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Lean Product Development: Making waste transparent

Christoph Bauch

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PRODUCT DEVELOPMENT
Massachusetts Institute of Technology
Prof. Warren Seering

PRODUCT DEVELOPMENT
Technical University of Munich
Prof. Dr.-Ing. Udo Lindemann

Diploma thesis

Registration Code 990

by

Cand. Ing. Christoph Bauch
Matriculation number 2017983

Thesis Title

Lean Product Development: Making waste transparent

Starting point

Lean manufacturing developed by Toyota is a production philosophy that focuses on streamlining of value added activities and eliminating waste within the process with the goal to better meet customer demand. It constitutes a production system that enables highest quality at minimal costs and reduced lead times. The reason for the high performance of the Toyota Production System (TPS) can primarily be seen in the underlying principles, rules and tools established, and how those work together.

It is supposed that lean principles like focusing on value, eliminating waste, making processes flow, and continuous improvement facilitated by high levels of transparency, also apply to product development in anticipation of the same positive impacts known from manufacturing. This may not be that easy since product development is different from manufacturing.

Objectives

The target of the present thesis is to investigate the transferability of some of those principles from manufacturing to the area of product development.

Procedure and methodical approach

- Analysis of lean manufacturing principles, rules, tools and techniques
- Working out the differences between manufacturing and product development as basis for subsequent investigations
- Definition and determination of concrete work steps to accomplish project targets
- Processing of the work contents according to the project plan, linked with the derivation of results
- Detailed documentation of results accomplished and procedure

Conceptual Formulation

Author	Christoph Bauch	
Advisors	Prof. Warren Seering Massachusetts Institute of Technology	Dipl.-Ing. Hans Stricker Technical University of Munich
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Dipl.-Ing. Hans Stricker, Thesis Supervisor

Feedback and Contact

The reader of the present thesis is invited to assess for him- or herself the quality of the results and their usability in practice.

For further questions, ideas and any kind of feedback please contact:

Author **Christoph Bauch**

c/o Dipl.-Ing. Hans Stricker
Christoph.Bauch@mytum.de

Advisors **Prof. Warren Seering**

Department of Mechanical Engineering
Room 3-433
77 Massachusetts Ave
Cambridge, Boston, MA 02139, USA

+1-(617)-253-8253 (Phone)
+1-(617)-253-9637 (Fax)

seering@mit.edu
http://www-me.mit.edu/

Dipl.-Ing. Hans Stricker

Department of Product Development
Room 2129
Boltzmannstrasse 15
85748 Garching, Germany

+49-(0)-89-289-15135 (Phone)
+49-(0)-89-289-15144 (Fax)

stricker@pe.mw.tum.de
http://www.pe.mw.tum.de

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A Introduction

A 1 Motivation

Introduction

Time to market still proves to be one of the key factors, beside quality and cost to market, for successful enterprises embedded in a high dynamic market environment with increasing product complexity, global markets and decreasing product life cycle times. Short time to market is one of the key elements. It provides the chance to gain higher market shares and thus to increase total revenue. At the same time it enables to faster proceed on the learning curve what may give the company a significant cost advantage compared with competitors left behind. In a long-term view it can provide the company with higher levels of flexibility in business. That is to say the ability to respond to customer demand more instantly than competition is able to and thus to supply the customers with products they want when they want them.

Problem

In the majority of cases, time to market for the most part consists of the *duration of the product development process*. In reality, development processes often contain a great deal of rework and iterations due to a large number of causes such as poor planning, execution, control and synchronization, deficient transparency regarding processes and disconnects in the information flow, all resulting in relatively long cycle times and additional risks. In aerospace industry, where development times between 10 and 20 years are not unusual, this proves to be very critical since used technologies may have a shorter life-cycle than the development of the aircraft lasts. In contrast, in the electronic industry, product life cycle time may be shorter than the actual product development time what in turn has great impact on development program structures and a company's system load.

Thus, improving the operation of product development processes has the potential to drastically speed up companies' products' time to market, and so contributes crucially to achieve the above mentioned benefits. But how to do this?

Solution/ approach

A common approach to improve processes consists in increasing their effectiveness and efficiency: the what and the how. This is very similar with the *lean philosophy* which suggests 'a way to do more and more with less and less – less human effort, less equipment, less time, and less space – while coming closer and closer to providing customers with exactly what they want' (WOMACK & JONES, 1996, p. 15*).* In other words, the goal of lean is to *increase value* creating activities and simultaneously *eliminate* non-value adding activities that is to say *waste*.

It has been suggested that *lean principles and tools*, established by the Toyota company, do not only apply to manufacturing, the area where they were pioneered, but also to product development.

Product development however is different from manufacturing, and can be understood as some kind of information creation factory: It is all about creating, gathering and evaluating information and reducing risk and uncertainty at the same time with the target to gradually develop a new and error-free product which then can be realized by manufacturing. In contrast, manufacturing's target is to faultlessly reproduce the exactly same product again and again. Dependent on the industrial sector that may vary in the magnitude between dozens and hundreds of thousands.

In order to tighten product development processes by using the above guidelines of increasing value and eliminating waste, two things have to be done: First of all it has to be elaborated what value and waste in this new context actually means, or in what way the respective definitions of the terms made in manufacturing can be applied to development. Once that is determined, the second question would be how to measure both value and waste, and how it can be made transparent to the people in the process.

Transparency may be considered as one of the most important tools within the lean philosophy. It is transparency that provides people with a clear understanding of different aspects of the current system performance and status, gives them feedback of performed activities and helps in making decisions, let them easier recognize interdependencies and thus enables higher levels of improvements.

Finally it is the combination of those three basic lean aspects, value, waste and transparency that are understood to improve product development processes in a significant way. Based on those aspects, it is supposed to provide a new tool to product development for the planning, execution, control and review of processes, a model that synchronizes the different process models in the minds of the engineers in order to create a common reference, to make the information flow more smooth and consequently to reduce product development cycle times. The contribution of the author will primarily be an investigation of waste in the context of product development.

A 2 The MIT research area and team project targets

The *Lean Aerospace Initiative (LAI)* at MIT is a research group that especially does research in the field of *Lean*, and is embedded in a large cooperation network primarily including enterprises from the aerospace industry. The overall objective is to better understand *Lean* and to gain new insights in this area, which then can be applied to different sections of business of the respective enterprises in order to improve their performance.

While *Lean* in manufacturing is rather understood, there still exist big knowledge gaps how to apply *Lean* to other areas like product development, or the bigger step, how to successfully form and realize the Lean Enterprise (➲ B 2.1.2).

The project, the author was part of for seven months, particularly deals with the investigation of *Lean* in the area of product development. The primary target of this research project is to improve the value stream in development processes, or in other words, to make the information flow within product development more smooth. The approach chosen to accomplish this, focuses on the investigation of the transferability of lean manufacturing tools and principles to product development. In particular, this concerned the essential aspects *value*, *waste* and *transparency*. Some further aspects are *measure and improve*, *decision on the lowest level possible* and *value stream mapping* closely related to transparency.

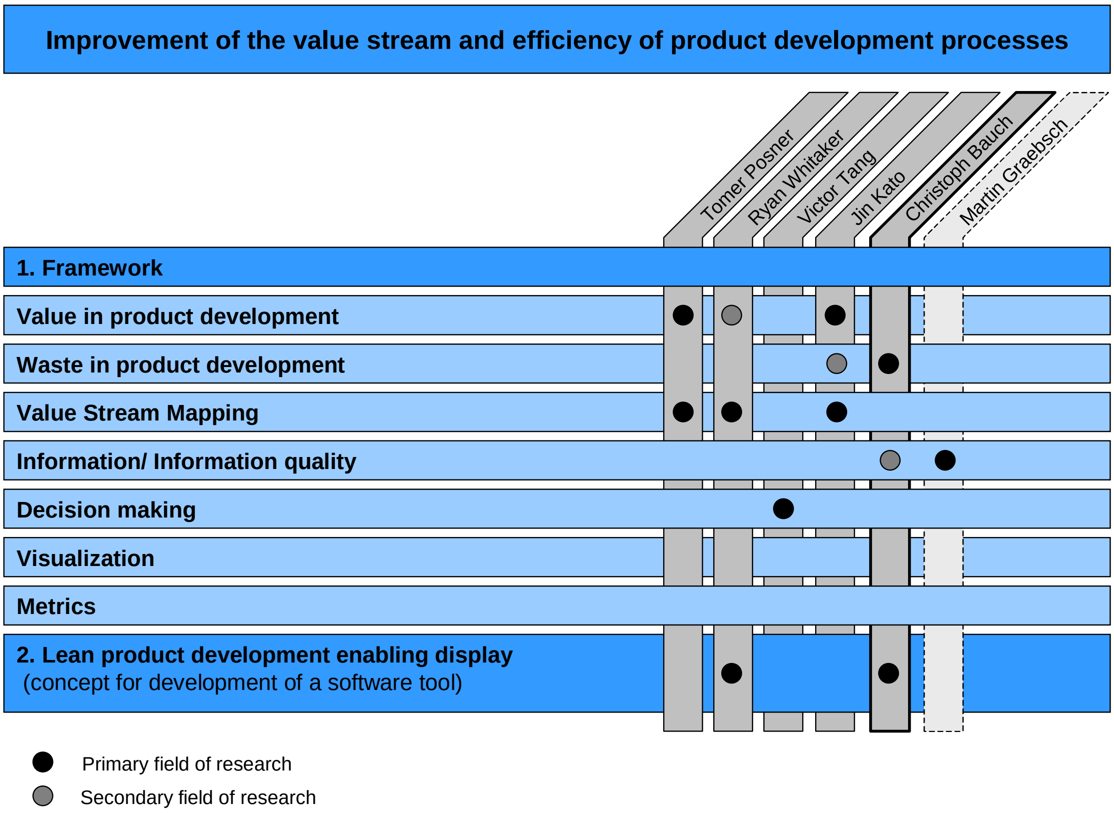
Looking to the area of product development shows that there is an increasing complexity of products, processes, organizational structures, supplier relations, etc. At the same time, there has not been too much effort to bring all those information together and to keep it transparent to all employees in a consistent way.

It is supposed and targeted that a new kind of display including an appropriate software tool, similar to *andon boards* (Lean Manufacturing tool ➲ Visual control) in production and usable for engineers for planning, execution, control and review of individual but also common processes, can essentially contribute

- to better synchronize engineering activities by providing information about the current status of the product development process
- to provide better feedback of engineers' activities and their possible consequences which is essential to set task priorities and making decisions

- to enable a better understanding of and predictability of processes by having and following a transparent standardized model and a kind of common reference
- to make the information flow in product development more smooth and, as a consequence, to significantly reduce product development cycle times
- to identify value adding steps and waste occurring more easily

However, creating such a new display tool requires some basic work first. As shown in ➲ Figure A 2-1, this includes investigations in the nature and definitions of value and waste within product development, the method of value stream mapping, some basic aspects about information, decision making, adequate metrics for a efficient process control and some research in the area of visualization. The following chart also shows the team members' assignments to the different fields of research.



Improvement of the value stream and efficiency of product development processes

	Tomer Posner	Ryan Whitaker	Victor Tang	Jin Kato	Christoph Bauch	Martin Graebsch
1. Framework						
Value in product development	●	○		●		
Waste in product development				○	●	
Value Stream Mapping	●	●		●		
Information/ Information quality					○	●
Decision making			●			
Visualization						
Metrics						
2. Lean product development enabling display (concept for development of a software tool)		●			●	

● Primary field of research

○ Secondary field of research

Figure A 2-1: Overview of the project team's different fields of research

A 3 Project objectives, approach and scope of work

Individual project targets and targeted results

The author's individual project targets and particularly the targeted results are specified in ➲ Figure A 3-1. As shown, the project targets are divided up into a primary and secondary one. The first is the investigation of waste within product development in consideration of the possible applicability of the lean seven types of waste from manufacturing to the area of product development. This will also deal with aspects like *what waste in product development means* and *how waste can be eliminated*. The second project target is directly related to the project team's target to create the display mentioned in the chapter before.

Since the author's participation in the project is limited to only a few months, the achievement of the second will strongly depend on the progress with the first one.

Individual project targets

Investigation of

- waste within product development based on, but not limited to, the investigation of the transferability of the lean seven types of manufacturing waste established by Toyota (*primary target*)
- how to apply the lean principle transparency to product development (*secondary target*: achievement will depend on progress with primary target)

Targeted project results

1. Lean philosophy

- Systematic and comprehensive overview of lean manufacturing principles, tools and practices established by Toyota as basis for further research

2. Waste in product development

- Comprehensive and manageable set of significant types of waste occurring in product development by investigating the transferability of the lean seven types of waste to product development
- Showing up a way to efficiently eliminate waste occurring

3. Lean product development enabling display (mockup)

- List of requirements for the development of such a tool
- Simple representation that displays the value stream and the status in product development to the people
- Concept to integrate the established waste types into the display concept enabling the early detection of waste happening

Figure A 3-1: Personal project targets and targeted results

Beside the project targets, following results should be accomplished:

A thorough understanding and overview of lean manufacturing principles, tools and practices is the first one as it is considered as a basic step for the author's further research.

The second targeted result associated with the investigation of the transferability of the lean seven types of manufacturing waste to product development, is the creation of a comprehensive and manageable set of waste types for the identification of waste occurring within product development. Based on this, a way to efficiently eliminate waste detected has to be worked out.

The third targeted result is the mockup of a lean product development enabling display as basis for the later development of an appropriate software tool. The display development bases on three significant sub-results: First, a list with all relevant specifications concerning the display, second, a concept of a simple representation that provides engineers with information about the value stream and the current status in product development, and third, a concept to integrate the results from the precedent waste analysis into the display concept enabling the early detection of waste happening.

Methodological approaches in this project

Even though it was clear that the project team would try to accomplish the overall project target by doing further research in the field of lean, the author made a step back and was also thinking about other ways to approach the problem in order to prevent a biased view.

As aforementioned, the overall target of the project is to improve the value stream and thus efficiency of product development processes in order to achieve shorter cycle times (➲ Figure A 3-2). In this context, value stream means the sequence of all specific activities required for design. From the view of information, the specific target would mean to reduce or rather eliminate all kind of disconnects occurring during the development process and to make the information flow more smooth.

Looking for improvement always offers two alternative ways. The first way consists in identifying key success factors and to find out why they are. Once you know that, a further targeted usage is possible and focusing on them will lead to positive results. This may also obtain for the transfer of key factors from a related area. The other way suggests the analysis of specific problems and their root causes and, based on that, the creation of specific solutions to overcome them. In reality, there often is a mix of both.

Altogether there were found different starting points or rather possibilities to approach the top project target. Some of those are depicted in the two 'belts' of the following figure (➲ Figure A 3-2).

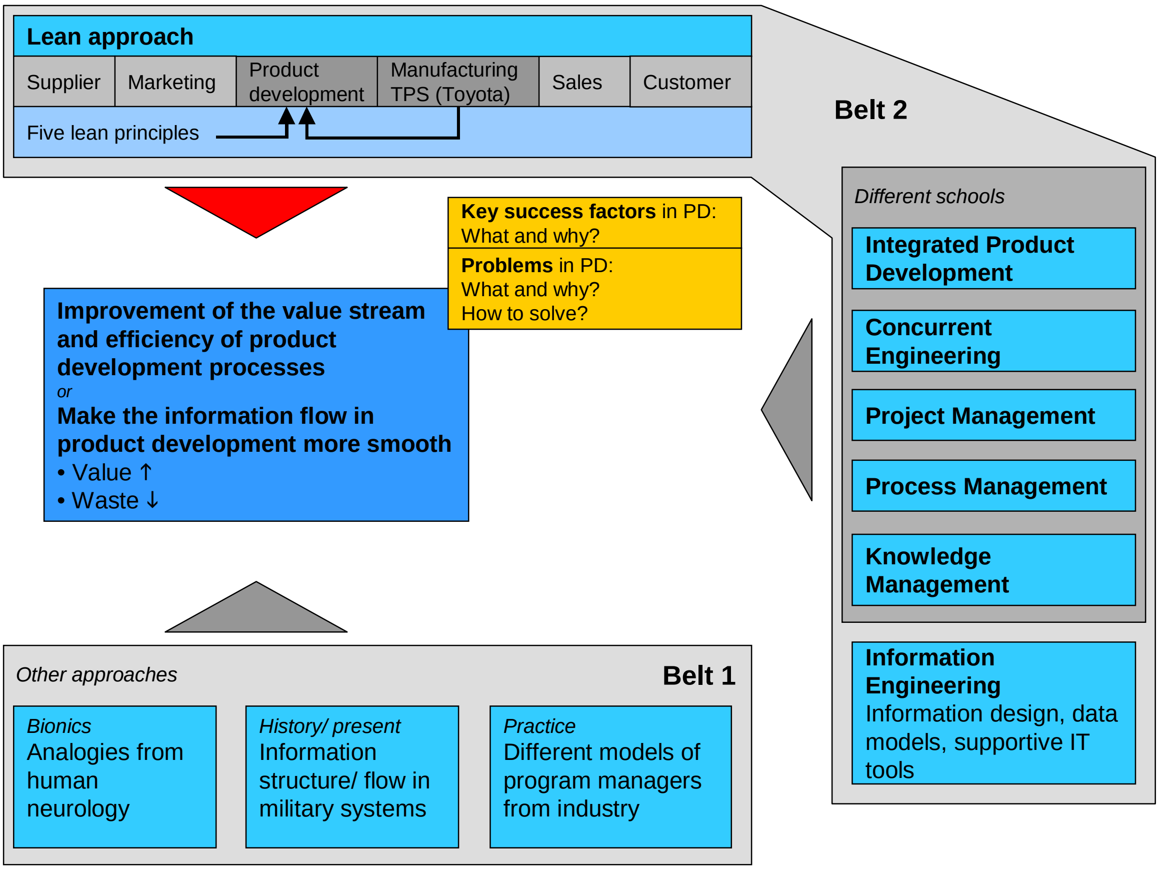


Figure A 3-2: Project approach

Belt 1 rather groups more 'exotic' approaches and fields such as *bionics* with an investigation of human neurology, or *history/present* with an investigation of the information flow in military systems, which both could provide new insights for a better design and performance of information structures in product development. A less exotic but more practical oriented approach would be to ask successful program managers from industry about their own and individual management models to gain some new information about what finally is essential and what not for managing processes successfully.

Belt 2 shows some further approaches. Especially those on the right side focus on the improvement of specific aspects in product development but are not exclusively limited to that area like project or process management. In contrast, the lean approach with its five basic lean principles and a number of fundamental rules, pioneered by Toyota, constitutes a more holistic approach since those principles draw through the whole value chains of companies' core tasks. The ideas of lean were originally born in manufacturing and only then systematically expanded to other areas like product development or sales. That also explains why those other areas at Toyota still do not have the same outstanding performance as the Toyota Production System (TPS) itself, and why it is reasonable to do research in this field instead of 'just going to Toyota and copy the perfect solution'.

Choosing the lean approach, there may be two different possible ways to achieve the project target of more efficient product development processes (➲ Figure A 3-3). The first is an empiric one and suggests the analysis of the product development system at Toyota in order to determine the principles and tools they use and act upon. The second way is a theoretical one and starts with the assumption/ hypothesis that lean principles and especially tools and techniques from the manufacturing arena may also apply to product development. The current project is primarily based on the latter.

