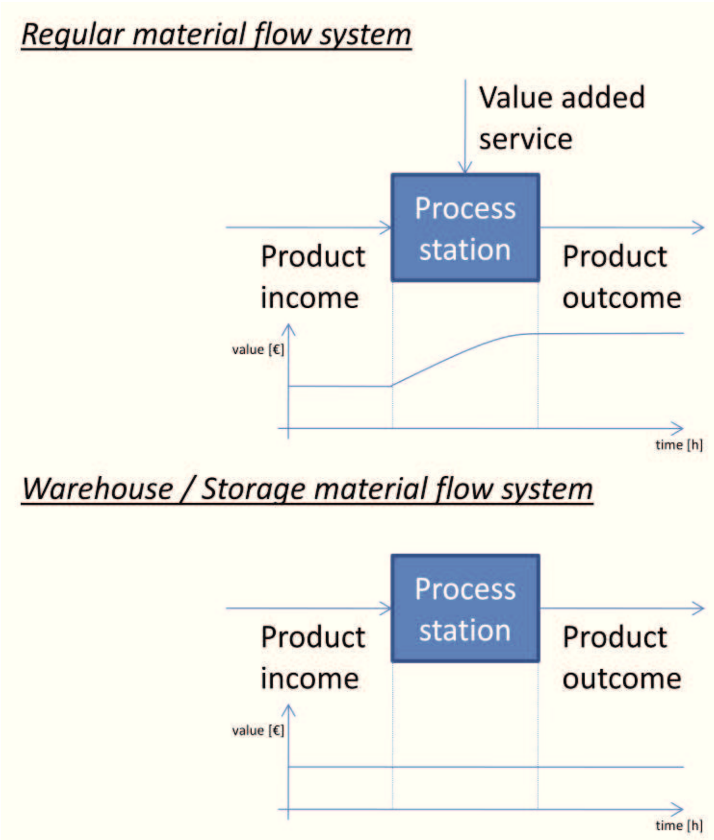

Figure 38 : Difference between a regular and a storage material flow system

But there usually there are other elements that could be found more in warehouses. These elements are transportation and waiting. The waiting process optimization is very difficult and must be made through the production planning or by synchronization of different steps in the production chain.

The transportation process in these systems is very complex. In big warehouses many possible transportation routes to different storage places and a high number of transportations could be found ($complexity = \sum transportation\ modules + \sum possible\ routes$). New problems rise through the fact of complexity. A high developed information technology system must be installed to handle many goods and if there is an automated guided vehicle system a control system must be introduced.

But other decisions must be made. Is there a strategy in the storage or a store plan? Where is it allowed to store a specific good by the strategy and also by the law? Are there any constraints by the size of the good?

Figure 39 : Different constraints which influence the storage

An appropriate set of rules must be found for storage otherwise it is not possible to manage such a store without losing time and money. An example is an undocumented storage, where it is very difficult to find a specific good because it could be everywhere in the warehouse and searching the good cost much time.

To design a storage the strategy must be known. There are two different kinds of strategies: the location and the movement strategy.

8.2 Location Strategy

The location strategy defines where a good is stored physically. There are many different strategies such fixed bin location, dynamic bin location, zoning, fast movers or event distribution strategy. But there are two major strategies: Dynamic bin location and fixed bin location. All other strategies are combinations of these two with some adaptions. [26]

8.2.1 Dynamic Bin Location

This strategy is very simple: the first available place is used for the good. A database stores where the good was placed. There is no algorithm or any other complex decision tree behind this strategy. A big risk is a crash of the database. If it crashes, no logic can find a product automatically. A manual inventory is necessary to get the data back.

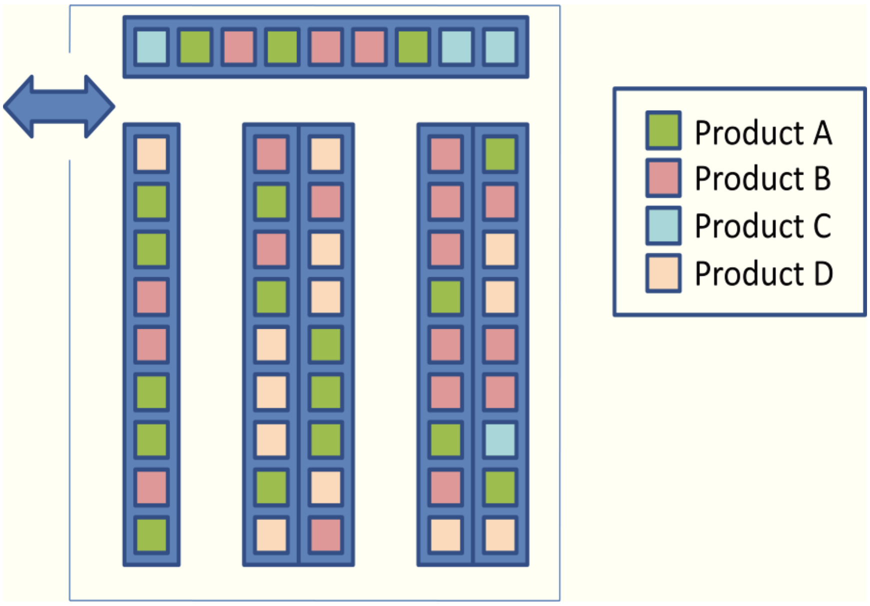

Figure 40 : Dynamic bin location storage

To use this strategy it is necessary, that the products have no constraints, e.g. dangerous goods or oversized products.

8.2.2 Fixed Bin Location

A fixed bin location strategy can be very complex. This strategy starts with clustering the products into different group by their attributes. This could be a division by size, their target machine or customer, weight, duration in warehouse or functionality. Next step is to calculate the estimated quantity of each group and the number of needed storage locations. After the expected number of locations for each group is established, the groups are sorted by a priorized attribute, e.g. duration time in storage.

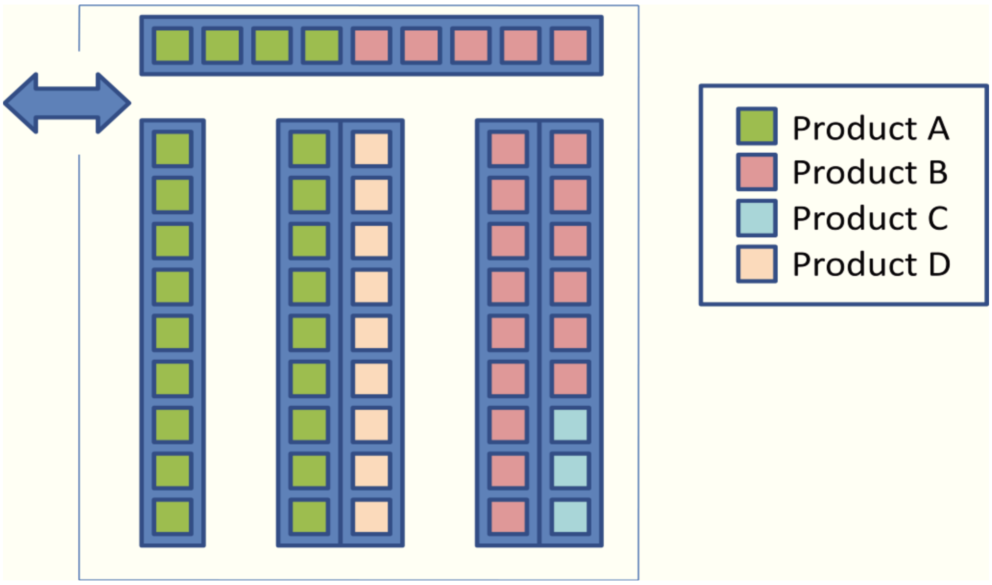

Figure 41 : Fixed bin location storage

The advantage of this kind of storage is that in small storages no IT system is necessary to manage it and to find goods in an appropriate time. But a risk is that if a big charge of a product is required there could not be enough space in the designated area.