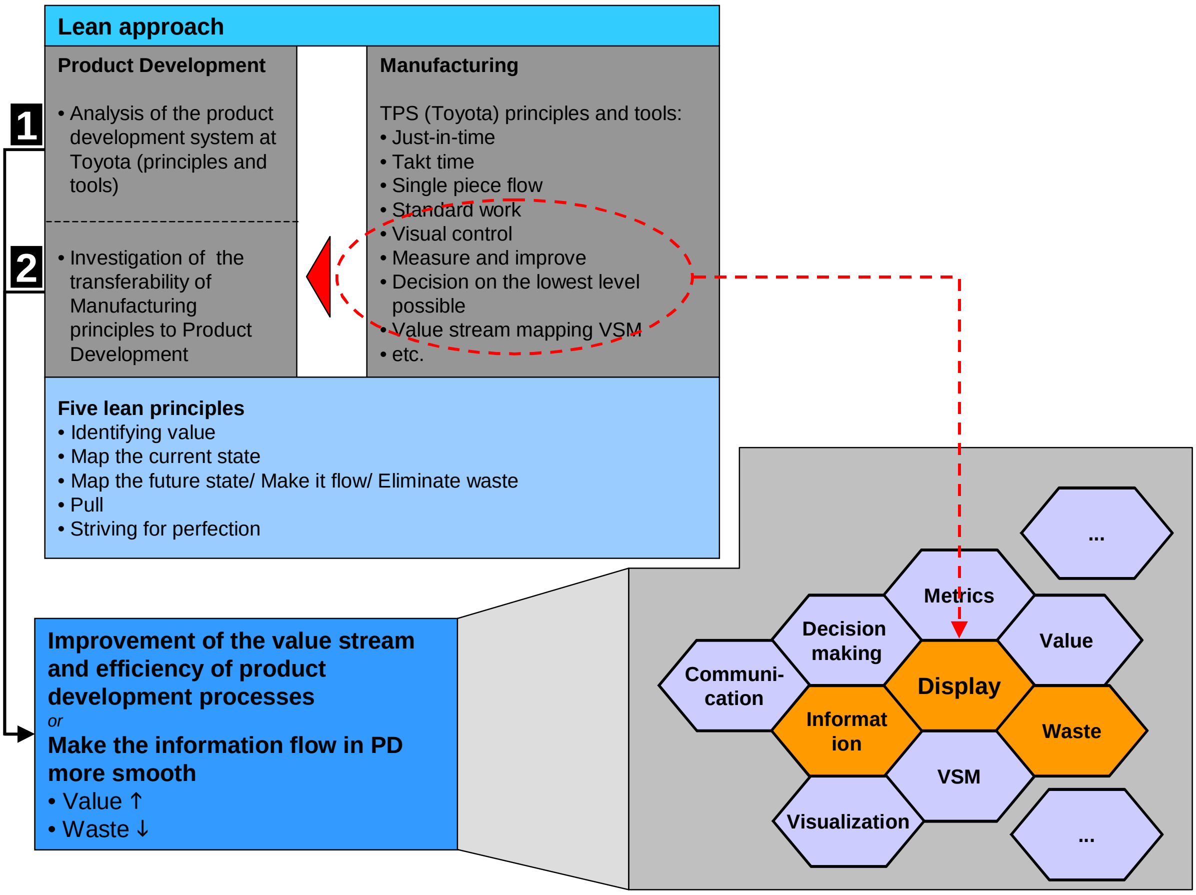


Figure A 3-3: Project definition

One of the strongest and most important tools found in manufacturing doubtless is *visual control* or *transparency* (➲ Visual control) as it considerably contributes to make the things better flow by providing the people with information about the current system performance and status, enabling immediate feedback of work performed and thus immediate adjustment if necessary. In the same way it supports people in deciding what to do best in case of emerging problems. As a result, transparency can be considered as a kind of key element for other rules like *measure and improve* and *making decisions on the lowest level possible*. The tool *value stream mapping VSM* is based on *transparency* as well.

➲ Figure A 3-3 illustrates that the idea of the development of a display in order to improve development processes by providing higher levels of transparency largely bases on the principle of *visual control* and the other few rules cited above. Parallel with or rather prior to the creation of such a display tool, some further aspects as shown in the right part of the above figure have to be investigated. Beside the display development, the author is involved with the analysis of waste and of the role of information within product development.

Work steps to accomplish the individual project targets

In order to accomplish the project targets, the author has established a set of work steps, which are tightly related to the targeted project results (➲ Figure A 3-1).

Planned work steps

1. Analysis of lean manufacturing principles, rules, tools and techniques

2. Working out the differences between manufacturing and product development as basis for subsequent investigations

3. Investigation of the specific role of information within product development

4. Investigation of waste within product development

- What is waste?
- Investigation of the transferability of the lean seven types of manufacturing waste to product development
- Working out a manageable set of waste types that applies to product development

5. Creation of a Lean Product Development enabling display (mockup)

- Identifying the specifications for such a display
- How might it be possible to integrate waste types into the display enabling the early detection of waste happening
- What information and what scope of information is reasonable for such a display
- Analysis of other and conventional ways to represent the value stream and even the status within product development
- Find a way to display the value stream in product development in a simple way to the people involved

Figure A 3-4: Work steps and targeted results of the author

According to the above ➲ Figure A 3-4, the first step will be to get familiar with lean manufacturing principles, rules, tools and techniques and thus to create a sound foundation for further research. Dealing with the transferability of principles from manufacturing to product development requires learning more about the differences between both. This is done by the next step. The fact that the product in development is not physical material but information, necessitates to find out more about information and the information flow within product development. The next step will be the investigation of waste in the context of product development. This includes finding answers to questions like *what is waste*, *what causes waste*, *to what extent can the lean seven types of manufacturing waste get applied to product development* and *how can those get eliminated.*

The last step directly deals with the creation of the display. This will start with a collection of relevant specifications as basis for a targeted development. One of the core issues will be to assess what information and how much information is reasonable for the display to ensure its usefulness. The analysis of other project representations like GANTT charts, Process flow charts, etc. may give important hints in this point and should be considered. The following creation of representation models displaying both the current value stream and waste will provide some different approaches, which get assessed in the subsequent evaluation.

A 4 Structure

The structure of the current thesis widely follows the work steps planned at the beginning of the project (➲ Figure A 3-4), and includes 7 main chapters in total.

After a detailed introduction into the subject in chapter ➲ A, the author starts his research with a concise review of the Lean philosophy in chapter ➲ B which is crucial for the understanding of the whole field of research. Beside some introducing aspects about the history of lean, this chapter brings to light the three major areas of the lean concept which together form the outstanding performance of the Toyota Production System (TPS): The five lean principles, Toyota's fundamental rules, and specific lean manufacturing tools, practices and flow techniques. Since the thesis at hand investigates the applicability of single aspects of those lean principles from manufacturing to product development, the last section of this chapter will display the differences and some analogies between both: *The product manufactured in product development is information*.

Based on that, the matter of chapter ➲ C is about information and its role in product development. This begins with some basic aspects concerning the differences between data, information and knowledge, information quality and functions of information. The following investigation of information creation on the micro and macro level illustrates that high performance in product development is a function of a huge number of variables. This starts with high quality of information exchanged, and ends up with the challenge of a consistent process design integrating functions, people, tools and the underlying information system and data models.

Chapter ➲ D constitutes the core chapter of the thesis and deals with the investigation of waste within product development. After discussing the question, what is waste, and what is wasted, including two new definitions about waste types and waste drivers, the author continues with the collection of problems within nowadays product development. This is followed by the derivation of a set of waste drivers that is based on the re-interpretation of the lean seven types of manufacturing waste to the area of product development. Since the product in product development is information, a great deal of those waste drivers refers to the information creation process on both micro and macro level as discussed in the prior chapter. In order to determine a sequence for the elimination of those waste drivers, a cause-effect analysis is performed. Based on the results, the author derives a checklist for waste elimination. A list of open points and questions rounds off this chapter.

Chapter ➲ E deals with the question of how to visualize value and waste in a value stream. It is an outline of the development of a display concept, and consists of two parts. The problem analysis defines the objectives for such a display and collects necessary specifications. The second part includes first development steps. It incorporates aspects about information contained by the future display, and describes some important results of an analysis of value stream mapping tools performed by MILLARD. The following list of open questions collected points to future research activities.

In the project review of chapter ➲ F, the author evaluates the project abroad from the viewpoint of organization, project work, supervision on the part of MIT and TUM, including a self-reflexion. A personal resume about the project and some recommendations to following students and universities round off this evaluation and the main part of this piece of work.

The following chapter ➲ G summarizes the project results and provides some concrete proposals for future research in this area.

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The author does not want to miss the chance to express his gratitude to all who have enabled and supported the project abroad in various ways. Special thanks go to following institutions, organizations and people:

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B Lean in Manufacturing

B 1 History of Lean

The Machine That Changed The World published in 1990 by WOMACK, ROOS & JONES, all three members of the MIT International Motor Vehicle Program (IMVP), dramatically changed and revolutionized the way people thought about ‘traditional’ car industry so far. The concept *Lean* was essentially coined by this case study, which has been the largest and most thoroughly ever undertaken in automotive industry. The goal was to compare the performance differences between car companies operating with traditional mass manufacturing systems and those using the Toyota Production System (TPS) (SALZMAN, 2000, p. 73).

The Toyota Production System which most people now associate with the term *Lean* or more with the *Just-in-time (JIT)* principle was already developed in the 1950s when Japanese car industry stuck in a severe crisis. At that time it became clear that the only way to escape from the possible impending doom of the automotive industry in Japan were drastic changes in efficiency and productivity (SALZMAN, 2000, p. 72). This was the hour of birth of the theories and principles of lean manufacturing, a production *philosophy that focus on the streamlining of value added activities and eliminating waste within the process with the goal to better meet customer demand*. Furthermore, it represents a holistic and consistent approach that bears on the Japanese cultural and geographic boundary conditions. This, for instance, includes Japanese people’s attitude to the conservation of material, but also to their more clan-oriented culture. These are factors that made it easier to implement policies to control material or to work in a team which is very fundamental for cross training of floating workers and total quality management (SALZMAN, 2000, p. 72). Another factor playing a major role was for example the proximity of supplier companies allowing more frequent deliveries in smaller batches.

Two of the famous and genius thinkers of the Toyota production system were *Shigeo Shingo* (1909-1990) and *Taiichi Ohno* (1912-1990).

Meanwhile, lean manufacturing principles have been adopted by diverse sectors of industry such as aerospace, consumer products, metal processing and industrial products (SPEAR & BOWEN, 1999, pp. 96-106). Despite of the very openness of the Toyota company about its practices, only few manufacturers have it really managed to successfully imitate or rather implement the Toyota system. This is no wonder. Once you look closer at the TPS you will begin to understand that the success of this approach is not just driven by the implementation of the identified various practices, control functions, and tools such as the pull system, kanban, andon lights, visual control boards or mistake proofing. Rather, it is the coherence and harmony of and with the underlying structure, organization and people’s mentality how tasks are arranged and performed. SPEAR & BOWEN (1999, pp. 96-106) designate that phenomenon as the ‘DNA of the Toyota Production System’ and suggest a set of rules that describe it. Those are inter alia explained briefly in the next chapter (➲ B 2.2).

Since the publication of the case study in 1990, there were undertaken a big number of attempts and high effort spent to adopt the lean manufacturing principles from car industry to the manufacturing section of various businesses, partially with considerable improvements. General Electric for instance made it to 100% on-time deliveries, other companies could reduce floor space by 50-97,3 % and/or improve their cycle times by 60-80 % (SALZMAN, 2000, p. 73).

Since people began to study the field of *Lean*, they gradually began to realize that the success of that system approach was not only limited to the manufacturing section but could also be expanded to other sections of business bearing a high potential of cost reduction and quality improvements.

Current research deals with the applicability of lean principles and lean improvement tools to different levels and sections of business but also tries to develop and go ahead with new ideas based on the *Lean* approach. One of those sections of business is product development. Due to its particular nature of high uncertainty and risk and low repetitiveness compared with manufacturing processes, the realization of such principles and tools but also the development of new ones turns out as much more challenging.

To get a better understanding of the *Lean* philosophy but also to provide the reader with some more background information about the author's work, the basic five lean principles identified by WOMACK & JONES (Lean Thinking, 1996), Toyota's fundamental rules and the most significant practices used within the TPS are briefly explained in the following chapter.

B 2 The five Lean Principles and more

Lean is lean since 'it provides a way to do more and more with less and less', that is to say less human effort, less equipment, less time and even less space while simultaneously producing products that customer really want. In this way it facilitates increasing value while decreasing waste at the same time (WOMACK & JONES, 1996, p. 15).

Waste means any human activity, which absorbs resources but creates no value. For instance, mistakes that require additional effort for rectification, production of items that nobody wants leading to inventories and remaindered products piling up, processing steps that are not required, movement of employees and transportation of goods from one place to another without any purpose, people in a downstream process waiting because one of the upstream activities has not delivered on time, goods and services which do not meet customers needs (WOMACK & JONES, 1996, p. 15).

A powerful toolkit against waste is provided by Lean Thinking (WOMACK & JONES, 1996) which suggests a way to specify value, line up value-creating actions in the best sequence, conduct these activities without interruption when someone requests them, perform them more and more effectively and so eliminate wasteful activities consequently. Compared with some other measures to rationalize the workflow, which oftentimes just take away jobs, this approach rather creates new ones and makes work more satisfying to the people through immediate feedback on efforts to convert waste into value (WOMACK & JONES, 1996, p. 15). The single steps of this proceeding are the matter of the following section.

B 2.1 Five Lean Principles

B 2.1.1 Specifying value

Providing the customer with the wrong good or service means waste irrespective if the process per se is performed right and efficiently or not. To further prevent this waste, the first step in lean thinking must be a thorough analysis of and dialog with specific customers in order to understand what their particular needs are at a certain time and what they are ready to pay for. Once customer needs are identified it becomes easier to define value in terms of specific products with specific capabilities offered at specific prices.

Finally, value can only be defined by the ultimate customer and is only meaningful when determined in terms of a specific product that meets the customer's needs at a specific price at a specific time (WOMACK & JONES, 1996, p. 16).

To accomplish this first goal might necessitate ignoring existing assets and technologies and introducing more strong and dedicated product teams. Reality often looks differently where the specification and creation of customer value gets hindered by immediate needs of shareholders and the prevailing financial mindset of senior management. Another issue frequently consists in the strong role of companies' technical experts. This may result in very complex, customized designs with sophisticated underlying processing technologies, which finally exceed customers' budgets, and furthermore rarely meet their real desires (WOMACK & JONES, 1996, p. 17).

Even though it is quite unrealistic that companies will successfully implement those changes overnight, it is important for them to get a clear understanding what the customer needs really are. Since all business processes within a company can be considered as a big network of supplier-customer relations, the current principle may also apply to in-house customers.

B 2.1.2 Identify the value stream

The next step in lean thinking is to identify the actual value stream i.e. the whole set of activities required to produce the specific product independent if it is a good, a service or a combination of both. This is a kind of a door-to-door perspective applied to the three major fields of activity in any business (WOMACK & JONES, 1996, p. 19):

- *Problem-solving task*: From concept through design and engineering to production launch
- *Information management task*: From order-taking through detailed scheduling to delivery
- *Physical transformation task*: From raw materials to the finished product of the customers

During the value stream analysis there will mostly appear three different types of actions along the value stream:

- *Value adding activities (VA)*: Painting a car, assembling of a bolt
- *Necessary but not value adding activities (NNVA)*: Inspecting painting to ensure quality
- *Non value adding activities (NVA)*: Activities that can be eliminated instantly.

The key of the value stream analysis is that you look at the *entire* value stream for each product or product family, beginning with the first supplier in the chain up to the ultimate customer. The potential of this procedure is based on a holistic view that goes beyond the single company. Once firms decide to do so they almost always reveal huge amounts of non value adding activities that is to say waste. In literature this kind of integral approach is called *lean enterprise*.

One of the reasons why firms still avoid this approach is the matter of confidentiality and the fear that any revealed information about internal processes and costs could be used against them by up or downstream partners. Concentrating on the own business but not on the whole value stream including the consequences of their internal activities for other companies along the stream is the logical result of this fear.

That attitude actually proves to be very dangerous in an age, when companies are outsourcing more due to an increasing product complexity and shorter cycle times. Rather, this development calls for a 'voluntary alliance' of all the different parties involved to examine each value creating step, to detect and prevent disconnects in the value stream (WOMACK & JONES, 1996, p. 21).

Of course, this requires a change of thinking about business networks and relations, and the establishment of some simple rules for regulating how companies interact with each other. Transparency as regards the process steps along the value stream might be one of the key issues since it does not only help to synchronize value creating activities more and more but also allows the participants to verify if the other companies act upon the agreed rules.

B 2.1.3 Flow

After specifying the value, mapping the value stream and eliminating not value adding activities, the next step in lean thinking consists in making the value-creating activities flow. This is a very critical step as it requires a change in thinking, away from the traditional batch thinking in the direction of continuous flow thinking.

The first people who absolutely realized the potential of flow were Henry Ford and his partners in 1913. By applying the continuous flow principle to the final assembly, Ford could reduce the effort required to mount a Model T Ford by 90 percent. Even this was an outstanding result, it only is a *special case* since Ford's approach 'only worked when production volumes were high enough to justify high-speed assembly lines, when every product used exactly the same parts, and when the same model was produced for many years' (WOMACK & JONES, 1996, p. 23).

In contrast, introducing continuous flow into low-volume production when only dozens or hundreds of copies of a certain product were needed, proves to be a much bigger challenge. It represents the *general case* as it more exactly describes the real situation with customers demand. Ohno and his associates recognized this challenge and worked out strategies and techniques to achieve continuous flow in small-lot production, in the majority of cases without the use of assembly lines. Mastering the quick change over of tools from one product to the next, and 'right-sizing' or rather miniaturizing machines in a way that processing steps of different production stages such as molding, painting, assembly, etc. could be conducted very close-by to each other, are two of those techniques. That this procedure is beneficial, some plants in North America and Europe proved where people involved in lean applied *kaikaku* which is some kind of radical improvement, compared with *kaizen* which more means continuous incremental improvement. In those cases, the production activities for a specific product were rearranged from departments and batch-and-queue fashion production to continuous flow what not only doubled productivity but also reduced product errors and scrap enormously.

Even if reengineering approaches tried to more focus on the value-creating process instead of organizational categories or departments, the concepts still adhere to disconnected and aggregated processes like order-taking for a whole range of products, instead of streamlining the entire flow of value-creating actions for the specific product (WOMACK & JONES, 1996, p. 24). What's more, those approaches often stop at the boundaries of a company and do not integrate the value streams of up and downstream process partners, even though major breakthroughs are achieved by considering the whole value stream.

The target of the flow principle consists in redefining the work of functions, departments and companies in a way that they positively contribute to value creation and to meet the real needs of the process participants at every point along the value stream so it is actually in their interest to make the value flow (WOMACK & JONES, 1996, p. 24). To do this successfully not only requires to focus on the specific product or service, and to create a lean enterprise for each product but also to ignore or rather to rethink traditional boundaries of jobs, functions, departments, careers, companies, specific work practices and tools in order to eliminate backflows, scrap and stoppages of any sort and thus to make the flow more smooth.

Once employees and managers begin with 'flow thinking' and learn to see it, it becomes also possible to apply flow to any activity performed. In principle, the procedure is in every case the same (WOMACK & JONES, 1996, p. 64):

- Concentrate on managing the value stream for the specific service or good
- Eliminate organizational barriers by creating a lean enterprise
- Relocate and right-size tools, and
- Apply the full complement of lean techniques so that value can flow continuously

A short overview of lean manufacturing tools and flow techniques primarily used in the flow context is provided in a chapter beneath (➲ B 2.3).

Applying the flow principle to business processes also seems to have some impact on the psychological state of employees. According to WOMACK & JONES (1996, p. 64), in a survey conducted by the psychologist *Mihaly Csikzentmihalyi*, University of Chicago, people consistently report those activities as most rewarding which were associated with a clear objective, a need for concentration so intense that not attention is left over, a lack of interruptions and distractions, clear and immediate feedback on progress toward the objective, and a sense of challenge – the perception that their own skills are adequate and sufficient to accomplish the task at hand. It was also found out that people experiencing these conditions are in a highly satisfying psychological state of flow.

In contrast, conventional batch-and-queue organized work scarcely facilitates psychological flow. The worker can only see a piece of the entire task, there often is no knowledge of whether the task was performed right or what the status of the entire system is, the assigned task only requires a small portion of the worker's concentration and skills, and there are frequent interruptions with other tasks the worker is in charge of. As a result, an organization that focus on the continuous flow of work and accordingly value, might also lay the foundations for psychological flow. The challenge to sustain a smooth flow without interruptions but also the focus on perfection, the last lean principle in this row, put the whole system in a very creative tension which demands concentration on the part of each worker and the whole product team (WOMACK & JONES 1996, pp. 65-66).

B 2.1.4 Pull

Lean thinking however is not only concerned with the question how to provide the exact goods and services the customer really wants, but also how to provide it *when* the customer really wants it.

The strategy behind is the pull principle, which means that you let the customer pull the product from your company as needed instead of pushing products onto the customer and so accumulating huge stocks of products that no one wants. Even though primarily looked at the end customer, this principle applies along the whole value stream and thus means that no upstream station should produce a good or service until the downstream station asks for it. An essential precondition for it is laid by the realization of the flow principle which can significantly reduce throughput times in product development, order processing and physical production by 50, 75 and 90 percent respectively (WOMACK & JONES 1996, p. 24). This creates high flexibility and thus the ability to design, schedule and produce exactly what the customer wants and when he wants it. Furthermore, the short response time to customer demand makes it also possible to accelerate the return on investment and to reduce inventories to a minimum even in a complex production and value stream. According to WOMACK & JONES (1996, p. 79) the secret for the latter can be seen in the ability to get parts resupplied very quickly from the next level of the system, which in turn enables to reorder in small batches. A special tool to control the resupply and to optimize inventories is *kanban* and *JIT* (Just in time), which is briefly explained beneath (➲ B 2.3)

What in theory sounds very comprehensible and simple might be a little bit more complicated in practice and takes a good while to implement. In fact, WOMACK & JONES (1996, p. 88) for example established that the amount of inventories of any given level of economic activities has not decreased very much in America, Europe or even Japan in spite of one decade of awareness about JIT or rather four decades of lean thinking in Japan. It is supposed that companies have more adopted JIT supply and not JIT production. Consequently, inventories of the same quantity were moved one step back towards upstream processes, which are product components or raw materials of suppliers.

B 2.1.5 Striving for perfection

The final principle in this row is striving for perfection which is some kind of reminder that there is no end in reducing effort, time, space, cost and mistakes while simultaneously producing more and more products which the customer really wants (WOMACK & JONES 1996, p. 25). Indeed, the above mentioned four principles interact with each other in a way that improvements in one of these often lead to some improvements in the others. For instance, product teams which are in direct contact with customers almost always find better and better ways to define customer value more concisely and thereby also find some new ways to advance flow and pull techniques. Another aspect in this context concerns new technologies in manufacturing and other areas which often reveal new ways to increase value and eliminate waste that again redefines the prevailing picture of perfection a company has.

Beside setting specific targets for improvement driven by *kaizen*, the lean philosophy also uses impossible targets for the improvement process, and paints the picture of a perfect process situation for the people. Even if it might be impossible to get to there, just the imagination provides a great deal of inspiration and in particular direction to the people what is essential to making progress along the path and to pull together (WOMACK & JONES 1996, p. 94).

One of the most important and fundamental principle on the way to perfection is transparency, which was already mentioned earlier (➲ B 2.1.3). Based on the fact that every member of the lean system whether subcontractor, first-tier-supplier, assemblers, distributors or even customer can see everything, it is much easier to find out better or even new ways to create value or rather to prevent waste (WOMACK & JONES 1996, p. 26). Above that, visual control boards often used in production, provide workers with nearly instant feedback of made improvements, which is very basic for the lean approach and a very powerful incentive for the people to further continue with improvements.

B 2.2 Toyota's fundamental rules

As established at the beginning of the chapter, the success of the Toyota Production System (TPS) is not just driven by the implementation of the identified various practices, control functions, and tools such as the kanban, andon lights, visual control boards or mistake proofing observed by a lot of people during their plant visits at Toyota. Rather it appears that those practices are just created as means to an end, which is to support a set of rules implicit with the TPS. Those were established and designated by SPEAR & BOWEN as the DNA of the TPS and especially focus on how work at Toyota is arranged and performed. The following five sub-chapters are an outline of SPEAR & BOWEN'S article *Decoding the DNA of the Toyota Production System* (1999, pp. 95-106).

When looking at the TPS for many people a paradox is arising: How is it possible that activities, connections and production flows in a Toyota factory are rigidly specified, but at the same time operations are highly flexible and adaptable? The key to resolve this problem might not be found in the practices themselves but more in understanding that the TPS is made up of a 'community of scientists' using the scientific method within their work. The scientific method differs from the engineering method, which is more problem specific, and can be generally captured by the following steps:

- Observe some aspect of the universe
- Invent a tentative description, called a hypothesis, that is consistent with what you have observed
- Use the hypothesis to make predictions

- Test those predictions by experiments or further observations and modify the hypothesis in the light of your results
- Repeat steps 3 and 4 until there are not discrepancies between your hypothesis and experiment and/or observation

For this reason, each time there is made a specification, there are also established new hypotheses, which can be tested. For changes, Toyota prescribes a rigorous and standardized problem-solving process including a detailed assessment of the current state of affairs and a plan for improvement i.e. a plan for the experimental test of the suggested changes. Without such a rigorous and systematic procedure, improvement would be nothing more than 'random trial and error'. This approach also suggests that workers and managers at Toyota experience their daily work as kind of a big experiment in which each of them plays his certain role. Finally it is this attitude, the readiness to experiment, that makes the system so flexible and that is widely recognized as the cornerstone of a learning organization.

In particular, SPEAR AND BOWEN established three rules of design which show that Toyota designs all its operations and processes as experiments, and one rule of improvement which characterizes how Toyota teaches the scientific method to people at every level of the organization.

B 2.2.1 How people work

The first rule determines that all work is to be highly specified as regards content, sequence, timing, and outcome. The reason for this is that missing specifications allow considerable variation in how work is done by the employees. 'All this variation translates into poorer quality, lower productivity, and higher costs' (SPEAR AND BOWEN, 1999, p. 99). What's more, it impedes learning and improvement in the particular field of activity since the direct link between how the work is done and the final results is concealed by the variation. Looking for failures by a root cause analysis becomes much more difficult and ambiguous, too.

In contrast, following a well-defined sequence of process steps gives immediately information about deviations from the specifications. A good example for this is the production line at Toyota where the 'length of the floor for each work area is marked in tenths' (SPEAR AND BOWEN, 1999, p. 99). As each step of an activity is assigned to a certain time it is easy to see for the worker and the team leader that he has fallen behind. In this particular case, performing the work as specified tests two implicit hypotheses:

- The person doing that work is capable to perform it correctly, and
- Performing the work creates the expected result or outcome

Since there occurred a problem, at least one of the two hypotheses was refuted. As a result, either the activity has to be redesigned or the worker has to be retrained.

The rigid specification of procedures and tasks also means some kind of standardization even if it might be a very dynamic one due to continuous improvement efforts. That not only provides people with a *common reference* when they talk about specific problems or improvement ideas, but also increases the chance of more frequent improvements due to a higher number of operation cycles based on the same procedure. The adjustment of people to a new job, assuring the same outcome, might also be easier and less complicated.

B 2.2.2 How people connect

The next basic rule stipulates that every customer-supplier connection (between up and downstream process steps) must be standardized and direct. It has to be exactly specified what people are involved, in what form and quantity the goods and services to be provided, how requests are made by each customer, and the scope of time in which responses or services must be delivered at latest (SPEAR AND BOWEN, 1999, pp. 98-100). Consequently, this rule creates a very strong supplier-customer relationship between each operator and the individual that is in charge of supplying that operator with the requested good or service, and so prevents ‘gray zones’ in deciding who is supplied by whom with what and when. Similarly, the number of persons in a team gets exactly defined by the types of problems supposed to emerge, the level of assistance the team members need, and finally the skills and ability of the team leader.

The advantages of that approach are various. On the one side it creates much more accountability since it is known who is in charge of what. The risk that something which is everyone’s problem quickly becomes no one’s problem, is consequently much lower (SPEAR AND BOWEN, 1999, p. 101). Further, this approach can enormously help to reduce variability within the process since there are certain requirements to respond to material or assistance requests within a dedicated time frame. Thus problems occurring can be solved immediately, and do not remain hidden, piling up and only get resolved much later when valuable information about the actual problem causes may have been lost (SPEAR AND BOWEN, 1999, p. 101).

In the case that the problem cannot be solved in the dedicated time frame, the hypotheses in the particular supplier-customer relation for assistance are confuted anew. Maybe the request was not performed correctly, maybe the assistant has a capacity problem because of too many other requests in this time, maybe he is no capable problem solver etc. Either way will result in some consideration how that problem can be prevented in future in order to make the system more stable.

B 2.2.3 How the production line is constructed

The third rule says that all production lines have to be designed in a way that every product and service must follow a simple, direct and specified pathway through the plant. This also implies that there are no forks or loops which might convolute the flow in any of the supply chains, and goods or services do not just flow to the next available person or machine but to a specific person or machine (SPEAR AND BOWEN, 1999, p. 101). However, the rule that every product may only flow along one prespecified path does not exclude that each path is allocated to just one specific product. In contrast, compared with other companies, there are running many more models of products on each production line at Toyota plants. Clear pathways not only refer to products but also to services. For instance, if one person needs assistance and his designated supplier cannot provide this at the moment, the latter himself will have a designated helper to send. Sometimes this kind of chain includes between three and five links, connecting the different levels of the company’s hierarchy.

Similar to the two paragraphs before, the fact that every pathway whether for product or service is rigidly specified, makes it possible that an experiment takes place each time the specific path is used (SPEAR AND BOWEN, 1999, p. 102). As soon as the actual demand for help or the capacity of a machine does not meet the requirements, the workers will review the design of the pathway, search for improvements and adjust the system repeatedly.

B 2.2.4 How to improve

The fourth rule prescribes that any improvement whether to production activities, to connections between workers, or to pathways of products and services must be performed in accordance with the scientific method, under the guidance of a teacher and at the lowest level possible in the organization (SPEAR AND BOWEN, 1999, pp. 98, 102).

People at Toyota are explicitly taught how to improve. By redesigning their own work they are often prompted to develop their problem-solving skills. To ensure the right procedure, a work group gets assigned to an experienced leader who trains the team to correctly frame problems and to establish and test hypotheses effectively. This leader may sometimes be an external expert to provide for the quality of the learning process. By asking specific questions the leader forces the factory people to exactly articulate and challenge their most basic presumptions about what could and could not be changed as those particularly define and constrain the way people would solve a problem (SPEAR AND BOWEN, 1999, p. 103). To realize the way that changes are made is considered as significant as what changes are made finally.

The people who are doing the improvements are on the one side the frontline workers improving their own jobs, and on the other side their supervisors providing direction and support. In the case that there are conducted major changes, special improvement teams get set up including those people which are directly affected and the supervisor of the particular pathway. Since also manager from higher level have some operational responsibility for supervising and ensuring a smooth work flow, problem solving and learning is not limited to the lowest levels but happens through all levels of the company. Finally it is the nature of the problems that defines who should resolve it and how the organization must look like to ensure a capable problem management. Thus it may be no wonder that there are different organizational structures beside each other in the same plant.

B 2.2.5 Notion of the ideal

Not a rule, and similar to the fifth lean principle (➲ B 2.1.5), is the fact that the people of Toyota have a common notion of what the ideal production system would look like. It is that shared vision that motivates the people to improve beyond the ‘normal’ required to just meet the current needs of the customer.

When the workers at Toyota speak about the ideal they have something very concrete in their mind, which moreover is very consistent throughout the whole company. According to SPEAR AND BOWEN (1999, p. 105), for them, ‘ideal’ means that the output of a person, work group or a machine:

- is defect free (product has the features and performance the customer wants)
- can be delivered on one request at a time (batch size of one)
- can be supplied on demand in the version requested
- can be delivered immediately
- can be produced without wasting any materials, labor, energy or other resources (such as costs associated with inventory), and
- can be produced in a work environment that is safe (physically, emotionally and professionally) for every employee

Even if Toyota has a clear understanding what the ideal production system would be, it sometimes neglects some of these aspects against other and more important ones. This for example concerns temporary practices connected with higher levels of inventory or production in larger batch sizes, quite different from what just-in-time actually is. The reasons for this may be certain circumstances occurring in practice (SPEAR AND BOWEN, 1999, p. 104):

- Unpredictable downtime or yields
- Time-consuming setups
- Volatility in the mix and volume of customer demand

Nevertheless, Toyota will adhere to strive for the ideal state, the ‘ability to create virtually infinite variations of a product as efficiently as possible’, at the lowest possible cost and with no defects (SPEAR AND BOWEN, 1999, p. 106).

B 2.3 Lean Manufacturing tools, practices and flow techniques

Tools and practices like *kanban*, *JIT*, *mistake proofing* were copied by many companies and widely understood as the secret of the TPS. Quite contrary, Toyota itself calls them 'countermeasures' and considers them rather as temporary responses to specific problems used as long as a better approach is found or conditions change (SPEAR AND BOWEN, 1999, p. 104). It is important to recognize that those countermeasures are designed to support the above established set of rules (➲ B 2.2) and lean principles (➲ B 2.1). They are supposed to counter very specific categories of problems occurring and to provide the system with some kind of 'built-in tests' to display problems immediately when and where they occur. This is especially true for the aforementioned unusual high levels of inventories sometimes observed in Toyota plants. For instance, in some cases it would be possible to reduce inventory by pooling it since the same type of product is kept in different types of inventory. The result of this approach however would be that the link between these high levels of inventory and the reason for maintaining it, that is safety stock due to unreliability, or buffer stock due to fluctuations in customer demands, would be lost (SPEAR AND BOWEN, 1999, p. 105). Consequently, keeping these inventories provides not only information about the ownership but also visual control of existing problems requiring some improvements.

The following list of tools, practices and techniques gives the reader a brief review how Toyota tries to realize the above mentioned set of lean principles and rules.

B 2.3.1 Tools and practices

- Kaizen

  Kaizen means a continuous, incremental improvement process for process flow and workmanship with the goal to create more value with less waste. Also called point kaizen and process kaizen (WOMACK & JONES, 1996, p. 307).

- Kaikaku

  Also called breakthrough kaizen, flow kaizen and system kaizen. Procedure to significantly improve activities with the target to eliminate waste. An example would be the radical reorganization of processing operations from previous queue and batch production to ➲ Single-piece flow, and thus the change from large space to short space shop floors.

- Hoshin kanri

  Also called policy-deployment. It is a tool for strategic decision-making and helps executive teams to concentrate on the critical and most important factors to accomplish the company's business objectives. Similar to quality function deployment, a visual matrix diagram is supportive to select between three and five key objectives, which then get translated to specific projects and subsequently broken down to the respective level for implementation. Thus, this method essentially helps to align resources and to establish clearly measurable targets against which progress is measured in dedicated time intervals (WOMACK & JONES, 1996, pp. 306-307).

- 5S

  Five rules that help to create a high efficient workplace, each rule beginning with the letter S. The following explanations use the English translation of the terms according to INTERNET 1 (2004).

  - Sort through and sort out: Separate needed tools, parts, materials and instructions from unneeded ones; remove, relocate or discard what is not necessary.
  - *Set in order*: Neatly arrange parts and tools so that they are easy to find, use and return in order to streamline work and prevent searching for them.
  - *Shine*: Conduct a cleanup campaign and thereby inspect equipment and work area.
  - *Standardize*: Organize all work areas in a similar way so that procedures are obvious, and defects are signaled automatically.
  - *Sustain*: Always follow the first four rules that they become habit. Only this will provide the total benefit of that practice.

- SMED (Single Minute Exchange of Dies)

  Shigeo Shingo developed a number of techniques for changeovers of production machines in less than ten minutes. Changeovers that require less than a minute are called one-touch setups. As Toyota strives for perfection, the long-term objective is zero setup, which means that changeovers can be immediate and thus will not interrupt the production flow in any way (WOMACK & JONES, 1996, p. 310). Only that will finally make it possible to disengage pure mass production for small and continuously changing series.

- VSM (Value Stream Mapping)

  Mapping method to identify all the specific activities and process steps along the value stream of a specific product or product family (WOMACK & JONES, 1996, p. 310). Value stream mapping is conducted in three steps: Mapping the current value stream, mapping the future value stream, and creating an implementation plan. An official workshop brings together people from engineering, manufacturing, sales and supply.

- Poka-Yoke (Mistake-proofing)

  A mistake-proofing device or procedure to prevent defects during order-taking or manufacturing. An example from manufacturing are devices that survey the shape of product parts. Deviations will instantly result in a stop of the dedicated machine. That will also apply if there occur failures in processing of the machine itself, or if a specific sequence of operations is not followed. To ensure error-free order taking, there was developed an order input system based on traditional ordering patterns signaling orders that deviate from that pattern and thus have to be examined. In the majority of cases the reasons are input errors or orderings due to misinformation. The survey and improvement process itself is called baka-yoke (SHINGO, 1992, pp. 254, 260; WOMACK & JONES, 1996, pp. 61, 308, 309).

- Jidoka

  Term that originally characterized the application of poka-yoke devices, and means not allowing defective parts to leave the station or machine that produced them. In particular, it referred to machines or the production line itself, which should be able to stop automatically when a problem occurs. For this reason it is also called *autonomation*, and deals with the transfer of human intelligence to automated machinery (WOMACK & JONES, 1996, p. 305).

  Jidoka also refers to the situation when an individual worker is facing a problem with the assigned task. If he cannot correct the problem by his own or because the designated assistant is not available, he is prompted to draw a cord to stop the line in place of risking that this is done at a later point in time by the defect (INTERNET 2, 2004). Jidoka often is followed by a root cause analysis.

- U-Cell-Layout/ L-Shape-Layout

  Work or machines of different types performing different processing steps are organized in cells, typically in a U-shape layout. Especially within the cells, that enables the flexible deployment of workers in a way that they can operate several machines at the same time (multi-machine working). The catenation of several cells may again exhibit a U-shape, or a L-shape. This kind of layout drastically reduces used space on the shop floor and thus enables shorter distances between single cells, which again betters worker's communication. Foremen and supervisors can reach stations with occurring problems in only a few moments assuring instant help, and because of the proximity of the start and end point of the work area they are responsible for, each walkabout is almost a closed loop and thus contains only little idle time for them (WOMACK & JONES, 1996, pp. 305, 308).

- 5 Whys

  Question practice of asking 'why' five times always people encounter a problem. One question cycle not only contains 'why' but also a whole series of questions: who, what, when, where and how? By conducting this cycle five times at least, it should be possible to identify the real root causes of a problem and to devise and realize effective countermeasures (SHINGO, 1992, p. 254; WOMACK & JONES, 1996, p. 306).

- Seven types of production waste

  To easier identify waste in production a set of seven waste types was established. According to WOMACK & JONES (1996, pp. 50-66, 309, 310) this includes
    - *waiting* for the next operation,
    - *transport* of materials and parts,
    - unnecessary *movement* by workers while they perform their job due to looking for parts, tools, assistance etc.,
    - *over processing* of component parts due to poor tool and product design,
    - higher levels of *inventories* than the possible minimum,
    - *overproduction* of parts and products before ordered, and
    - *defective products*.

B 2.3.2 Manufacturing flow techniques

- Systems capability

  The integration of core team members all along the value stream with a good understanding of the process steps and systems capabilities is the basic precondition for enabling a smooth product flow through all process steps from the start to the finish (SLACK, 1998, p. 41).

- Takt time

  Technique used to synchronize the rate of production with the rate of customers. It sets the pace of production and helps to prevent over or even underproduction and thus to reduce inventories.

- Visual control

  Visual control, also called transparency, pursues the goal that every person involved must be able to see and fully understand the different aspects of the process and its status at any time. This reaches from neatly organized workplaces (5Ss), status indicators like andon boards (lighted overhead displays providing information about the current status of production and emerging problems), updated standard work charts, displays with key measures to financial status reports about process costs. Transparency plainly is one of the key principles of the TPS, enabling immediate feedback of current work and thus immediate adjustment if necessary to finally meet customer demand (SLACK, 1998, p. 41; WOMACK & JONES, 1996, pp. 61, 305, 311).