8.3 Movement Strategy

In difference to the location strategy, the movement strategy defines the sequence of the to-bin and from-bin transfers to be carried out by the conveying system. [26] There can be some restrictions for these strategies, such as a hard FIFO (First-In-First-Out), a soft FIFO to avoid obsolescence or a LIFO (Last-In-First-Out) concept. Under these restrictions, it is possible to choose a movement strategy to optimize the throughput, the to-bin or from-bin times. [27]

Single Duty Cycle

The conveying system performs either an input operation or an output operation. It is not possible to combine an in- and output cycle to optimize the capacity of the system. There are many unloaded drives. It is a simple strategy, which is easy to implement.

Double Duty Cycle

The double duty cycle strategy minimizes unloaded drives of the conveying system. It combines in- and output cycles, which requires an advanced information system. Therefor the implementation is not as easy as the singly duty cycle strategy.

Track optimization

This strategy can be used for conveying systems, which can transport more than a good at once. In- and Output cycles are combined to minimize the distance. Thus a high developed algorithm and information system is required to use the track optimization.

Shifting

Shifting reorganizes the storage, when the conveying system is idle. It relocates goods to optimize future cycles. This strategy can be combined with all other movement strategies.

Avoiding of Change of Aisle

Usually the change of aisle requires much time. Therefor this strategy avoids the conveying system for unnecessary aisle changes. This strategy is used in big storages with many aisles and can also be combined with a many other strategies.

Maximum In- or Output

In some cases it is necessary to fill up or clear the storage as fast as possible. Thus, this strategy concentrates on inputs or outputs. It is an additional strategy, which can exist beside the others. [28]

9. Controlling the Flow

After the flow was reengineered it must be controlled. It is very important because the improvement must be measured and an open loop controlling must be established.

9.1 Measurement

Before it is possible to control the flow, a measurement system must be set up. It is required for collecting data and conducts adjustment and controlling. In most cases a material tracking system must be established to trace products and routes through the system. Material tracking systems also haunt product's quality over the different stages of production. In market different methods can be found. They vary in used techniques for tracking products and a decision for a specific technology is given by production's environment. But all realization ways excluding manual tracking, share an attribute: They are all connected to a database to share different information from each production state.

Next part of this chapter handles with common techniques of material tracking with their advantages, disadvantages and under what conditions they are used.

9.1.1 Punched dot codes

Punched codes are common in production raw material industry. This could be in steel industry for marking slabs. Many dimples, positioned on a given virtual matrix, are representing the code. These codes can only save a small amount of information, because it is limited by the dimension of product. The information is given by the combination of the dimples.

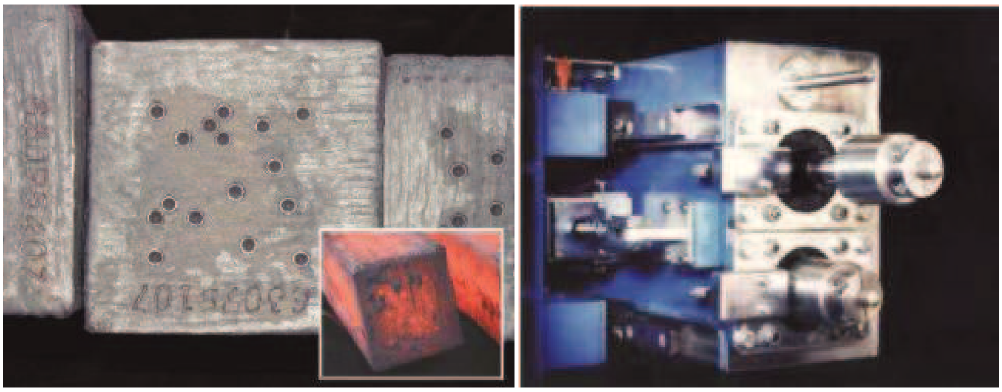

Figure 42 : A punched dot code on a slab on the left and a punch machine on the right side [21]

The picture above shows a dot code on a steel slab. It is impacted with a full automatic machine at the beginning of the production.

The reader is in most cases a camera in combination with a laser. The laser projects a line on the product. Light absorption where the line meets a dot is not equal to the normal absorption. A camera detects the deviation to the normal state and makes a virtual dot on the matrix. After scanning the whole product, the complete dot matrix appears (Figure no. 44).

1	0	0	0	0	0	0	0
0	**1**	0	0	0	0	0	**1**
0	**1**	0	0	0	0	0	0
0	**1**	0	0	0	0	0	0
0	0	**1**	0	0	0	0	0
0	0	0	0	0	0	**1**	0
1	0	0	0	**1**	0	0	0
0	**1**	0	0	0	0	0	**1**

Figure 43 : Virtual dot code matrix

For adjusting the camera and controlling the matrix, two border diagonal dots are implemented to guarantee completeness of the information. This is possible if the matrix is symmetric, otherwise three controlling dots in each angle are necessary to identify the code and its orientation.

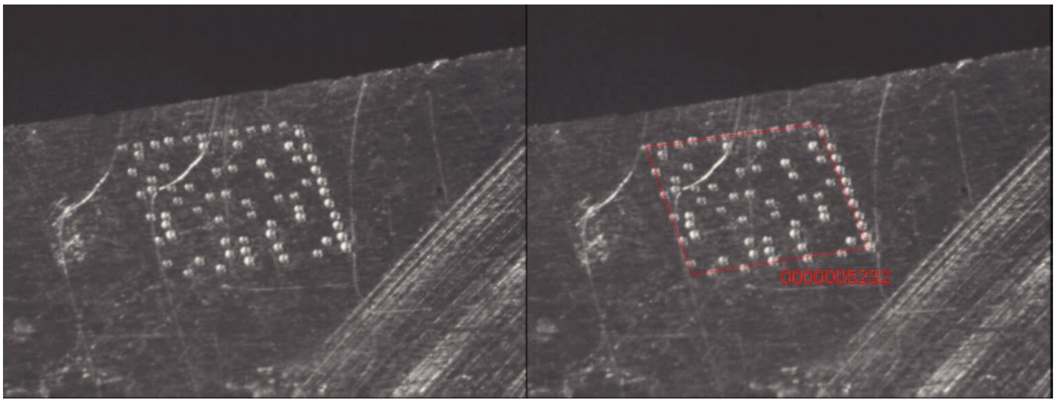

Figure 44 : A dot code with a higher density [22]

The biggest advantage of punched codes is their resistant against high temperatures and shocks. Another positive aspect of punched codes is the life time of the code. Due to the fact that the code is nearly undestroyable, it is used in tough environments.

Disadvantages of the code are given to code's dimension. It is impossible so to save much information on it. In most cases only an identification number is found in it. Other problems resulting out of the readers dimension and investment costs. A special camera and laser is required for reading the dimples. Instead of using mobile reading stations, it is common to use fixed installed readers. If there is a mobile reading system, it needs a data connection like all fixed stations to a database, where information about the product addicted to its identification number is stored. This makes such a tracking system uncomfortable.

9.1.2 Barcodes

A barcode is an automatic readable code. It can be read by scanners and cameras. A code consists of different parallel bars. These bars have an unequal width. Today there are a many barcodes with dimensions from one to three. First experiments with four dimensional codes were done, but they are very expensive, because they need a moving element for the fourth dimension.

Codes in the first dimension are very easy to print. Usually they have under the bars a human readable code. The code could be only a number or a full ASCII character combination (ASCII table can be find in appendix). There are many different codes in the industry. The EAN 128 is one of these standards. It was very common to use it, because it is clear defined, which information is stored in it. Another advantage of an EAN 128 is the validation number and bar. This guarantees high processing assurance.[23] It was developed by a board of International Numbering Association (EAN), Uniform Code Council (UCC) and Automatic Identification Manufacturers (AIM). This affirms the common use of this kind of code.