- Just-in-time (JIT)

  Flow technique that aims at minimum stocks and inventories by providing the right material and parts in the right quantity and at that point in time when it is needed. According to WOMACK & JONES (1996, p. 307) the key elements of JIT are flow, pull, standard work (standard in-process inventories) and takt time. Just-in-sequence (JIS) is a special case of JIT and means that in addition to the above characteristics for delivery also the sequence of delivered parts is defined. A good example for this may be the supply of car companies with seats when it is vital to install the right seats in the right cars without any interruptions in the flow because of a wrong order.

- Kanban

  Kanban is a small card attached to parts' container, and is part of a control system used to practice pull for the in-plant material flow by signaling upstream processes new demand which results in production and/or supply of the particular parts (WOMACK & JONES, 1996, p. 307).

- Heijunka (Level scheduling)

  Level scheduling is used to sequence orders in a repetitive pattern and so to smooth the day-to-day variations in total orders in terms of longer-term demand. Some type of level scheduling is inevitable for every producer, whether mass or lean, unless he and all his suppliers have unlimited human and machine resources and zero changeover times so they can immediately respond to demand. Nevertheless, since lean producers continually try to create excess capacities and to reduce changeover times through continuous improvement efforts, the short-term discrepancy between the level schedule and effective demand can be minimized step-by-step (WOMACK & JONES, 1996, p. 306).

- Physical proximity

  Production steps are arranged in close physical proximity and in sequence to reduce excessive transport actions (➲ U-Cell-Layout/ L-Shape-Layout) but also excessive movement of the workers. On the macro level, this may refer to the proximity of the engineering departments to the shop floor, or the proximity of suppliers to their customers. Either way leads to better mutual integration and communication (SLACK, 1998, p. 42).

- Single-piece flow

  A process in which the incrementally finished products, one at a time, flow along the prespecified pathways of order-taking, design and production without any interruptions, loops or scrap. This model is in stark contrast with conventional batch-and-queue processing and thus eliminates inventories between the process steps. Furthermore, quality problems can be detected and eliminated on a single piece basis instead of a whole lot of parts (WOMACK & JONES, 1996, p. 310; SLACK, 1998, p. 42).

- Capable processes

  Capable processes, equipment and employees are the precondition for high process performance with low levels of variability, defects and scrap. To ensure capability, certification processes of both process equipment and workers are conducted at regular intervals (SLACK, 1998, pp. 42, 43).

- Standard work

  Each activity is concisely specified regarding to cycle time, takt time, content and sequence of the different sub-tasks, and the minimal number of parts (inventory) required to accomplish the particular job. Performing work as specified counts among the basic conditions to reduce variability through a continuous improvement process with the goal to achieve fully capable processes. Additional, standardized work helps other workers to learn new tasks more quickly (WOMACK & JONES, 1996, p. 310; SLACK, 1998, p. 43).

- Cross training

  Cross-trained workers are intended to sustain flexibility in task assignments. This flexibility is required to encounter any resource shortfalls along the flow that may occur for any reason. Thus it helps to reduce the risk that the process gets interrupted due to resource bottlenecks (SLACK, 1998, p. 43).

- Total productive maintenance (TPM)

  Set of methods to ensure 100% availability of every machine and equipment used within the production process. Since it not only eliminates wait time waste due to ‘normal’ machine breakdowns, but also defect waste and rework associated with non-conforming parts due to machine or tool wear and tear, it is one of the basic strategies for capable processes (WOMACK & JONES, 1996, pp. 310, 311; SLACK, 1998, p. 44).

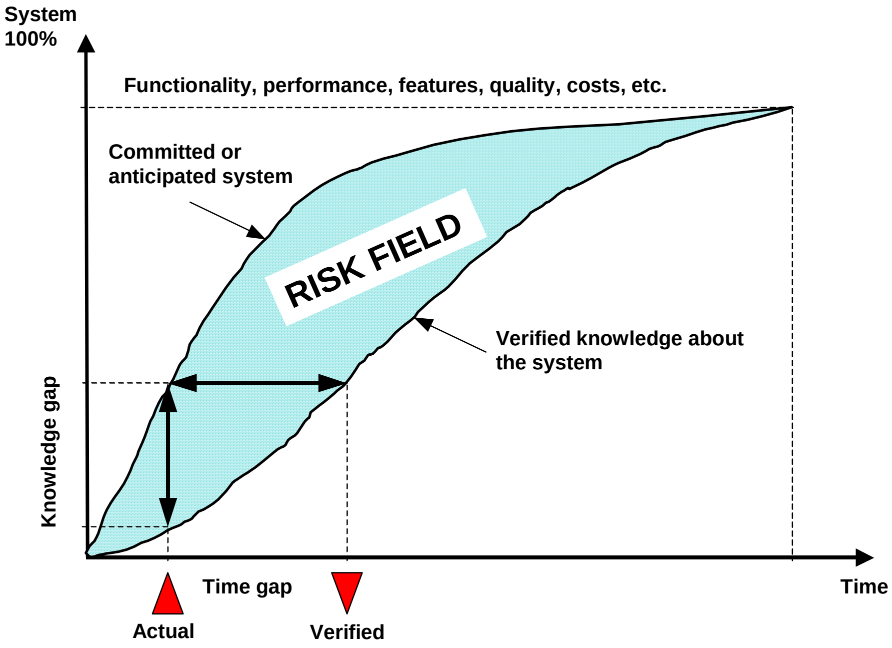
Finally, it is important to understand that neither the five lean principles, nor Toyota’s basic rules, nor the number of different tools, practices and flow techniques gives the TPS its unique performance. Rather it is the way how all of these elements are orchestrated and consistently linked with each other.

B 3 Differences between Manufacturing and Product Development

Applying lean manufacturing principles to the area of product development is not that easy and has to be discussed thoroughly since there are a number of significant differences between both.

Finally, it is the purpose of each process that makes them so different. Both departmental organizations can be considered as some kind of factory in which something is happening that creates value for the enterprise. In product development, value added consists in the creation of new and useful information in order to develop new product data, specifications and instructions, or some kind of ‘product recipe’, which then can be realized by manufacturing. According to NEGELE ET AL. (1999, p. 2) product development processes per se can be understood as *multidimensional process nets* where processes and process chains are highly interconnected, and feedback-loops and interactions cross multiple hierarchical levels. Further, product development processes can be characterized by the following set of attributes (NEGELE ET AL., 1999, p.2): creative and innovative, dynamic, interdisciplinary, strongly interrelated, strongly parallel, iterative, communication intensive, anticipatory, planning intensive, uncertain and risky.

The following figure (➲ Figure B 3-1) illustrates one of the most significant problems within product development processes: uncertainty and risk. It means that at any time during product development and even later, the characteristics of a system, concerning, functionality, performance, features, etc. are planned and specified. However, the actual knowledge about the system at this point in time, gained and confirmed through testing and verification, always falls below the planned level (WENZEL & BAUCH, 1996, pp. 126, 127). Consequently, there always exists a knowledge gap between assumed and verified characteristics. Since it always lasts a while until planned features are verified, there also exists a time gap between assumption and verification. During this time, unexpected problems can occur and the whole development may be based on wrong assumptions what in turn can end up in loops and high levels of rework. This is exacerbated the more the later problems are detected. According to the 'rule of ten', the effort (time, money) to realize changes in order to eliminate discovered product failures increases from late phases in product development to manufacturing and to customer by a factor of ten each time i.e. from 10 to 100 and to 1000. Taking both facts into account, that is to say the 'rule of ten' and the risk field which is made up of knowledge and time gap, it becomes obvious why product development may last very long (WENZEL & BAUCH, 1996, p. 127).



Modified from WENZEL & BAUCH, 1996, p. 126

Figure B 3-1: Uncertainty and risk - a very characteristic within product development

Risks in product development however do not only refer to problems and uncertainties in terms of the technical feasibility of a new product. Furthermore, there are also some risks due to assumptions in time, costs and resources.

In contrast, risk in manufacturing more concerns the manufactured product quality, and the reliability and availability of processes in order to meet delivery dates.

Even though the different meanings and definitions of risk reflect the particular purposes of product development and manufacturing, the differences between both areas are not limited to only the mentioned aspect of risk. Further differences are listed in the following table (➲ Table 1). The medium column specifies some attributes for the comparison.

Product development	**Attributes**	**Manufacturing**
Functionality and performance	*Targets*	Degree of excellence
Highly networked Sequential and parallel processes (Highly) iterative Not highly repetitive Uncertainty, Risk Repeatable (target)	*Processes*	Sequential Repetitive Non-iterative Tolerances in factory operations
Data, specifications, instructions	*Product*	Physical product
Specification of a product (recipe)	*Output*	Product itself (physical material)
Months, Years, decades	*Through put time*	Days, weeks, months
High	*Determination of product costs (cost responsibility)*	Low
Low	*Causation of product costs*	High
Engineers	*People*	Skilled worker, craftsmen
Milestones, fulfillment of customer specifications	*Measurement*	Compliance of tolerances
Information flow	*Flow*	Material flow
Multidirectional, loops and iterations possible and planned	*Flow direction*	Unidirectional, loops and iterations not planned
Difficult	*Simulation*	Easy
Low	*Potential of automation*	Medium, high
Knowledge	*Character of work*	Proficiency
Time on the critical path	*Focus on*	Costs and expenses as measure of waste
Gates	*Reason for queues*	Batches/ lots
Knowledge gaps, time gaps, assumptions regarding time, costs, resources	*Risk*	Reliability and availability of manufacturing processes

Table 1: Differences between Manufacturing and Product Development

Even if there can be seen some parallels between manufacturing and product development like the idea of flow, there still exist a lot of differences which might mean some more or less big hindrances for the application of lean manufacturing principles and tools to product development at this point in time. This for example refers to the principle *measure and improve.* Since there only are a very few complete development cycles in a few years compared with manufacturing where may be thousands and more in the same time, the implementation of improvements within development processes turns out as a much higher challenge. To what extent those differences may finally impact and restrict the transferability of other principles and rules like waste, which is the topic of the current thesis, has to be discussed in particular (➲ D).

C Role of information in Product Development

In chapter ➲ B 3, product development was already referred to as 'information creation factory', a place, where 'new and useful' information is created for a new product which then can be realized by manufacturing. In other words, the product of product development is information.

Therefore, it seems important to learn more about the object 'information' and the information creation process. This includes questions about what information is (➲ C 1.1), what its properties and quality attributes are (➲ C 1.2 and C 1.3), what functions information may have and how information can be categorized (➲ C 1.4), and what elements an information creation process consists of (➲ C 2).

Some of the aspects already constitute some basic thoughts regarding the display development (➲ E). The particular usage of those aspects and ideas however has to be decided yet.

C 1 Basics

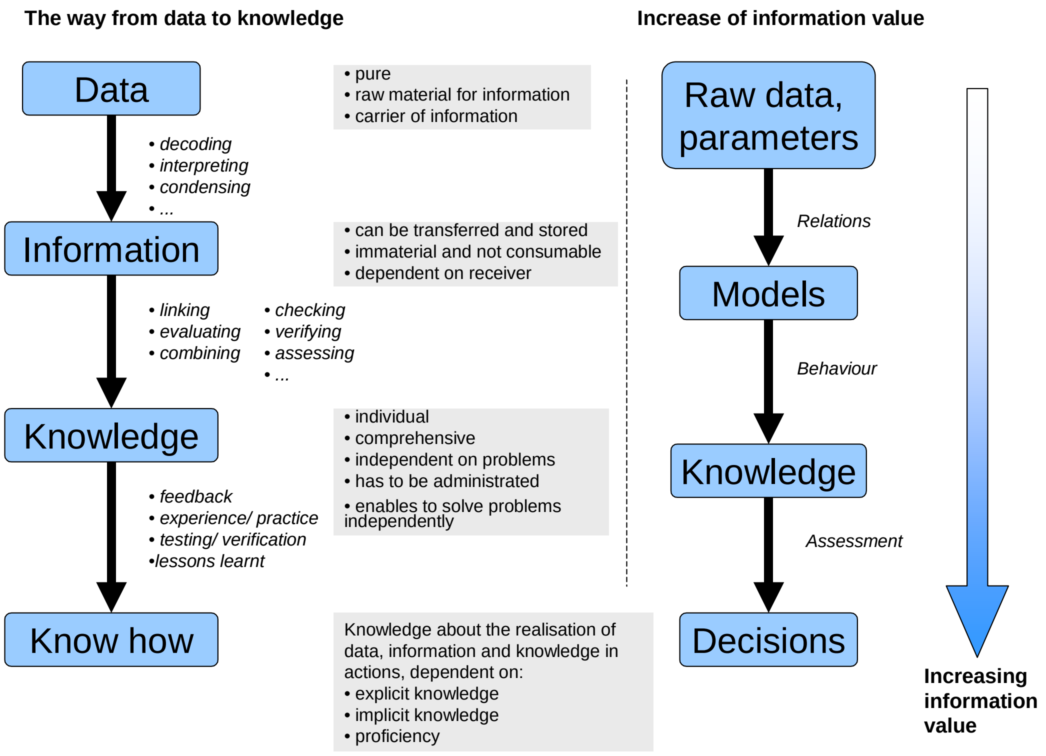
C 1.1 Data, information, knowledge

According to SCHWANKL (2002, pp. 77–81) there is a mutual dependency between data, information and knowledge with a smooth transition (➲ Figure C 1-1). At the very beginning of the depicted chain there are data, which are made up of a sequence of characters or symbols used in the particular context. They may describe certain aspects of a state, situation or event, and thus they are the 'raw material' for and the carrier of information. Important, however, is that the transition from data to information will only be possible if the relevant context is also known by the recipient.

Information itself is defined as the *knowledge of circumstances and procedures* (➲ Figure C 1-3) and always has a particular purpose within a certain context. Only by incorporation, linkage and transfer of information, knowledge can be generated which in turn can be seen as the entirety of all parts of knowledge and abilities the individual uses for problem solving. An essential precondition for the accurate transition of information to knowledge consists in the interpretability of information by the recipient. This is especially true as knowledge per se cannot be transferred directly from person A to person B, but has to go the way via data and information. Another point that has to be mentioned is that not everything that begins with data and information will necessarily end up in knowledge. Furthermore, the built up of new, accurate and useful knowledge is essentially affected by the information processing abilities of the respective person itself but also by the quality of incoming information which is explained more detailed beneath.

Following SCHWANKEL'S work, the knowledge in product development consists of knowledge regarding the *produc*t, *project*, *process* and *roles*, and thus it represents a very basic prerequisite for a successful development process. Another and less asset-related view suggests the distinction between explicit and implicit knowledge. The reason why explicit knowledge can be imparted and utilized very well is because of its easy description by words and numbers what again allows an easy documentation. That also explains why explicit knowledge represents the area that traditional education and approaches of knowledge management focus on. In contrast, implicit knowledge is very personal, hence very difficult to access and to describe. It primarily results from individual activities and experiences but also from the exchange of experiences with others. As this might be very constrained and dependent on the particular situation or issue, the only way to make implicit knowledge accessible often is the availability of the person itself.

Thus, to stand the future dynamics of markets, it becomes more and more important for companies and their employees to regard knowledge as kind of a factor of production beside the conventional such as raw material, capital and work force, which can bring the company considerable advantages in their business and position on market. For this reason it becomes obvious that to tap the full potential of information and knowledge available in the company or rather in the heads of the employees requires new approaches in information and in particular in knowledge management and transfer. Replacing experienced engineers in their mid 50's with university graduates or young professionals with relatively limited experience seems to lead in the wrong direction and may be considered as a great source of waste namely the waste of knowledge, that a lot of companies are still not aware of.


The way from data to knowledge

Increase of information value

According to Schwankl, 2002, pp. 77 - 81

Figure C 1-1: Data, information, knowledge and their value added

Going back to the chain (➲ Figure C 1-1) there might be an additional category which is know-how or knowledge in action, that is to say the knowledge about the *realization* of data, information and knowledge into actions (INTERNET 3, 2004). Even if the word know-how is often used in the context of company's core competences, it must be clear that it actually refers to the company's individuals' explicit and implicit knowledge and even more to their abilities. Abilities mean the concrete and adjustable individuals proficiency, which can be, trained in a way that certain behavior patterns or procedures become routine such as the application of methods or specific tools (SCHWANKL, 2002, p. 81). For further improvement of these abilities, testing, verifying and feedback will play an essential role in this context.

Each engineer's capacity to act gets determined by the extent of the three factors, which are explicit knowledge, implicit knowledge and proficiency. Especially the last two are very personality related.

Another way to look at information focuses on the quality rating of information and distinguishes four different categories whereby the value of information increases with the transition from one to the next (SCHWANKL, 2002, p. 78). This is shown on the right part of ➲ Figure C 1-1.

Based on the correlation of raw data, parameters and values of variables there are created different models within the product development process. Based on the behavior of those models during testing or simulation, and the gained insights by systematic verification, new knowledge can be generated. This in turn may support in the assessment of certain issues at hand and finally in making well-founded decisions. At this point it becomes obvious that the collection and particularly the selection of appropriate parameters for the build-up of the models in the early stages of the development process has a direct impact on the quality and accuracy of later decisions.

Before concentrating on the qualitative aspect of information and knowledge it is useful to first think about the properties of information which are described in more detail in the following chapter.

C 1.2 Properties of information

Similar to material, there are also some fundamental properties, which characterize information and simultaneously determine some advantages and shortcomings accompanied by information handling. This includes the following aspects (INTERNET 4, 2004):

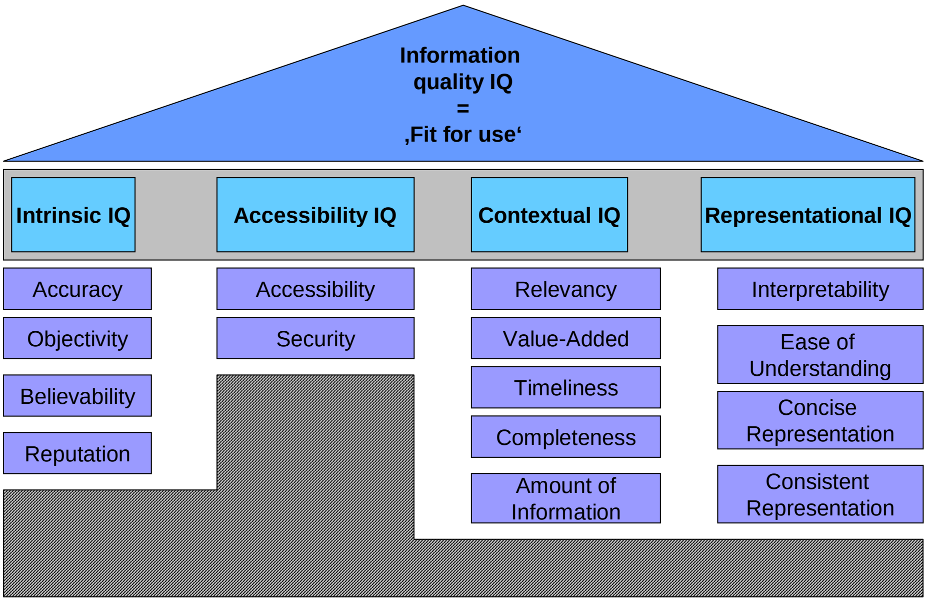
- Information is an *intangible* good that is not used up with repeated utilization
- Information is *valuable for the user* if he can realize it in his actions
- Information is *no free good*, thus information can be associated with a particular but often hard estimable price
- The value of information is dependent on the *particular context and the time it is used*
- The value of information can be changed by adding, selecting, concretizing and omitting; thus information is *open-ended and condensable*
- There are different *attributes of information quality (IQ)* such as accuracy, completeness, timeliness and reliability
- Information can be *transported with speed of light* even if the underlying objects (specified elements) cannot be transported with the same speed
- *Buyer of information* only get copies of the ordinary information, thus the enforcement of exclusive rights and in particular of property rights turns out as very difficult
- Information is *transferred encoded* which requires common standards for the exchange
- *Copying* of information is easy and cheap
- *Obsolescence* of information which is not caused by usage but by its timeliness at most
- *Ambiguous ownership* of information due to multiple possessors
- Almost arbitrary *divisibility* of information
- *Identification of owner* often is difficult; problems with protection of data privacy and data security
- Easy *logistics* of information, primarily electronic
- *User-defined possible combinations*; accumulation improves information value and quality

C 1.3 Information quality

Improvement in the manufacturing area is tightly linked with defining and measuring direct or indirect quality attributes regarding to product and process. New quality management is based on an explicit supplier-customer oriented view and considers ‘fitness for use’ on both macro and micro level as the key criteria for quality.