(01) 04012345123456

Figure 45 : EAN 128 code [23]

But also the EAN 128 Code is limited to the first dimension and it is not possible to save much information on given space. Another standard was the UP-Code (Universal Product Code). It was quite similar to the EAN code and most readers could read both codes. But these code systems (EAN and UP-Code) are replaced by the Global Trade Item Number (GTIN), which leads to a worldwide number system. [29] [30]

Another possibility of barcodes is a two dimensional code. It is a stacked code with more than minimal two levels. In comparison to a code with only one level, it is possible to save the number of levels more information. Printing and reading this code is not really difficult, if there are not so much levels and the size is not too small. Codes equal dot code matrix with a higher density. As the picture below shows, there are many different codes. Some of them have a serial number below the matrix, but it is not common. It is possible to save a lot of information in them, starting from identification number and weight, going over size information and ends by specific data about the marked good, such as if it is a dangerous product. Common for all codes excepting the round one, are the validation dots. These three dots define the adjustment of the code. The stacked bar code, which is not included in the picture, is also common. It is a multi-line single dimension code. Usually up to ten single dimension barcodes are stacked to a multi-line barcode.

Figure 46 : Examples for 2D codes [24]

Another option to save information with a higher density per given space is a three dimensional code.

The third dimension in these codes is the color. A camera scans the code and divides it first in the basic layer, like a two dimensional code. Than it analysis the colors and builds a virtual matrix. X- and y-axis stay for column and row and the color for depth.

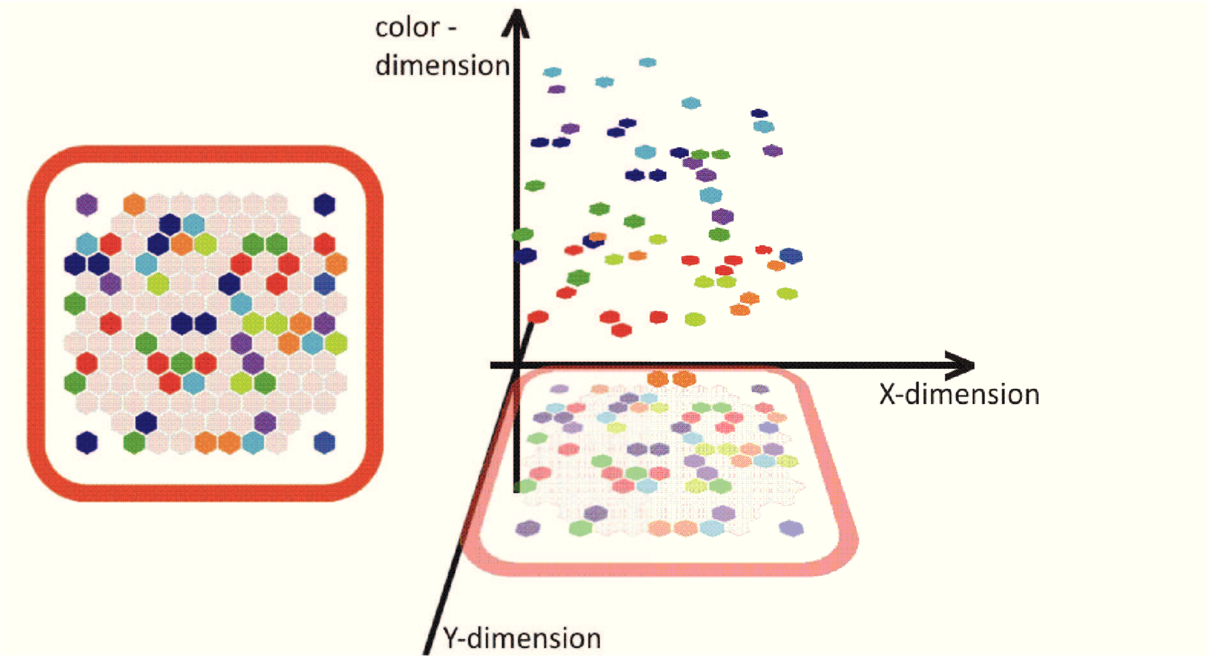

Figure 47 : A 3D Matrix code and its division into the different layers [24]

It is possible to save much different information in such a high dimensional matrix. If the dots are changing its color, a four dimension matrix is given. But these codes are only experimental at the moment.