This definition can also be applied to the area of information. Consequently, high-quality information then gets defined by the information consumer and involves two important aspects, which are the *usefulness* and *usability* of information. But how to understand and use both terms?

Strong et al. (1997, pp. 38 – 46) have created a taxonomy that provides more grip in this issue. It embraces four main categories of information quality (IQ) with altogether 15 further aspects or rather dimensions underlying these categories, as shown in ➲ Figure C 1-2. Beside classic attributes like completeness or accuracy, this collection also includes the important aspect of information accessibility, which often is a major problem within nowadays, information systems. Even though there exist much more specific quality attributes as partially seen in literature, the present collection represents the most concise and workable of those.



Terms taken from Strong et al., 1997, p. 39

Figure C 1-2: Information quality attributes

As various the IQ attributes are, as various may be the influencing factors of information quality. This particularly becomes clear if one is analyzing information processing on the *micro* and *macro level* (➲ C 2.1 and C 2.2) within a product development process, that is to say engineering and accordingly departmental level with all its different aspects and elements. On the one side, all of those are necessary to build up such a process, on the other side they bear some risk for insufficient information quality occurring. Two general areas, where deficiencies in information quality may arise, concern the information production process itself and its technical side regarding problems with storing and accessing of information.

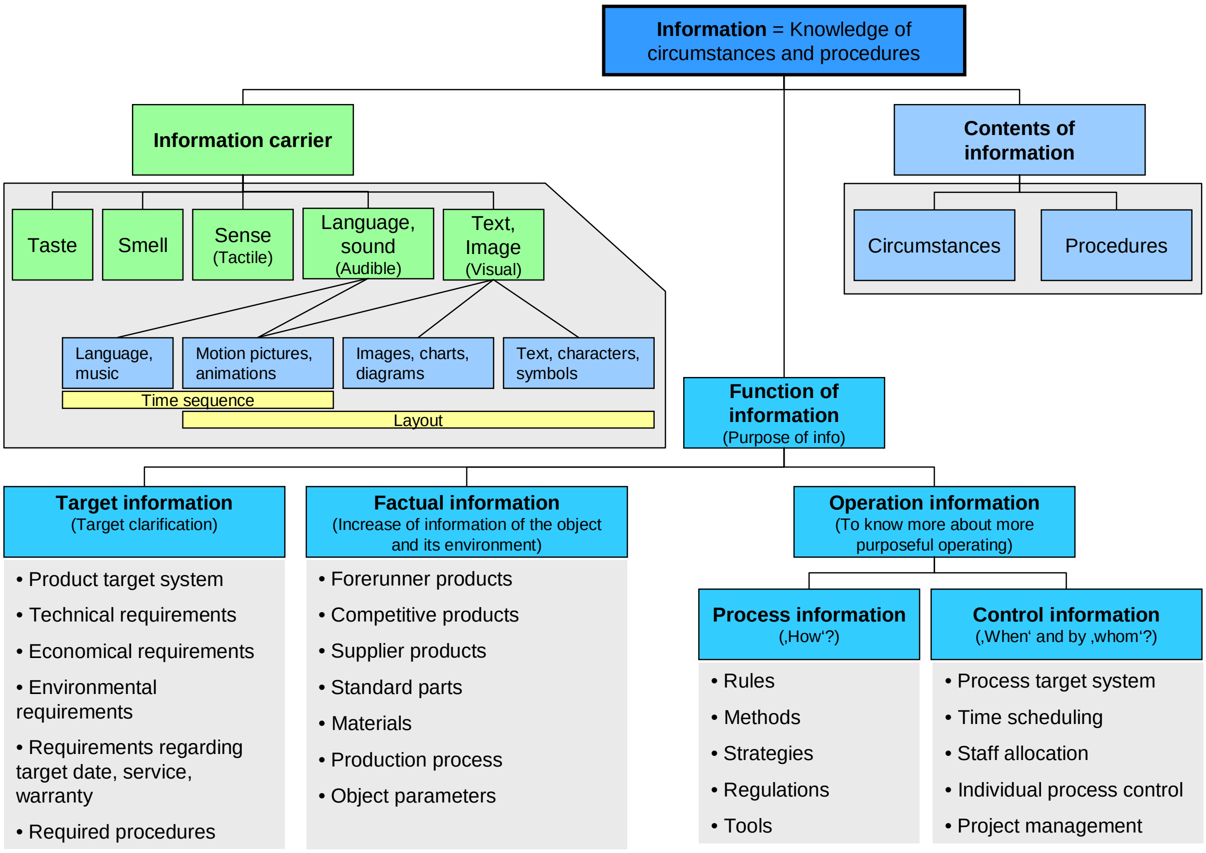
Maintaining information quality throughout the product development, facing high levels of uncertainty and risk (➲ Figure B 3-1), proves to be one of the biggest challenges since deficiencies and carelessness in information quality let emerge defects easily. However, compared with manufacturing, where even little quality deficiencies of a part/ assembly often result in scrap or expensive rework, little deficiencies in information quality can often be put right very fast, and sometimes even be compensated by the knowledge and experience of the information consumer.

C 1.4 Information functions, categories and carriers

Information functions and categories

Regarding to its contents, DIN 44300 defines information as the *knowledge of circumstances and procedures* (➲ Figure C 1-3). Its value for the recipient always depends on the particular purpose within a certain context.

Another aspect of DIN 44300 refers to the purpose of information or rather its function, and distinguishes between the three major categories *target information*, *factual information* and *operation information* with its both sub-categories of process and control information. This is depicted in ➲ Figure C 1-3 which at the same time specifies, what kind of information, or rather what contents may be allocated to each of those categories. For instance, information that refers to the 'how' of purposeful operating provided by rules, methods and strategies, constitutes *process information*, a sub-category of operation information, as it is fundamental for processing tasks. All other categories and examples cited can be understood in the same way. Below each category's term, the reader will find a short description that in brief explains the purpose of the respective category.



DIN 44300: Modified from www.-rpk.mach.uni-karlsruhe.de/vorlesungen/IDPK-Vorlesung/IDPK-Kapitel_2.pdf (30.3.2004)

Figure C 1-3: Functions of information in accordance with DIN 44300 (INTERNET 7, 2004)

There also exist some other approaches to structure information such as the simple distinction between 'control data' and 'user data' (INTERNET 5, 2004). Two of those, which especially refer to the area of product development and which offer more differentiation, are briefly explained in the following, as they constitute a reasonable approach and basis for the development of the targeted display.

The first approach suggests three categories by which information in product development can be organized. These are the result of an investigation undertaken by SIEMENS, and directly taken and translated from INTERNET 6 (2004).

- Task related information

  Task related information refers to the respective product component or process planning activity. As a rule, it is generated by a single person or a team assigned to the particular task. The result of it is available to all members of the process.

- Control information

  Control information is information such as project target dates, actual status information of the development process, accrued costs as well as achieved results in product development and process planning. It arises parallel with the task related information of the product development process, and serves for activity control. Management information, which must be made available to all process members due to a peripheral project management.

- Context knowledge

  Context knowledge represents a *particular type of information*. Examples include objectives and backgrounds of decisions or stipulations regarding the development process, assessments of technologies regarding product or process, applied know how, informal knowledge about organization and communication structures, etc. That kind of information normally is personal and thus is only available to a person subgroup based on informal communication relations.

Compared with other definitions and classification systems, it also includes the aspect of *informal information and knowledge* based on informal communication relations within companies. This already allows a first clue of the ‘social’ side of development processes, which can be strongly determined by micro policies and personal relations. The success of the planned display will finally depend to a large extent on the readiness of people to make those informal information transparent and to give up power based on it so far.

The second model emanates from SLACK (1998, pp. 30-35) and operates with the classic criteria of product, process, project and business.

- Product information

  Information that is directly related to the ultimate product after the successful completion of the product development process. This category includes the transformation of customer requirements to parts requirements, and the transformation of parts’ requirements to design parameters, which are finally required to create the physical product and manage the technical effort, associated with the product.

- Process information

  Information about how the product development process is to be executed and directions on how employees can accomplish their job functions. As proposed it includes a set of procedures, which satisfy ISO 9000 requirements for work processes to be documented.

- Project information

  Information that is directly related to the management of the project or program. Project information includes project related resource planning information, cost management information and schedule management information as well.

- Business information

  Information related to the business processes of marketing, sales and finance. It includes general ledger, accounts receivable, accounts payable, revenue accounts, inventory, purchasing, order and sales.

Compared with the other both systems, the advantage of the last mentioned model can mainly be seen in the clear and meaningful terms of the proposed categories.

Information carrier

Another interesting aspect of information, also shown in the above figure (➲ Figure A 3-2), concerns the question about what kind of carriers information uses, or in other words, in what ways information can be represented. In fact, this is strongly related to the human five senses of which the audible and especially the visual perception prevails. According to this, language and sound or rather text and images are the most dominant forms. In practice, both are often connected with each other, which also implies the combination of the two underlying principles of time sequence and layout respectively (INTERNET 8, 2004). As shown above, the 'visual' or rather the 'audible' category of information carriers includes a number of examples. Differences among them primarily consist in the fact how much information they are able to contain and how easy it is to understand it.

With respect to the used information system, an additional criteria to categorize information carriers might be the distinction between analog and digital data, and in particular referring to text and images the distinction whether data are available in paper or electronic form. For instance, inconsistent information policies or rules badly complied with by the employees are one of the causes of waste happening within companies irrespective of the specific functional department.

C 2 Product Development: The information creation factory

After analyzing the basics of information, this chapter describes how this all links to product development.

Product development or rather product creation is one of three major overlapping business processes beside order fulfillment and customer satisfaction (Suggested by CHRIS THEODORE, Vice President Advanced Product Creation of the Ford Motor Company, in a presentation at MIT in March 2004). It is dominated by Engineering and Design, and connected and supported by a number of other disciplines like Manufacturing, Purchasing, Marketing and Sales, etc. The tasks in product development mainly refer to problem solving, engineering changes and design.

Similar to manufacturing, product development is a concatenation of different processes and sub-processes with the 'only' difference that those exhibit much higher levels of complexity based on the nature of product development (➲ B 3). The improvement of processes' performance must always start with an analysis and understanding of the actual state and present problems in order to reveal the 'weak' links and bottlenecks in the process chain. Two very helpful views in this concern include the consideration of both the performance of single tasks or rather elementary process units performed by single persons or teams, and the built-up of super ordinate processes and how those are linked and coordinated.

The following two sub-chapters refer to those two mentioned views applied to the area of product development, and provide the reader with a better understanding about the huge number of various influencing factors. Their respective performance and consistency in and with the whole development environment is of significant importance for the overall performance and thus quality of the information creation process.

C 2.1 Information creation: micro level

Information creation on the micro level primarily focuses on the specific engineering work of a single engineer, or a team in the special case. Consequently, a product development process can be represented by a whole network of those elementary units.

The engineer's work

Based on incoming data and information, the engineer's task consists in creating specific output data that aligns with his/her organizational function and the defined and committed targets concerning results, quality, costs, and schedule. As shown in ➲ Figure C 2-1, the engineer's work includes different primary information processing activities as the provision, the actual processing, transport and exchange, and finally the storage of information. The way he/she is able to perform the task assigned essentially depends on his/her individual capacity to act, that is to say, the ability to process information and to use tools and methods adequately. This may also refer to the handling and management of restricting boundary conditions and other disturbance factors like unexpected changes in customer requirements or resources.

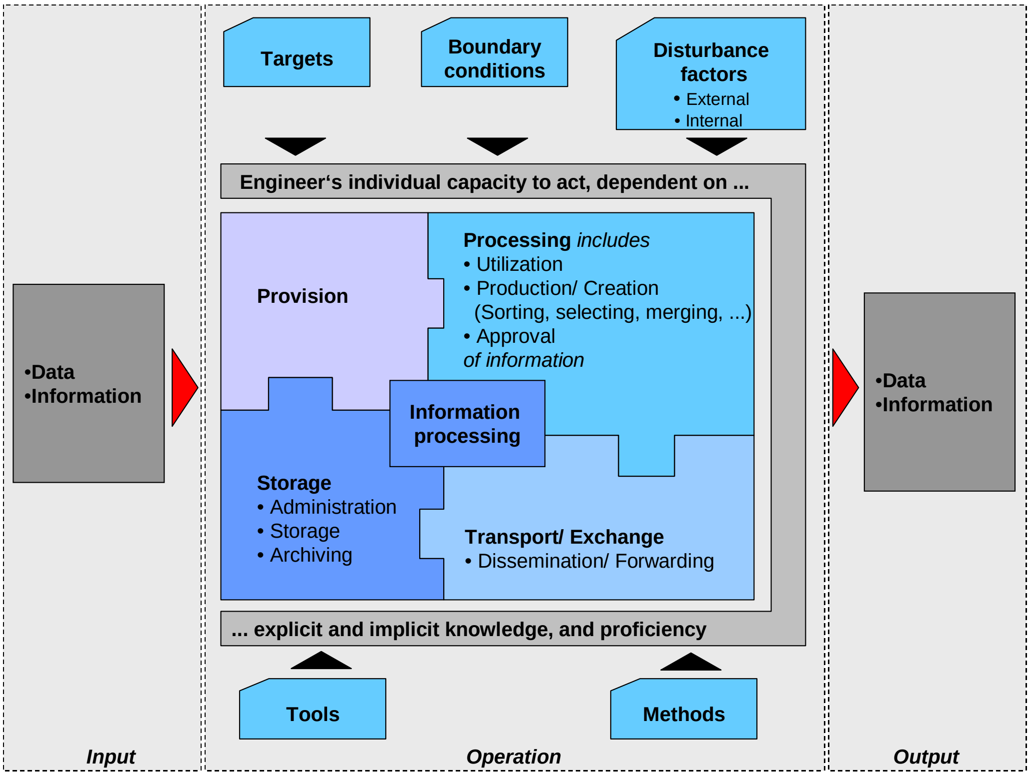


Figure C 2-1: Information creation on the micro level: Elementary unit of info creation

It becomes clear that a single engineer's competency and training is fundamental for the quality of such an elementary process unit or rather its output. Even quality deficiencies and lacks concerning incoming information and data may then be compensated by the engineer.

It's not all about competency

However, sometimes there also exist some boundary conditions and constraints, which affect the quality of an engineer's work. For instance, an engineer's proficiency in a software tool will not make a positive contribution to the output, if the tool is not available in the company or if it cannot be run reliably due to less powerful computing resources. Another example refers to the application of methods especially those, which have to be performed within a multidisciplinary team. As long as some team members are not conscious about the usefulness of methodical approaches and refuse to participate in, a great deal of people's potential and creativity and thus improvement may be lost.

C 2.2 Information creation: macro level

When the author uses the term 'macro level', he emphasizes that information creation also must be seen in respect to the whole process and the challenge to connect and synchronize all of its parts in an efficient way. The degree of how well that works is a measure for the information creation on the macro level and thus for process performance.

Process performance

Achieving high performance within the information creation process not only depends on the performance of the single elementary process units (➲ C 2.1). Just as important is how efficient those units constituted by the basic process elements tasks, people, tools and data models are connected with each other and sequenced in order to build up super ordinate processes and process chains (➲ Figure C 2-2). This already begins with the design of the development process during the planning phase, and continues during execution and integrated control.

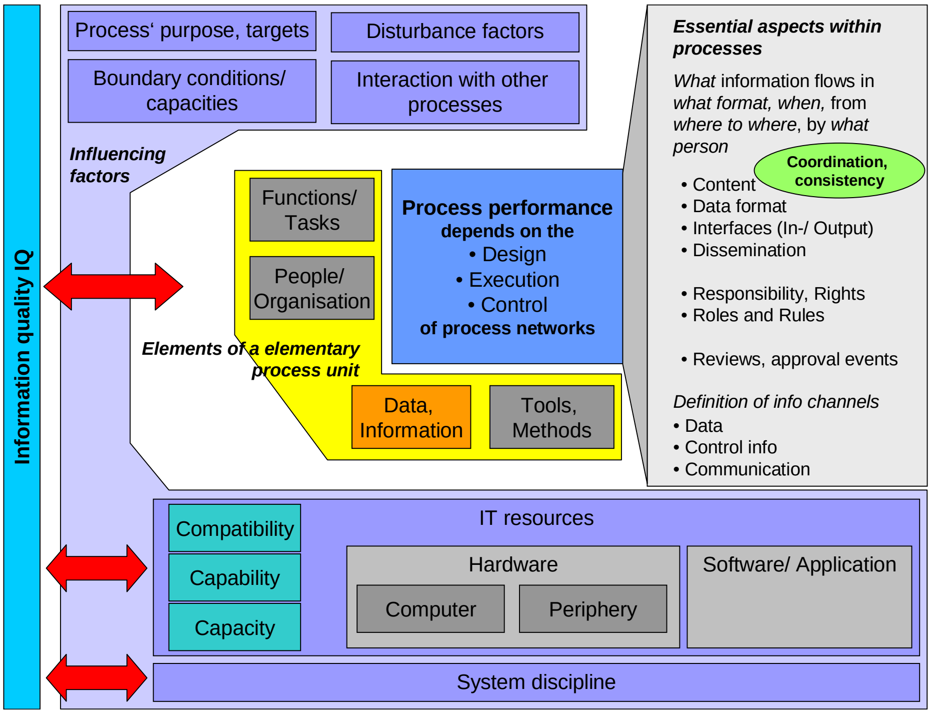


Figure C 2-2: Influencing factors within the information creation process on the macro level

Influencing factors

Keeping the process transparent and synchronized however turns out as one of the biggest challenges in practice. The reason for this is a number of different influencing factors that open a highly dynamic environment. This for instance concerns high dynamic in targets (moving targets), boundary conditions and available resources but also high levels of external and internal disturbance factors. Thus, maintaining the system's performance requires high levels of continual adjustment. The high connectivity with other processes often exacerbates this situation additionally.

Since data and information represent one of the four basic elements processes consist of, and nowadays data landscape exclusively is depicted in electronic information systems, the importance of powerful IT resources increases rapidly. Powerful primarily means high levels of compatibility, capability and capacity of hardware and software/ applications as well. Deficiencies in this area can drastically slow down the whole process during execution or can even affect the process design in a significant and negative way from the beginning.

A last factor that should be considered in the context of information creation concerns system discipline. If the commitment of the employees towards the designed process in terms of targets, contents, roles and rules, schedules, and software systems used is low, the performance of the whole process will deteriorate drastically.

Information quality

On this point it becomes clear that a successful information creation process and thus a smooth information flow within product development depends on a big number of different factors. Information quality, which describes the usefulness and usability of information created within the process strongly interacts with the quality of those factors.

Different levels within the information creation process

When looking at the above figures (➲ Figure C 2-1 and Figure C 2-2) the reader should keep in mind that the product development process is not limited to only one process level in the hierarchical structure of a company i.e. the engineering level. Also product development related tasks and issues may involve multiple levels of management for process control and the coordination with other projects. Decisions that not only refer to one specific product but the whole product program connected with cost changes, often need a broader basis of covering.

Open questions

During studying this area it turned out that there are a lot of different terms describing the same or a similar aspect of information. This is especially true for terms like information types, categories, representations, etc. For a systematic development of the display, it might be beneficial to sort these things out. Further, as the reader may have recognized, the matter of information is closely associated with the area of communication. Thus, looking for further improvement also suggests to do some more research in this direction. Unfortunately, this is beyond the scope of the current work.

D Waste in Product Development

Chapter D is the core chapter of the present thesis and tries to make a contribution in the investigation of waste occurring in product development.

In first chapter (➲ D 1), the author will introduce new definitions of terms within the waste context. In particular, these bear on *waste types* and *waste drivers* or rather the questions *what can be wasted* and *what are the underlying causes*.

Even though there have already been some approaches concerning waste within product development by different people, which especially refer to the re-interpretation of the lean seven waste types (➲ Seven types of production waste) to the area of product development, the author starts his analysis with a collection of problems occurring within product development in order to get a more independent view and better overview in this issue (➲ D 2).

Based on different approaches and re-interpretations of the lean seven waste types made by different experts inclusive of the author's one, a set of waste drivers including 10 main categories with totally 37 sub-categories is provided in chapter ➲ D 3.

Since the established set of waste drivers represents a large network of problems with a huge number of interrelations, a systematic approach in form of a cause-effect analysis is performed to prioritize and sequence those waste drivers for the waste elimination process (➲ D 4). Based on the result, a checklist for waste elimination is derived (➲ Table 2).

D 1 What is waste *and* what is wasted?

Starting with the investigation of waste within product development very quickly lead to one of the core questions in this context: *what is waste?*

In manufacturing for instance, Toyota has established a set of seven types of waste such as waiting, overproduction, defects, etc. (➲ Seven types of production waste) which helps the workers and operators to recognize waste or rather to reduce it as far as possible. From the author's point of view however, this collection does not provide an explicit answer to the question *what waste is* and *what it finally is that gets wasted*. Rather it gives a clue about *why waste is happening*. Because of that, those waste types suggested should rather be considered as the reason for waste.

Studying the approaches of other authors dealing with the issue of waste within product development, also shows that there seems to be not too much awareness about those mentioned distinctions and the need for clear definitions of terms used. This however is necessary for further research.

During his investigations the author established some helpful work hypotheses for the work in this area. This concerns the definitions of the two terms *waste types* (primary and secondary) and *waste drivers* (➲ Figure D 1-1):

What can be wasted: waste types

Mapping the ideas of different researchers, in particular MORGAN'S types of waste, sensitizes for thinking in cause-effect chains or rather networks. Beyond that, it makes aware of the final impacts of those waste types which are additional engineering effort, expense and time spent on the rework of certain tasks due to quality problems (➲ I 2). Dependent on the particular extent, this might significantly impact the effectiveness and efficiency of product development, and thus the project targets concerning quality, time and costs. The performance of all three factors in turn determines companies' flexibility within projects but also in terms of projects associated with new identified market opportunities.

Regarding to the question what things could be wasted, totally six different factors were found. Those may also be seen as some kind of factors for production within product development (➲ Figure D 1-1).

- Resources

  Negligence in task performance but also poor compliance with established standards by single people often causes rework. This may begin with tasks that can be reworked in a few minutes like correcting and resending emails, and end up with repeating a whole sub-process which not only consumes capacity of a single engineer but of a whole team or group. Since engineering work, especially in design, is closely related with software applications, this also means the waste of machine resources which another person might have be able to use in this time but now has to wait for. In worst case, this may delay other projects.

- Time

  This aspect is tightly related to the precedent factor. Various team meetings like quality or steering circuits often are an integrated part of a person's assigned task. Poor communication discipline, bad preparation and purposeless procedure make meetings unproductive and require additional ones. This obviously wastes people's time. Another aspect for instance refers to the fact that people must frequently wait for software applications loaded.

- Information/ Knowledge

  Processing and creating new information and knowledge is the core task in product development. Lost knowledge, deficiencies in information quality and poor information sharing due to less powerful information and knowledge management systems just mean waste. Levels of information or of knowledge once gained during development should not be lost again. This is very critical with a high number of handoffs.

- Opportunity/ Potential

  The oversight of people, tool and technology potential, which could be used to better achieve the specific project targets with less effort and resources, constitutes another example for waste.

- Money/ Invest

  Finally, the entire project effort in respect to spent resources and materials is assessed in money. This however is natural and does not necessarily mean that money is wasted. In contrast, money used for testing equipment with low utilization rates, unnecessary software tools, and prototypes based on vague and unreliable preliminary studies and results that finally could have been avoided by thorough analysis work, however describes waste in this point.

- Motivation

  Motivated people do not only feel responsible for their assigned tasks but also the output of the whole process. Furthermore, processes driven by motivated people exhibit much higher levels of dynamic and performance than any theoretical approach for project management could provide since control loops are done automatically and independently, and not made dependent on predetermined checkpoints. Consequently, decreasing people's motivation or even loosing them must be considered as wasteful for the company.

Since those factors are closely connected with the project targets quality, time, costs and flexibility, a further distinction between primary and secondary waste types is useful. Both build up the top of the waste pyramid (➲ Figure D 1-1).

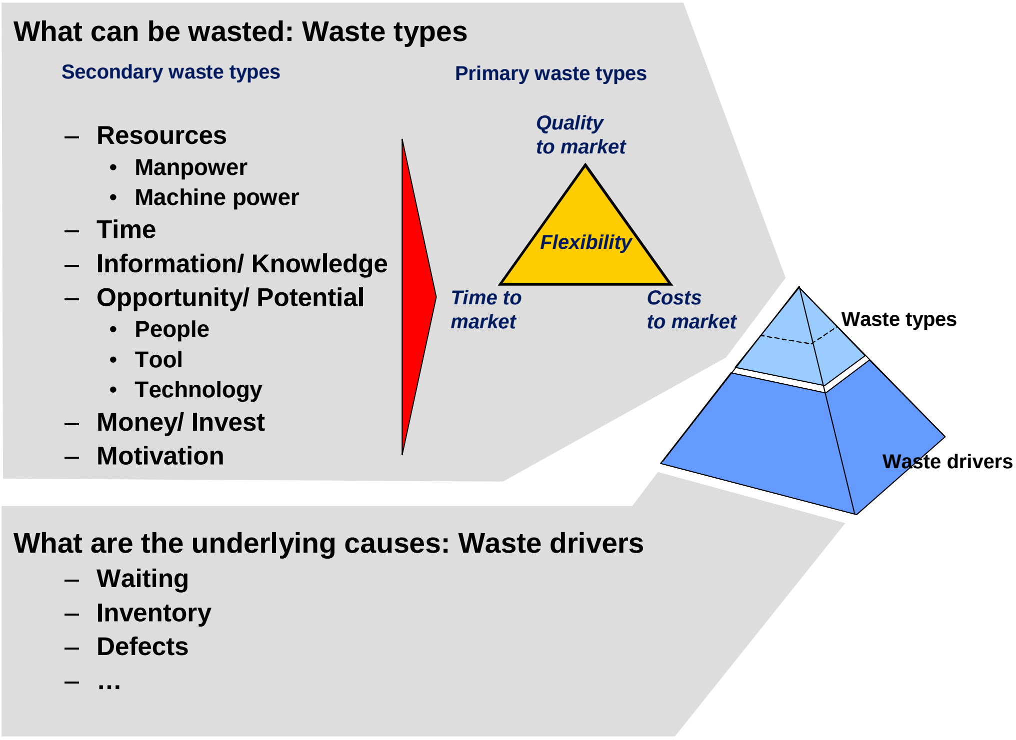


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Figure D 1-1: Waste pyramid

Why are things wasted: waste drivers

The bottom of the above waste pyramid composes the waste drivers, which are the reasons for why things are wasted, or rather why there are problems with the achievement of the project targets. In manufacturing for example, this is exactly expressed by the ➲ Seven types of production waste, suggested by Toyota. Which of those aspects may also be applied to the field of product development and what aspects have to be added, is the matter of the next section ➲ D 3.

Following the idea of root-cause analyses with the target to provide a long-term solution by rectifying the root-causes, the term waste should rather be used in connection with the waste drivers. In fact, the wasteful thing when performing a rework loop due to certain deficiencies is not to see in the rework activity itself since that finally contributes to reduce risk and uncertainty and thus to create value. Rather one has to look at the factors and thus the root-causes, which made the rework steps necessary.

Analysis (➲ D 2) reveals that there might be a huge network of problems or rather waste drivers. It is supposed that within this network there were a certain number of ‘big fishes’ i.e. main junctions or main root-causes whose elimination would lead to substantial improvements for development processes.

D 2 Getting started: Problems in Product Development

Thinking about waste, whether in terms of manufacturing or other organizational functions, suggests that the nature of waste has to do with deviations from the ideal possible, or even with discrepancies between actual and planned. And simultaneously this of course asks the question for the reasons of those happening.

In practice, a lot of companies struggle with various problems within development processes which finally result in gaps between expectations and actual results (WENZEL & BAUCH, 1996, p. 118). These gaps also mean a discrepancy between planned and actual status. There seems to be some closer connection between problems and waste.

To get a better idea of those problems, the author collected and structured a large number of problems by means of a 'modified' fishbone diagram (➲ Figure D 2-1).

D 2.1 Background to fishbone diagrams

Fishbone diagrams, also called cause-effect diagrams, are a common method applied in the context of quality management issues with the target to systematically analyze the causes of a problem. Primarily, they get used for quantitative, that is to say measurable problem fields (ZÄH ET AL., 2002, Ü3-22).

The method is typically performed within a team. At the beginning the moderator presents to the team a first and rough structured draft of a flow diagram characterized by the pattern of a fishbone structure. The head of the diagram then specifies the current problem to be solved, like too long lead times, the 'main bones' represent clusters of causes. In manufacturing, those are often denoted by the terms human, machine, method and material. Thereafter, the team members start with the collection of relevant problem causes, which are filled in the diagram by the moderator according to the identified clusters.

The great benefit can be seen in the preliminary structuring of and, as a consequence thereof, the much higher transparency in a certain problem field. Thus, it is a first and essential step for the actual problem analysis. Since it is mostly performed within a team, this method also provides the team members with a 'common reference' when talking about certain aspects. The aforementioned clusters' nominators like human, machine, methods etc. suggest a standard approach to quickly identify relevant root causes. In special cases, of course, these nominators have to be adjusted to the particular problem.

According to ZÄH ET AL. (2002, Ü3-22), the shortcoming of this method consists in the fact that the different identified problem causes, displayed in the diagram, have to be discussed once more in terms of the following problem solution or rather the search for solutions. From the author's point of view, another disadvantage is that even if this method is an excellent way to visualize problems and root causes, it gives the team members less information about problem interrelations.

D 2.2 Procedure

Targeted Results

In the current case, the target associated with the application of this method is to identify problem areas or rather specific problems that decrease the effectiveness and efficiency of development processes. The expected problem structure is supposed to provide more transparency in this issue and a better way to grasp them. Based on that a root-cause analysis may be performed to find major problem sources within product development.

Sources for problem collection

The number of problems found is very large, the sources primarily were literature (WENZEL & BAUCH, 1996; MCMANUS, 2004; MORGAN, 2002 and SLACK, 1998), conversations with different people (especially with Victor Tang, Ph.D. student of the Engineering Systems Division at MIT) but also the author's own experience in car industry.

Problem clustering

To conceive and to structure all these problems in a reasonable way requires not only to focus on single aspects but all system elements, product development consists of. During studying literature, the author came across two helpful approaches in this issue. For analyzing sociotechnical systems like product development is, the first, used by MORGAN (2002, p. 17) for his own work, suggests to split up the system in a *technical subsystem* with the elements process, tools and technology, and in a *social subsystem* concerning people, culture and organization. While 'the objective of the technical subsystem is to produce the core output' of an enterprise, 'the purpose of the social subsystem is to coordinate the activities among people and to assure the long-term survival of the enterprise' (MORGAN, 2002, p. 17). The second one, used by WENZEL & BAUCH (1996, pp. 118-119) is similar to the first one, but then adds a further view when they especially refer to phases of the product lifecycle.

D 2.3 Results

The fishbone diagram worked out for collecting and clustering problems within product development, exhibits three major areas, each with different problem clusters (➲ Figure D 2-1):

- *Social subsystem*: Leadership, strategy/ objectives, organization, people, communication, organizational learning/ culture
- *Technical subsystem*: Tools and methods, Information handling/ processing, technology, complexity
- *Product life cycle*: Product planning/ strategy, product definition, development process, production/ sales/ distribution, environment/ market, supplier management

Even though the present analysis work is coined by the two mentioned approaches, the author also noticed some gaps and thus added a few more classifiers like communication, information handling/ processing, product planning/ strategy and supplier management.

In general, all displayed classifiers (name of the clusters) can be understood as essential factors that have to work well for successful product development. With exception of the cluster 'environment/ market', all can fairly be controlled and mastered by the company and its employees. Deficiencies in one of them will lower the performance of the whole product development system. Associated possible reasons or rather causes frequently occurring in practice are listed below each classifier.

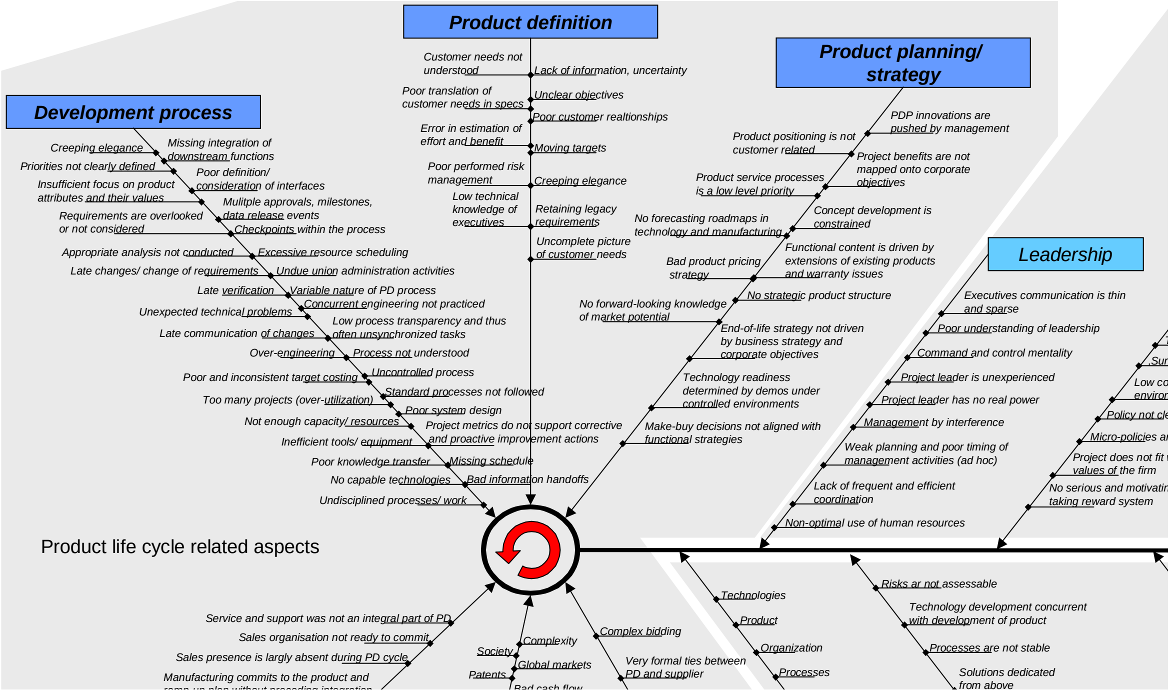


Figure D 2-1: Problems within product development

A complete view of the above chart can be found in appendix ➲ I 1.

D 2.4 Root-cause analysis

Cause-effect networks

Collecting and clustering the causes for a problem, which in particular means low performance within product development, is the first step for improvement. Solving problems in a long-term view however suggests to go to the root causes (➲ 5 Whys) in order to eliminate the sources of problem. In fact, a lot of problems often are the result of deeper underlying problems and thus just the symptoms of those. Hence, eliminating the 'big fishes' first will consequently reduce other ones.

Looking for the 'big fishes' based on the above problem collection turns out as quite a problem. Of course, single problems like 'Late communication of changes' are considered as stronger and 'earlier' in the root-cause chain than 'Storing of useless data'. The attempt however to identify the root causes by just thinking about or even by the use of simple cause-effect chains seems not to be successful due to the high number of problems and interrelations among those. In fact, there rather are complex cause-effect networks than simple cause-effect chains easy to isolate.

➲ Figure D 2-2 exemplarily shows three different grades of cause-effect relations. In reality of course, the transition between them is fluid. The current problem with root-cause analysis faced by the author is illustrated by the cause-effect network depicted in the third example. Compared with the first and second, the difference not only consists in a much higher connectivity among the 'factors' but also in different directions of the cause-effect arrows what generally decreases transparency in the whole system and simultaneously increases the probability of backflows and thus closed loops. The marked elements represent some special cases. Element 1 can be considered as a source since it has a lot of 'outgoing' arrows towards other elements. In contrast, element 2 has more the qualities of a sink due to a lot of 'incoming' arrows. As a result, improvement efforts should concentrate on the elimination of element 1 first.

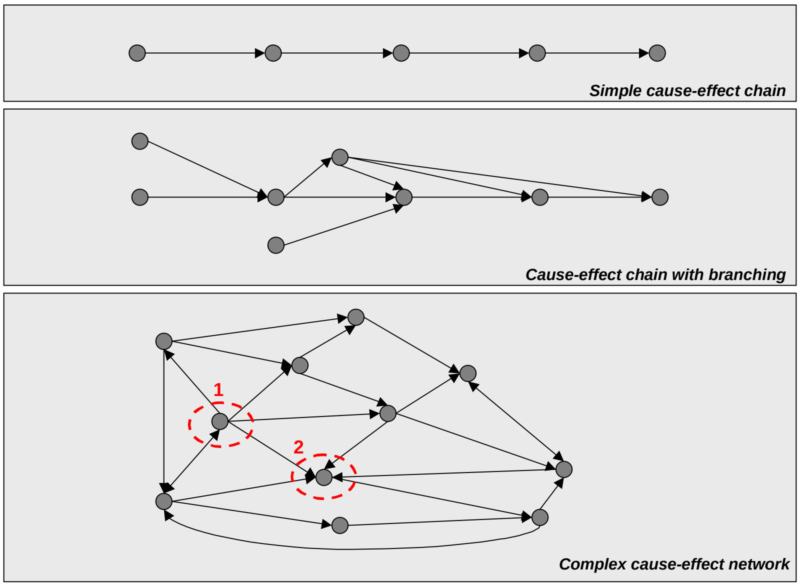


Figure D 2-2: Grades of cause effect relations

Cause-effect analysis

A systematic approach to analyze the relations and interdependencies among a big number of factors is the cause-effect analysis method. Based on a matrix, the relation of each element with each other is assessed step by step. Following the specific procedure leads to a classification of all elements in active, critical, passive and neutral elements, and a recommendation for prioritization of those elements.

In view of the huge number of factors (295), performing that analysis would mean the assessment of about 87,025 relations. Apart from the fact that this goes beyond the scope of the thesis, the problem also consists in the calibration of the cause-effect matrix. In order to obtain a consistent matrix and thus a reliable result, two basic rules have to be followed:

First, the method sometimes requires to go back to previous fields and to adjust the assessments. This not only means additional effort but also demands thinking in a network and to remember previous assessments. This may already be difficult with a limited number of problems but highly difficult on a basis of 295 factors.

Second, the assessment has to be performed within a short period of time and by the same team to ensure a quite consistent assessment from the ‘same’ view. Especially the former might be very critical.

D 2.5 Evaluation

The chosen approach to first collect and structure problems occurring within development processes irrespective of the lean background provided some significant benefits accompanied by a few shortcomings.

Benefits

- The established classifiers provide a good basis and view to understand and to analyze sociotechnical systems
- Differentiated view of problems: Regarding problems as internal or external disturbance factors; in addition there may be seen a difference between product related i.e. pure technical problems like engineering problem solving tasks, and non-technical problems like employee’s attitude and commitment towards their jobs.

- Comprehensive collection of possible problems within product development shows up a lot of potential improvement since problems always are ‘the levers for corrective actions’ (WENZEL & BAUCH, 1996, p. 118).
- Sensitization for and more transparency about the complexity of product development
- Fishbone diagram can be used as kind of a checklist within root-cause analyses associated with specific problems
- Useful tool to analyze the waste theories of other authors regarding existing gaps and aspects within their approaches; thus better re-interpretations on the part of the author
- *Understanding that actual waste must have something to do with root-causes of problems*

Shortcomings

There were also some shortcomings associated with this approach:

- Results cannot be directly used for further investigation in the waste issue
- Large number of problems identified impedes ergonomic handling and the performance of a cause-effect analysis
- No weighting of the single problems

Based on the insights in possible problems within product development gained by this first approach, the author can now focus on the investigation of the transferability of the lean seven types of manufacturing waste to the cubicle and the derivation of a set of waste drivers.