Three dimensional codes have a big problem. The color must be very clear and some adjustment dots for the color and matrix itself are required. Color cameras are needed with a high contrast to divide the different color codes from each other. Investment costs for reading and printing such codes are relative to lower dimension codes high.

In general barcodes are very common in the industry. They are very easy to print and read. They are used for in consumers' goods industry and most freighters use them to control their cargo. But they have three big problems. First of all it is not possible to read the code from a distance. Therefore the code and camera's solution is too small. So every good must scanned next to each other. Another problem is the environment. When it is not clean outside the code gets dirty and is unreadable. High temperatures could also destroy the code, because in most cases it is printed on thermal active printers. This means that the bars are "burned" in the paper and high temperatures are burning the whole code. The last problem is also connected to the printer. The code is not re-writable. It is not possible to add more information to the label after it was printed.

9.1.3 Visual Tracking

Visual tracking is another material identification pursuit method. Visual tracking is based on an attribute of the product. This could be the form itself or the change of product's form. The form can also be given by radiation. Radiation, e.g. temperature, is captured with a special camera and processed like a normal picture.

Important is the contrast between object and background. It is only possible to trace an object, when contrast values are high enough and the picture shows the product in a distinctive way. When an object is moving, tracking might be also possible when an object is not visible for a short time. The movement is converted into vectors and a computer can calculate the estimated way of an object.

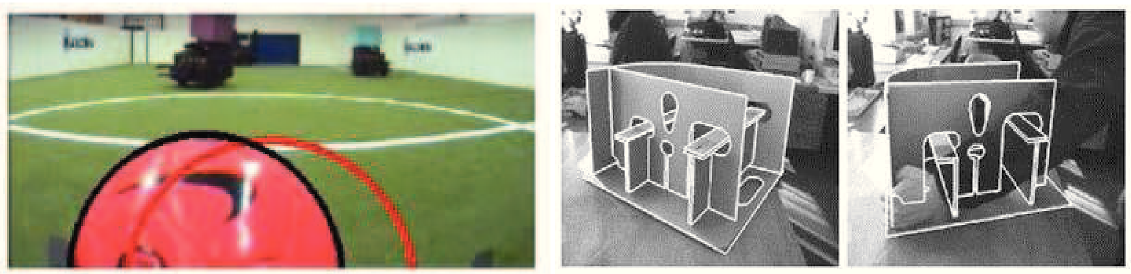

Figure 48 : left side: a ball is tracked (red half circle) right side: a model is pursuited by the camera. [24]

Visual tracking is used when it is not possible to touch or label a product. A reason could be a high temperature or radiation. It is very expensive to build a visual tracking system, because fast computers and a lot of knowledge are necessary to convert images into data. Therefore visual tracking systems are only used exceptional cases.

Another range of operation is in the military and security sector. In this sector visual tracking is used to follow a target without targets knowledge or to identify objects by their shapes.

9.1.3 Radio-frequency identification (RFID)

RFID is the fastest grown technology in the last years. At least two things are necessary for a RFID system: A tag and a reader. Tags are very different to each other. They vary in size and resistance against temperature and other environmental impacts. The tags are implemented or attached on product or on product carrier, e.g. a bin. In general active and passive tags can be defined as major RFID tag groups. Active tags have their own power supply and their signal range is very big. A tag is called passive, when no power supply is required. It gets his energy inductive by the radio signal of the reader. When an active or passive tag gets a signal, it sends back stored information. This means, that the reader sends a signal to “power on” the tag and received tag’s information. Information could be only an identification number, but also a complete set of data, e.g. temperature trend over time.