D 3 Derivation of a set of waste drivers

D 3.1 Review of existing approaches

Starting point and problem

The transferability of lean manufacturing principles and tools explained by WOMACK & JONES in their book *Lean thinking* in 1996, to the area of product development has kept busy a lot of scholars and people form industry during the last ten years. Of course, this also includes the aspect of eliminating waste. Accordingly, there have been a number of approaches in terms of re-interpretations of the ➲ Seven types of production waste to the cubicle.

Studying the different authors proves that even specialists in this area do not have the same conceptions, and focus on diverse aspects. Consequently, the re-interpretations of the lean seven wastes for product development processes have led to more or less consistent sets of or rather theories of waste. This approach underlies the fact that in product development the actual product is not physical material like in manufacturing but information. Taking into account the nature and the differences of both, some of the manufacturing waste drivers can be transferred more directly than others do. Beyond that, the pure ‘transfer’ of the lean seven waste drivers seems not to offer a sufficiently complete picture of waste drivers within product development.

Thinking about the different aspects however emphasizes the need for a comprehensive set of waste drivers, which includes all those interesting and relevant aspects in a consistent way.

Derived target

Based on the different approaches found in literature, the next target is to work out a quite comprehensive, consistent and workable set of waste drivers relevant to product development, which addresses about 80 percents of the most important problems, and thus provides a reliable basis for the subsequent waste elimination.

It is intended to provide the reader with an effective tool for his own investigations and improvement effort in the area of product development. In addition, the targeted result should offer a good basis and some kind of common reference for further work and communication in this matter.

Used sources and methodical approach

The first step on the way to create the targeted set of waste drivers consisted in visualizing and sorting through the diverse theories, aspects and terms of different authors. In particular, this included the following sources as shown in the following ➲ Figure D 3-1: Morgan (2002), Mc Manus (2004), Poppendieck & Coldewey (2003), UGS PLM (2004), Ward (2000), Colfax (2001), Slack (1998), Millard (2001) and Chris Theodore, Vice President Advanced Product Creation of the Ford Motor Company, in a presentation at MIT (March 2004).

The boxes along the four sides of the chart list the main categories and terms used by the different authors within their approaches, and simultaneously make obvious which ones rather correspond to the waste categories established by manufacturing. In contrast thereto, the boxes in the middle represent clusters for all the different aspects, and can be regarded as a first draft of the targeted set of waste drivers. Some of the clusters can further be combined since they are closely related as regards contents. This for example applies to transaction waste, extra features and processes, and over processing.

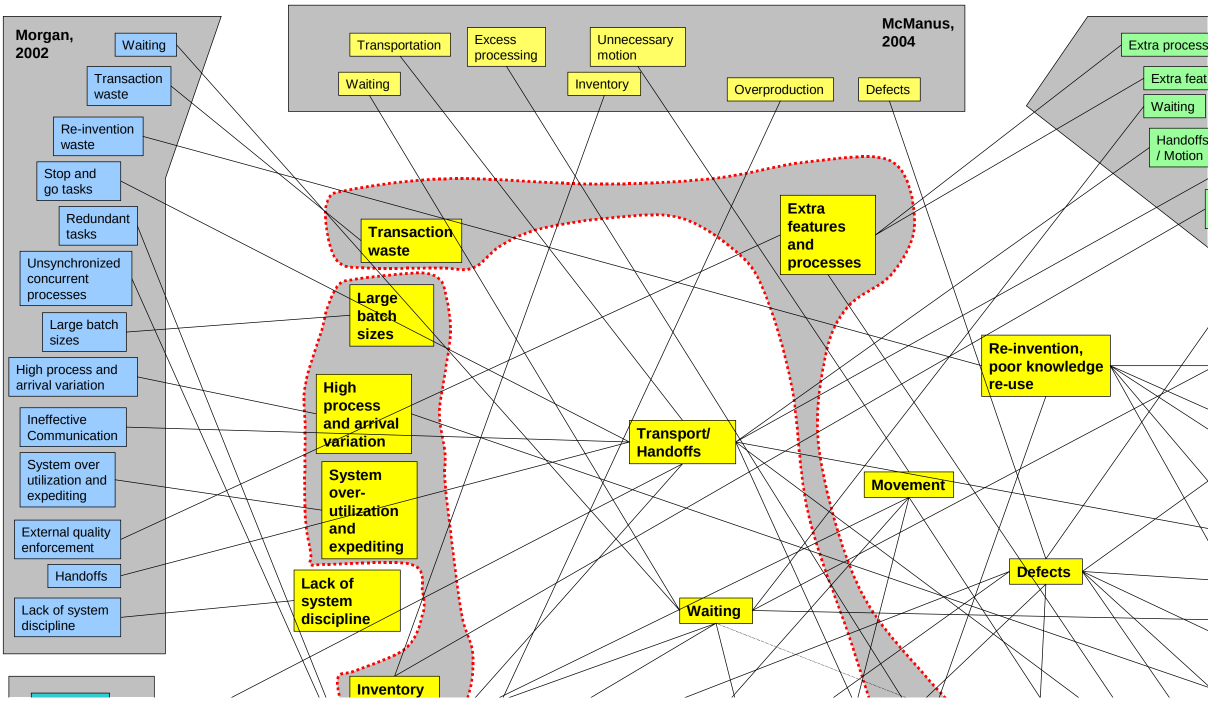


Figure D 3-1: Clustering waste categories of different authors

For a big size chart please see appendix ➲ I 3.

Different views complete the picture

Even if each of the found and displayed approaches adds some more or less new aspects compared with the other ones, for the author's work the following sources turned out as most helpful:

- MORGAN (2002)

  MORGAN'S collection of waste types within product development bases on a case study that contrasts product development processes of companies in North America with those performed by the Toyota company. Thus his work is very practical oriented and enriched with 'Toyota thinking' at the same time. MORGAN concentrates on 'process waste' and suggests a good number of new and useful aspects that were not covered by other approaches and re-interpretations of the lean seven types of waste.

- MCMANUS (2004)

  MCMANUS'S re-interpretation of the lean seven types of waste focus on the actual product of product development, which is information, and provides a very concentrated approach in this important aspect. His work includes a comprehensive list of appropriate information waste examples and also suggests a number of possible causes for each example.

- SLACK (1998)

  SLACK'S re-interpretation of the lean seven types of waste deals with common problems and waste aspects within product development and herein provides a number of details and good examples that were not covered by MORGAN or MCMANUS. In addition to the original seven types of waste, he adds two further categories in respect to the peculiarities of product development: *time lag* (➲ B 3) and *complexity*.

Taking the ideas of those three sources together compensates lacks of each one and provides a sound foundation for the development of a comprehensive set of waste drivers. Other sources cited can complete the picture by single aspects.

Advantages of this procedure

- Overview of and transparency in people's approaches as a basis for further research
- Studying the re-interpretations not only questions in what way the ideas of manufacturing can be transferred to product development, but also in what way the aspects of other sources can be combined with that model. This in turn implies automatically the creation of a more comprehensive and consistent 'waste system'

Shortcomings of this procedure

- Allocation of the different aspects to the clusters sometimes is not that clear and needs some background knowledge to understand better which is not displayed on the chart
- Chart gives overview but has not enough grip for its practical use

Resume for further procedure

The waste model pioneered by Toyota for manufacturing primarily focus on aspects associated with flow operations. Even if the product within product development is not physical material but information, the smooth and continuous flow of the 'product' has the same importance. In fact, the re-interpretations performed by some authors have lead to some very interesting and reasonable analogies towards product development. For this reason, the manufacturing waste model can be considered and used as framework for further work. Other relevant aspects that were not addressed by the seven categories so far have to be supplemented by new categories.

D 3.2 10 Categories of waste drivers

Based on the work of the aforementioned sources, and the waste categories or rather waste drivers identified in manufacturing, and own re-interpretations, a new set of waste drivers relevant to product development was worked out (➲ Figure D 3-2).

The inner belt of the chart once more refers to the questions what actually can be wasted within product development, which was the matter of the last chapter (➲ D 1). The outer belt contains the main categories of waste drivers found during research. Beside the classic seven from the area of manufacturing, three further categories were added to completely describe all relevant aspects found. In particular, those are *Reinvention*, *Lack of system discipline* and *Limited IT resources*.

Looking at those 10 main categories of waste drivers, however, only gives an idea of what aspects they do contain, but nothing concrete. Thus, to provide the waste system with more grip and to make it more manageable practical use, totally 37 sub-categories were added which incorporate the most important aspects of the main categories.

Some of the terms used to name the sub-categories are directly taken from examples found in the different sources like *Ineffective Communication* and *Poor testing and verification*.

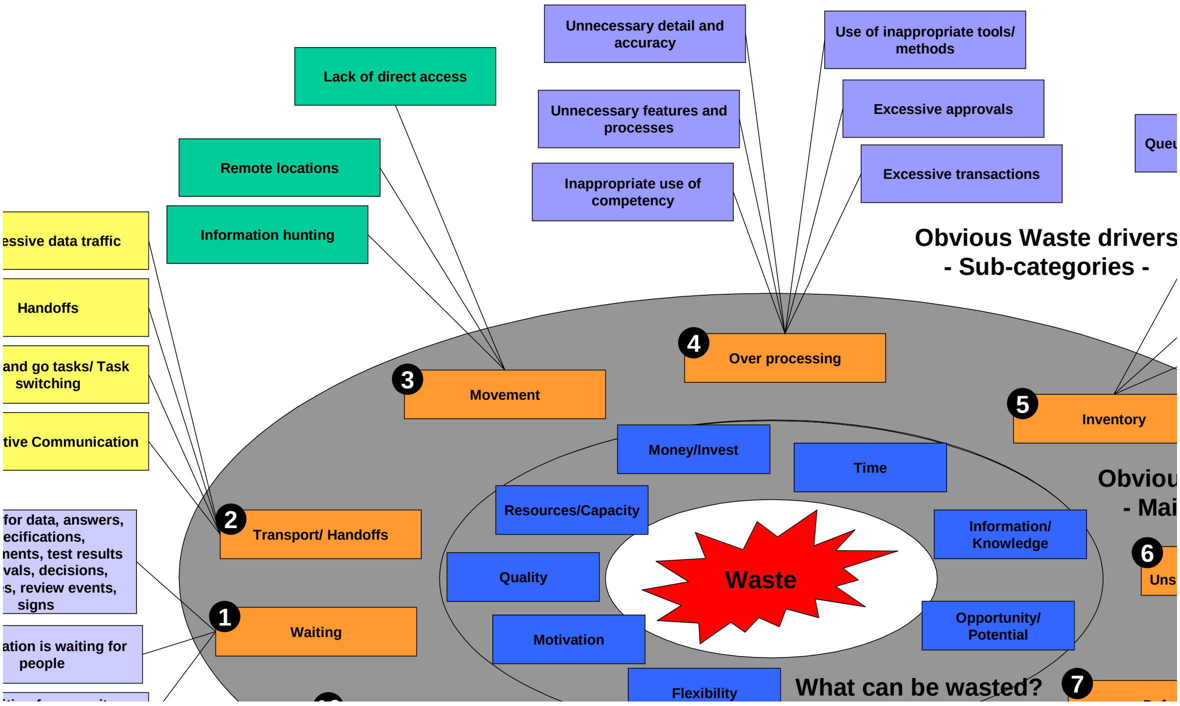


Figure D 3-2: Waste drivers: Main categories and sub-categories

A big size chart of the above figure is provided in ➲ appendix I 4, a compressed description of the displayed waste drivers and their sub-categories for practical use can be found in ➲ appendix I 5.

The following chapters explain the single categories of waste drivers including their sub-categories in detail. Each chapter consists of two parts. The first briefly discusses the according waste category in terms of manufacturing. The second part then describes aspects gained from the re-interpretation of that waste category to product development. This is supplemented by additional and important aspects, which were not covered by the re-interpretation but just belong to the category and must be taken into account.

D 3.2.1 Waiting

According to SLACK (1998, pp. 36-37) wait time waste is the 'difference between the total processing time and the time required for just the value creating activities'. Thus it addresses *that part of processing time when the creation of value remains static and, so to speak, the value stream is considered as 'non-flowing'*.

Production

In production terms it is a condition caused by a production operation that is waiting for maintenance, or for material and parts from previous operations, tooling, operator readiness, etcetera. Parts waiting in a queue (in batches) for further operation do also fit in this category of waste (LEAN AEROSPACE INITIATIVE, 2003, p. 76).

A very illustrative example for this kind of waste is the distinction between primary and secondary handling steps in assembling. Only the former do really add value to the product whereas the latter are supportive and necessary but not value adding. Hence, in order to improve the ratio between value-added and not value-added operations and thus the efficiency of processes, necessary but not value adding steps should be reduced as far as possible, and non value adding steps must be eliminated completely.

Product development

Going to the area of product development, waiting waste is considered as the *idle time due to unavailable information, manpower or computing resources* MCMANUS (2004, p. 50). For better understanding, the following scenarios are listed.

■ People waiting for data, answers, specifications, requirements, test results approvals, decisions, releases, review events, signs

Waiting for information in its multifarious forms doubtless is one of the most occurring, well-known and obvious type of waste engineers of product development are faced with.

The underlying reasons are manifold as well and, more often than not, indicate some major problems in the development project such as deficiencies in IT tools, or poor project planning and execution.

An excellent example in this context are bad planned and scheduled *milestone and data release events*. Stable data are often retained until the official release event instead of passing it on the downstream operations immediately and thus enabling them to start or to continue their work (MORGAN, 2002, p. 155).

Another example for this sub-category of waiting waste is the widespread problem of *multiple authorizing signatures*, for instance in terms of supplier's invoices to be paid or not (SLACK, 1998, pp. 36-37). The determination if that invoice should be paid or not has already been made by low level management adequately. Passing the matter through the multiple levels of management does not lead to any difference in the result, but rather consumes a lot of time and causes many interrupts and waiting time on the execution level (➲ Stop and go tasks/ Task switching). The *extensive approval of engineering change documents* is a similar but more critical example for this sub-category (SLACK, 1998, pp. 36-37).

As we go ahead with the discussion of the different waste types in this chapter, it soon becomes apparent that examples cannot only be allocated to one specific waste category. For instance the last two examples are also connected very closely with ➲ Transport/ Handoffs or ➲ Excessive approvals.

- Information is waiting for people

  Also this version of waiting waste is happening. The waste risk in this case is that too soon created information may be obsolete (➲ Defects) by the time it is really used and thus may end up in rework (MCMANUS, 2004, p.50).

  One of the major reasons for this waste occurring can directly be seen in the insufficient synchronization of processes (➲ Overproduction/ Unsynchronized processes). Beside the timely aspect, synchronization can also refer to the alignment as regards contents.

- People waiting for capacity available (human or machine)

  The workflow of people is interrupted because human or machine capacity is not available.

  An example is when person A needs to personally meet person B to discuss some urgent issues, but person B is not present or available due to busy schedules or even vacation. High task priority for person A does not necessarily mean high task priority for person B in the special case, and busy schedules of both often are the bottleneck in finding a common time slot for a meeting.

  In his last practical training in car industry, the author was confronted with exactly the same kind of problem. The project was about the development of a simple application to monitor and control the quality landscape that is to say the sum of all quality issues including warranty issues in the area of series engineering. The need for such a system arose, as the requirements of series engineers and their executive were not met in a proper way by any of the known software applications of the company.

  During the search for apt solutions, the author came upon a lot of questions regarding to the capability of the different and already existing systems for managing quality issues. The real problem then was to find people that not only had insights in the functionality of the software systems but also in how the systems work and how they are linked from the view of software engineering. After the author was successful in searching out such a person, it finally took three more weeks to get a 15 minutes phone interview with this person. However, the benefit of that talk was very high as it helped the author much in understanding the relevant parts of the software systems and thus to assess the feasibility of present solutions and ideas in a better way. On the other hand, getting that piece of information last three weeks of a total project runtime of 18 weeks, valuable time that was missed in the further procedure and only could be compensated with overhours. From the projects point of view that time delay was pure waste as the required information could have been obtained three weeks earlier with some more readiness to cooperate on the part of a few colleagues.

  Similarly, people may also *wait for machines* like CAD workstations or some experimental equipment for testing. Even excessive waiting for programs loaded on your personal computer belongs to that sub-category of waste.

  Poor scheduling, low speed of the information system and a lack of computing resources in general (➲ Limited IT resources), are one of the underlying causes of this sub-form of waste.

D 3.2.2 Transport/ Handoffs

Production

Transport waste in production is associated with the time the product is in transport between point A and point B. During this time no physical transformation of the product is taking place and consequently no value is added to the product either (SLACK, 1998, p. 37).

As transportation is one of the basic operations to enable flow it will not be possible to completely avoid this flow operation. Rather, it must be the goal to reduce the excessive movement of product parts, materials and tools between production operations, between facilities, or from and to storage to a minimum (LEAN AEROSPACE INITIATIVE, 2003, p. 76). Another dimension of transport waste in production may be considered as the 'number of times the product is picked up and put down' (SLACK, 1998, p. 37).

Product development

Generally speaking this type of waste addresses the inefficient transmittal of information (papers where files are needed) but also the unnecessary movement of information (data transfer), that is to say papers, faxes, emails, files and bits (LEAN AEROSPACE INITIATIVE, 2003, p. 76). Analogous to manufacturing the number of handoffs can be seen as a second measure for this category of waste within product development. The following sub-categories of the transport waste will provide some more details.

- Excessive data traffic

  Even though new IT technologies and tools helped a lot in reducing the time of data transferred, new problems were/are emerging. One of those definitely is the missing interoperability and incompatibility of the different software and hardware systems and tools (➲ Limited IT resources) as well (SLACK, 1998, p. 37), that cause a lot of additional effort in terms of converting, re-formatting or even re-entering data (➲ Use of inappropriate tools/ methods).

  As those activities are strongly connected with the transport operation, they may be considered as one of the main drivers of excessive transport actions. The excessive data traffic does not only mean the *transfer of converted or re-formatted data itself, but also the whole underlying communication effort getting these things done*. Another big driver of this issue are ➲ Overproduction/ Unsynchronized processes in general, which cause a great deal of *additional communication effort in form of emails, papers, files, etc.* among the process participants.

- Handoffs

  A handoff occurs when the *responsibility for a product or process gets transferred* from one person or group to another within or between functional departments. Even if some handoffs are necessary and beneficial (MORGAN, 2002, pp. 76, 154), most are not, since valuable knowledge and time is lost each time. Another effect is, that with an increasing number of handoffs, as a consequence of high specialization of tasks, it becomes more and more difficult to keep the accountability unequivocal.

  A similar problem occurs when a *separate group, which is responsible for the quality,* finally takes the ownership away from a person or group, and thus makes the responsibility ambiguous. To counter this problem, additional inspection events (➲ Excessive approvals) are built in the process, which in turn often result in additional waiting time (MORGAN, 2002, pp. 76, 154). Unclear roles and responsibilities will additionally aggravate this issue.

  Another case to be considered is the fact, that in practice information paths often are unclear and thus *information is handled by multiple people* before arriving at the right user. As a result, the number of handoffs before the value adding step can be seen as a measure of waste.

  The problem with *multiple authorizing signatures* explained in detail in the context of ➲ Waiting waste also fits to the transport waste category. Especially papers for sign-offs are moved and forwarded from one management level to the other, often without any change in the paper's results, let alone value added.

- Stop and go tasks/ Task switching

  The stop and go effect occurs each time an engineer has to *reorient himself to a certain task* and it is like a setup (MORGAN, 2002, p. 76). The more often tasks are interrupted and the more time passes until they are continued, the more and longer mental setup time it requires.

  Poor synchronization of tasks in the project (➲ Overproduction/ Unsynchronized processes), but also too many running projects can be regarded as the major underlying reasons. Even if it is proven that permanent task switching can quickly lead to a 50 % loss in productivity, people get still assigned to several projects concurrently (POPPENDIECK & COLDEWEY, 2003, p. 76).