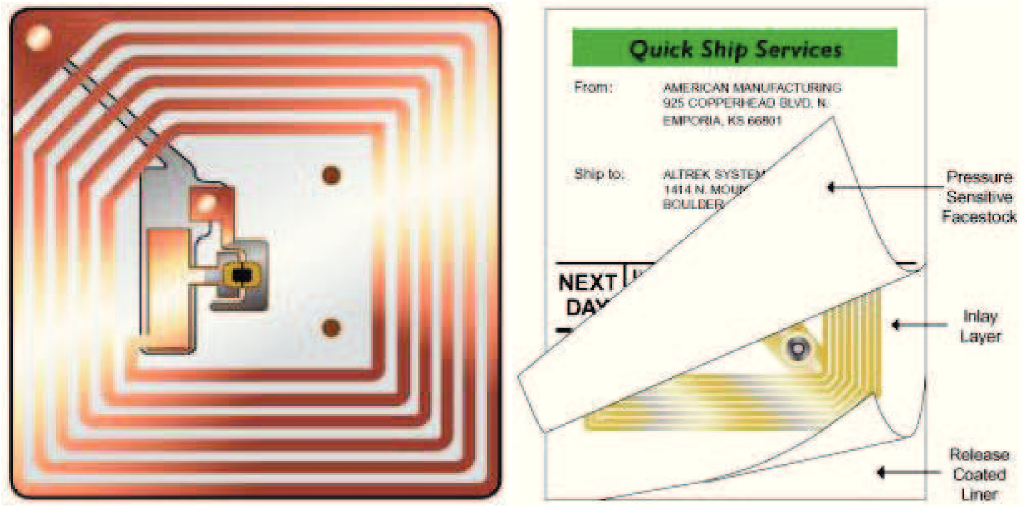

Figure 49 : A Typical Tag used in the consumers industry to follow and secure products. [25]

The picture above shows a typical RFID tag in the consumer industry. The left side represents the inlay of a label. The right side of the picture shows the complete label. This example shows that no intervisibility is necessary to read the tag (tag is behind a protective layer).

RFID has big advantages. First of all it is not necessary to see the object for getting its information. It is also possible to read more than one good per scan. This saves time if a company wants to check his inventory. An advantage in contrast to barcodes is that a dirty environment isn’t a problem and that many data can be stored. Another opportunity for RFID technology is that most tags are re-writable. It is possible to add information after the tag was written. Unlike punched dot codes mobile reading is no problem at all. The readers are very small and mobile.

But RFID has other problems. At the beginning investment costs are higher than barcode investments. Also electric magnetic radiation interferes the readers and tags. Thus it cannot be guaranteed for data persistent and completeness. The reading range is also addicted to the environment. If there are many metallic barriers between reader and tag, the range is reduced.

However public concerns about security and this is definitely the biggest disadvantage of RFID. Security cannot really be ensured, because everybody is able to read the tags. Information about a whole storage can be read from outside, what could be an interesting information for competitors. But it is not only possible to get information from storage or production, tracing a person which bought something with a tag in it, is also possible.

9.1.4 Location Identification

But a material tracking system requires more information as the simple identification of an object. It is also necessary to identify the location, where it was read. There are different methods of the identification of a location. All methods can be classified in two categories: Identification of the location by a known position of the reader or directly by the trackable object.

Objects, whose position can be directly identified, usually use a satellite based identification system. This can be the Global Positioning System [31] or the upcoming Galileo [32] system. These systems get the position information by calculating the difference of the signal propagation time of different satellites.

The other method to identify the position is by reader's position. This kind of location identification is usually used in a plant. Each reader has a defined position, e.g. a barcode reader. If the reader recognizes an object, the object information and the information of the reader, including the position, is combined and send to the information system. These visual reading methods also include cameras and RFID readers. Another non visual method is to get the position by the difference of the signal propagation time. This position fixing method can be used with RFID or other wireless readers, if there are more than two readers. Thus, this method requires a developed tracking system with a high density of wireless readers for an exact positioning. [33]

When a tracking system is implemented in the production, collecting data can start. Throughput times, position number, identification numbers, quality indicators and other key indicators can be stored in the database.

9.2 Analysis

After a material tracking system is set up, it is possible to implement continues improvement, because all required data is stored in the database. With these data exact control of the product flow through production is possible. Problems can be analyzed very fast and adjustment can be done. For example if a machine has a quality problem and the products do not meet customers' requirements, the failure can be found by tracing all products and find the station where each product crossed. Deviations in throughput times can also be detected in real time and a better planning is possible due to the fact that all current data is known.

Another opportunity is that simulations can be made with real time data to improve storage and buffer sizes. Usually when a simulation is done, current data is not available because it is not collected. So if a material tracking and measurement system is set up, all information is found in the database.

10. Conclusion

Usually introducing a material flow management is expensive, because rearrange machines to optimize the flow can be very difficult, if the machines are very big and heavy. But it must be calculated, if investment and downtime costs are lower than the expected savings in the time fence, the machines should be rearranged. It really depends on product mix, which is produced in the plant. There could be different scenarios, e.g. a product is produced for a long-term. Than in most cases it is cheaper to find a new facility layout before going in mass production. Another possibility is that the factory is moving to a bigger site. In this case the machines must also move and a repositioning is very simple. In general it can be said, that a rearrangement is reasonable, when costs decrease under the investment level over product’s lifetime.

But there are other aspects for reengineering the flow through the production. In many natural grown companies the transportation ways are really far. From a point of risk management and reducing working capital it is necessary to reduce these ways. Risk is minimized by decreasing the number and distances of transports and its shipment. If there are less transportation ways and distances between different machines, not so much goods are moving at the same time. This also means that the working capital is reduced. Another advantage of minimizing transportation routes is easier controlling of product’s movement.

One of the biggest weaknesses of creating a new stream through production is the whole project planning. Starting such a project is only possible with a clear defined project plan including its targets. But it is not as easy as it seems to define targets. In most cases the primary target can be reducing costs. Mostly this is the initiator of introducing a material flow management system. Also a target can be reducing complexity for an easier control or just the try to identify and govern all processes in the own company. This can be a big business advantage, because if all processes are known an introduction of a new product is much smoother. A new product usually is not produced on the same machines or same machine order as the old one. Or the production only produces additional to the old products a new one. Than it is necessary to know the whole production process and all machine throughput times to calculate a new production plan, which does not interfere the old products or it constraints them only a little bit. This happens due to the fact that unused capacities are mobilized to produce the new good.

Identifying unused capacities and controlling products sweeping through factory is in most cases a little bit difficult. To detect facts about production a measurement and tracking system should be implemented. An adapted material tracking system as described in the last part of this thesis is the base for finding unused capacities and governs all processes. Analyzing material tracking's data helps identifying weaknesses and strength of the own production and shows possible improvements for the future. It also supports the quality of goods, because an unidentified failure in a machine can be traced by following the goods back. An additional advantage from a material tracking system is that a better planning and controlling is possible due to the fact that all data are given in real time. It is also the base for future automation projects. They can be realized very easy, because all required controlling and adjustment information for automation is accessible. This is another opportunity for saving costs.

In future there will be an additional way on optimizing the flow. In today's market product lifecycles become very short. This means a production must react very fast on new customer's impacts and also development is accelerated. At the moment factories are very static. In most cases they cannot react on a change in their material flow. Therefore high dynamic factories are needed to reduce costs on changing production tables. New systems must be developed to meet this requirements.

In future another tool to optimize flows will be used much more often. Simulations can answer many unreached questions and reduce risks by minimal costs. At the moment it is not the missing software that holds companies off. They haven't identified this tool as a potential to reduce costs with minimal investments. Failures, problems and new production tables can be tested in a simulation without risk. An optimal set of adjustment parameters can be set up without many online tests. The flow can be optimized on a computer and the new found parameters can be transferred to the real system.

It is all about information: to control and govern a production or to make a simulation. To use gained information for the company a tool is required. Material flow management is a such a tool to reduce costs, but primary to get transparency and a reduced complexity in a company.

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