- Ineffective Communication

  Communication is a key element in each project and its performance is strongly dependent on the single team members and exceptionally on their soft skills (➲ Lack of system discipline). Miscommunication, inaccurate communication owing to non-standard terminology and meanings used by different departments, but also a lack of communication such as ineffective feedbacks or inadequate discussions of project objectives within the team, are the major reasons for *misunderstandings* in projects noticed in practice (MORGAN, 2002, p. 156).

  The implications are obvious: Unproductive and hence many meetings. On the one hand this wastes the team members' time spent in the meetings, and on the other hand it may result in a lot of rework and scrap. Especially misunderstandings often lead to additional but unnecessary engineering changes (MORGAN, 2002, p. 156). This sub-category of waste is often associated with a ➲ Lack of system discipline, which primarily addresses the lack of clear roles and responsibilities, clear goals and objectives, and low accountability as well.

D 3.2.3 Movement

Production

Compared with transport waste this type of waste does not refer to the unnecessary movement of materials or tools between production operations but more the unnecessary movement of employees. More precisely it is understood as any human and non value-added actions or motions beyond the minimum required to accomplish a certain task (LEAN AEROSPACE INITIATIVE, 2003, p. 76). Examples are excessive reaching and bending, searching or excessive walking for tools, parts, materials and drawings as well as excessive force or energy needed for operations (LEAN AEROSPACE INITIATIVE, 2003, p. 79).

Product Development

Movement waste can primarily be considered as any *human movement necessitated by a lack of direct access*. According to MCMANUS (2004, p. 51) this also includes the user movement between tools or systems regarding the underlying information system. As its design constitutes the backbone system of development projects, it is easy to recognize that its quality and performance is the essential and determinative influencing factor in this issue. The concept of access may be considered in different ways as follows.

- Lack of direct access

  The nature of this sub-category is that *information needed is available but not directly accessible* from the workplace via one integrated information management system. As a result, people often have to walk to distant central information access points to gain or access that information they are looking for. A very well-established example for this is the retrieving of printed materials such as instruction manuals or regulations (McManus, 2004, p. 51).

The causes for it can basically be seen in a lack of direct access, i.e. distributed (paper) or online access (digital files) (McManus, 2004, p. 51). This example also includes the often-occurring case that accessing internet data only is possible from a few centralized terminals located in the library of a company, but not directly from the workplace.

A similar problem engineers are frequently facing in practice is the necessary switching of computers from CAD to PC or the other way round due to major incompatibility of the underlying operating systems (➲ Limited IT resources) (McManus, 2004, p. 51). Attempts to bridgeover that problem with adapted software solutions more often than not cost a big part of the computer performance. Another prevalent solution suggests the use of two computers for the two different systems (CAD and PC). Even if this solution has some excellent advantages such as the independent work with each, there still arises the question about the utilization rate of that equipment.

- Information hunting

  Another kind of access problems occurs when *information or data needed is theoretically available and accessible but people have to go searching for* physically in form of leaving their workplace and directly asking people, or by searching through the project directory structure on a server. The question of *how many 'stations' an engineer has to go through to get help for his problem or rather the information needed*, is also associated closely with this issue (Poppendieck & Coldewey, 2003, p. 76).

  The reasons often are unclear and thus poor performed rules in handling and naming files, and in the same way a lack of clear information paths, clear roles and responsibilities with the result, that information is often pushed to the wrong people and 'places'. A further factor driving this sub-category of waste is the lack of clear information creating processes to produce information needed (➲ Overproduction/ Unsynchronized processes) which again makes people search for exactly that piece of information missed.

- Remote locations

  The *local distance of departments and facilities* such as test stations more often than not has negative impacts on the project team or rather people's work. The first is the direct loss of time required to move to and from the remote location, the second is, that remoteness indirectly acts as kind of a barrier and entails people not to make that trip as they would do in the case if it was located very close to their workplace (Slack, 1998, p. 40). As a result, distributed teams have much more difficulties with the coordination and organization of their work and an efficient information flow due to much less spontaneous communication opportunities than co-located teams do. Beyond that, remoteness inhibits the formation of right teams.

  The reasons for this may be very different and range from physical restrictions of company buildings and obsolete organization structures to an inadequate thinking or consciousness in terms of creating a success enabling project environment.

D 3.2.4 Over processing

Production

Over processing waste means extra processing steps and will emerge, if oversized equipment, not properly maintained equipment or *equipment which is not designed for the task at hand*, is used and thereby requiring excess processing time and costs compared with the use of a proper tool for that job (LEAN AEROSPACE INITIATIVE, 2003, p. 76). In the same way, if a design has not applied the guidelines of design for manufacturing, additional steps and manufacturing run times, which are not the optimum for the required part feature, will be the result (SLACK, 1998, p. 39). Unnecessary *enhancements in product and precision beyond customer needs* also fit in this category as well as excessive testing (LEAN AEROSPACE INITIATIVE, 2003, p. 76).

Product Development

The preceding definition of over processing waste in production yields a good basis for further investigation of this waste category within product development. This includes unnecessary product features, unnecessary detail and accuracy of information, excessive transactions, inappropriate use of competency and the use of inappropriate tools to accomplish the results. Another point in this case is the conduction of excessive approvals, which often slow down the information flow and are one of the reasons for ➲ Stop and go tasks/ Task switching effects in product development.

■ Unnecessary features and processes

This sub-category refers to the macro level of over processing waste and just means that the *product provides more features that the customer needs*. If so, the effort for developing each single additional feature including all additional processes required is pure waste. An excellent example is nowadays software development, when especially the development of 'little' features only takes few more minutes to realize from the viewpoint of the software engineers. However, in the overall process with testing, debugging, service etcetera, these few minutes often result in few more days or weeks (POPPENDIECK & COLDEWEY, 2003, p. 76).

The reasons for this kind of waste occurring are various and may also be associated with upstream departments like marketing in the early stage of the product definition. One of the main reasons surely is the problem with unanalyzed or rather not understood product or process requirements. Even if there are big efforts in collecting and achieving data and performance requirements, more often than not data are gathered for its own sake, get more and more, and remain unanalyzed (MORGAN, 2002, p. 155). The whole effort expended was without success and the actual purpose of this action, which is the derivation of requirements based on customer needs analysis as a reliable base for efficient product development activities, is failed. A second reason relates to the tendency of carrying-over of requirements from the last product dealt with, even if they are not identified by marketing or excluded by previous lessons learned (SLACK, 1998, p. 39). A third factor connected with this issue often are individual interests of system participants and their missing commitment to the product's or company's benefit (MORGAN, 2002, p. 155).

■ Unnecessary detail and accuracy

Compared with the above mentioned, the waste sub-category at hand rather relates to over processing on the 'micro level' of requirements. Even if they are precisely and accurately defined by marketing, it often happens, that the *features get over-engineered and finally exhibit more technical finesse that was expected and necessary*. In most cases this is caused by the engineer's tendency to perfectionism and is aggravated by poor insights and feedback in business economics and life-cycle costs.

But the aspect of over-engineering and its causes cannot only be considered in terms of specifications and requirements, because these merely are the final outcome of the product development process beside different other data and instructions. Rather, it has to be discussed in the context of the whole information creating environment of product development. Even if the process per se is synchronized well as regards time and content (➲ Overproduction/ Unsynchronized processes), it occurs *that information* *exchanged has too much detail and accuracy* (MCMANUS, 2004, p.50), and in this case provides *more information than actually required*, especially in early design stages.

The partially *excessive and custom formatting of data or information* (MCMANUS, 2004, p. 50), sometimes just required to meet someone's 'standard' (SLACK, 2004, p. 37), is another case in this point, which frequently points to a lack of standardization such as templates for project reports or product documentation.

- Excessive approvals

The critical role of approvals has already been mentioned earlier in this chapter (➲ Waiting) and consists in the fact that *information such as engineering changes or other documents has to go through different levels of management before it can be released to the downstream process*. The duration of an approval, which is dependent on several factors such as the number of management level, the current availability of the managers but also the matter itself and its priority, is the most critical factor since it entails some interrupts and waiting time for the engineers on the execution level. A very popular example concerns the approval of engineering changes.

Even if the procedure with approvals is based on careful consideration, in order to ensure overall performance and consistence, the problems engineers frequently facing in practice simply are too long throughput times due to a big number of interrupts in the information flow and a great deal of ➲ Stop and go tasks/ Task switching effects. Dependent on the grade of interdependency, this may not only affect the work of a single engineer, but more the work of a whole team or even more.

Excessive approvals often bear on old and strongly hierarchical organization structures with no or poor cross-functional teams, a prevalent command and control mentality, and turf protection (MCMANUS, 2004, p. 50). The problem is further exacerbated by the failure of defining some significant business cases for approvals, that allow to treat the different issues more specifically and so to avoid applying the one defined and same procedure to all issues albeit if some steps are unnecessary.

- Excessive transactions

Excessive *spent time and effort on non-value added steps, which are necessary to get the primary tasks done*, characterize the sub-category at hand (MORGAN, 2002, p. 77). Activities like contract negotiations, quote meetings, complex supplier bidding and supplier selection systems, but also resource scheduling and union administration actions all belong to this category, fix a great deal of manpower, but do not contribute to customer value (MORGAN, 2002, p. 155).

- Inappropriate use of competency

A lot of engineers still *spend a lot of time with necessary but not value adding activities* such as creating presentations and project status reports, updating databases and schedules, or other union administration things. Engineers' core tasks however consist in problem solving, design creation and changes, etc., and that actually is what they get paid for. Any *effort spent on those activities means an inappropriate use of competency and thus waste of resources*. Of course, there are also some tasks like the creation of important presentations to upper management levels which mostly require engineers' full attention and so justify the effort. This however is more the exception than the rule.

The integration of qualified trainees and working students demonstrates a good and easy way to solve that kind of problem, finally with benefits on both sides: Engineers are relieved of 'time stealing' tasks and can concentrate on the big problems, students gain some new insights in business processes, train their skills and additionally get some money for that.

The reason for the issue at hand often is associated with people's poor insights in time management or insufficient support from management regarding the mentioned approach with employing students or assistants.

However, the inappropriate use of competency can also mean, that engineers may be not qualified or trained enough to do the task at hand. This in turn leads not only to longer process times but also often to inadequate and deficient results.

- Use of inappropriate tools/ methods

This sub-category of waste focuses on the use of inappropriate tools, which necessitate additional processing steps in order to accomplish the result and thereby cause longer processing times than would be required with a proper tool. As product development is all about the creation of product information and is spread over a whole network of different functions and people, it becomes obvious, that this kind of waste must be considered on two different levels: The first concerns the inappropriateness of one single tool, the second is, to what extent tools of upstream and downstream stations are capable of working together seamlessly. The better they do so, the less effort with converting, reformatting and, in the worst case, re-entering data will be necessary. Because of the strong dependency of these activities with the transport function, much less ➲ Transport/ Handoffs waste will be the result as well.

The reasons for this sub-category of waste happening are primarily based on the incompatibility and poor interoperability of software and hardware systems (➲ Limited IT resources), which often makes it difficult to create integrated solutions without any seams. Incompatible information types (drawings vs. digital descriptions) may exacerbate the situation additionally (McManus, 2004, p. 51). Another major problem consists in a lack of availability, knowledge or training in conversion and linking systems on the part of the employees(McManus, 2004, p. 51).

A frequent example from practice refers to *multiple conversions of model data for simulation purposes*, which partially consumes quite a lot of time, instead of using existing tools enabling an automatic conversion in a more accurate way and in much less time. According to Slack (1998, p. 40), such kind of situations may arise when different departments use different tools.

A second example is the *use of antiquated IT technology, especially of mainframe software systems* (Slack, 1998, p. 40), which can be very 'complex, slow, labor intensive and frustrating in handling', and beyond that necessitates exorbitant support activities compared to PC based software applications. The use of such old systems is often caused by the fact, that the data cannot be transferred from the old to a new system due to various incompatibilities (➲ Limited IT resources). The only way to do that would be the manual transfer, that is to say the re-entry of data by hand, which often is critical in economical terms. A widespread problem that just let it come to this in many cases is the poor farsightedness of executives in respect of the potential of IT technology.

Another example concerns *excessive keyboard or mouse operations* occurring, if the way of retrieving or creating information is complicated and far away from the optimal solution (McManus, 2004, p. 51). Possible causes are again a deficiency in training, poorly designed and incompatible user interfaces, and incompatible software suites, but also too huge amounts of information to sort through (McManus, 2004, p. 51).

Even if the sub-category at hand primarily focus the use of IT tools within product development processes, the *inappropriate use of methods* can also be mentioned in this context. This often is driven by a poor knowledge or experience with the application of methods on the parts of engineers, and is exacerbated by prejudices versus new or not before used approaches.

D 3.2.5 Inventory

Production

Inventory waste in production refers to the fact that raw materials, semi-finished parts or finished parts are kept in excessive stocks irrespective of the current production situation and customer demand, or rather in queues (work in progress or WIP) as buffers between un-synchronized production operations (LEAN AEROSPACE INITIATIVE, 2003, p. 76). The problem with inventories is that they do not add value, but in the same time fix capital and so consume valuable resources, which could be used better for other value creating actions (SLACK, 1998, p. 38). The most obvious reason for this waste occurring is overproduction explained more detailed in the next paragraph (➲ Overproduction/ Unsynchronized processes). However, going further left in the root cause analysis will lead to one big issue, which is the bad synchronization of processes under aspect of amount and time regarding to production. In other words, a great deal of inventory and overproduction is happening, because a great deal of work is not pulled by downstream process steps in the value stream. Obsolete and out-of-production parts and materials as a result of frequent design changes or of an undisciplined configuration management also belong to this category (LEAN AEROSPACE INITIATIVE, 2003, p. 76).

Product Development

The above definition of inventory waste in manufacturing provides a useful clue where to start looking for inventory waste in product development, even if some of the aspects have to be rethought carefully and re-defined in terms of product development. The reasons therefore basically are the difference in the variability and repetitiveness of both processes.

For example, the different nature of manufacturing and product development has a direct impact on the concepts of stocks and queues and how they must be considered in each environment. While in manufacturing stocks and queues rather refer to the excessive and unnecessary availability/ number of materials and parts waiting for processing embedded in a highly repetitive context, in product development they more describe huge amounts of heterogeneous information stored on computer drives and file folders, and which are waiting for further processing by a functional department or rather for release to downstream processes by gates.

While queues in manufacturing are always to eliminate, queues in product development may be even useful to load resources efficiently (REINERTSEN, 1997, p. 49). Following this argumentation, work in progress (WIP) does not necessarily lead to waste.

Another aspect concerns stocks or rather data storage in product development. Even if the storage of information per se is not expensive, its inefficient administration is a much bigger issue in this concern, which can cause a great deal of other waste types like ➲ Information hunting. This problem is not only dependent on the underlying information system, but also on the people's commitment to practice it (➲ Lack of system discipline).

A last point this waste category addresses is testing equipment and prototypes, which often fix a lot of resources and are under utilized or rather unnecessary since they do not provide really new information to the development process.

- Unnecessary testing equipment and prototypes

  This point just refers to the fact, that a lot of R&D (Research and Development) experiments and product testing is conducted on in-house test stands, which are very expensive and fix a lot of capital, what especially is true when they are designed and fabricated in-house (SLACK, 1998, p. 40). And even this would be acceptable, if there would not exist another matter of fact, which is, that these test stands often have very low utilization rates. In many cases it would be better to use outside test laboratories with similar facilities for carrying out the required tests or rather whose core competence it is to design and built experimental equipment (SLACK, 1998, p. 40) (➲ Inappropriate use of competency).

Another issue can be associated with the *administration of testing equipment* and addresses the recycling aspect regarding to testing devices etcetera. If a new test stand is designed and a great deal of the required parts and materials should actually be available from previous tests, but could not be found due to a lack in the administration of testing equipment, then waste is obvious.

As important as testing and verifying is during the development, it is as important to exactly *specify and plan the experiment and what should be achieved*. Aside from deficiencies in that concern, a lot of experiments conducted are characterized by *testing to specification and not testing to failure, which is more valuable* (MILLARD, 2001, p. 28). This fact not only bears on single test parts but also to total prototypes in the different stages of development (➲ Poor testing and verification).

- Excessive data storage

This sub-category of waste is just based on the fact that in the information system used, whether it is an electronic or not, more information is being kept than needed. In this point, more information primarily means more in terms of redundancy and different representations about the same, what again is a very critical issue regarding the quality of information. Otherwise it fixes a lot of computer memory or rather storage space.

Multiple and redundant sources of information are counted among the most known examples from practice (MCMANUS, 2004, p. 50), and often indicating a lack of integrated information systems (➲ Limited IT resources). And even if they exist but do not meet the requirements of the users, the chance to benefit from that approach is questionable. As a result, people will continue in using the old non-integrated applications and databases with the higher risk of inconsistencies in data. Finally, they will have two systems they work with and spend effort on. The maintenance of private databases is one good example therefore. Furthermore, in addition to electronic files, paper files of the same information are often kept updated in several places as well (LEAN AEROSPACE INITIATIVE, 2003, p. 81).

In some cases where it is not required to have such an integrated solution like a product from SAP because of the smaller size of the company, it is at least necessary to establish a set of adequate standards and practices concerning the administration of data and information. That this is a widespread problem too, is proved by the *existence of numerous and fragmented reports, which could actually be merged and so,* help people to keep a better overview of their documents (MCMANUS, 2004, p. 50).

A similar point in this issue are *outdated and obsolete data and files* respectively, which are not used anymore but still kept on servers (MCMANUS, 2004, p. 50). They do not only consume a lot of memory but also make it difficult for people to find the files they are looking for (➲ Information hunting). This is also true for *designs, which has never been used, completed or delivered* (UGS PLM, 2004, p. 4). As mentioned above, this is largely caused by the lack of a disciplined system (➲ Lack of system discipline) for updating new and purging old files, and thus the tendency to retain raw data long after it has been summarized and incorporated into higher level information (MCMANUS, 2004, p. 50).

A last example in this sub-category is the frequently occurring problem with *'just-in-case' data and information* (MCMANUS, 2004, p. 50). Whether or not a specific end-user has been identified, every piece of information that the system designer can think of is collected, processed and stored. On the one hand side this may be considered as some kind of over-engineering, on the other hand side it often depend on the general uncertainty with development processes but also a missing understanding of the essential things in development. Bad experience with executives focusing on negligible issues may exacerbate this situation.

One of the main drivers that applies to all aspects of this sub-category simply is the fact that there has been a tremendous increase in computing systems over the last 15 years and thus a tremendous increase in electronic file traffic, size, and storage as well, which consumes a lot of memory space but also network capacity (SLACK, 1998, p. 38). Otherwise there has only been little effort in managing and conserving these kinds of resources due to an insufficient awareness of this kind of waste on the part of the employees.

- Critical path related queues

As mentioned earlier queues i.e. 'work in progress' does not necessarily result in waste. Whether they do or not strongly depends on their relationship to the critical path of the development project. If such a *queue is on the critical path, it will delay the project and instantly increase the cycle time, and dependent on the extent of that delay, the costs might be enormous* (REINERTSEN, 1997, p. 49).

As mentioned, there even might be some positive aspects with queues such as the efficient load of resources. Furthermore, they turned out as a helpful tool to monitor a process and can be considered as kind of a health barometer, since they provide instant information about the status in product development from the view of unfinished tasks compared with other monitoring tools (REINERTSEN, 1997, p. 64).

However, more often than not the negative effects of queues like the big interrupts in the information flow and thus a great deal of ➲ Stop and go tasks/ Task switching effects outweigh.

A very well-known example from practice for queues occurring are functional organizations, where incoming information and contracts are piling up and the different projects are competing for priority in tasks accomplished (SLACK, 1998, p. 38).

To better understand the behavior and the critical role of queues and to make the next step in the root cause analysis, it is very useful to look at the *three influencing variables of queues which are capacity utilization, variability and batch sizes* (REINERTSEN, 1997, p. 51). The following section gives a review of different problems involved with these factors and in what way they affect the process.

- High system variability

Compared with manufacturing, product development processes are highly variable by nature what makes it very difficult to manage queues, not to mention to eliminate them. According to REINERTSEN (1997, p. 51) this variability depends on the *arrival rate of the tasks* but also on their *duration*, which is again effected by *differences in the contents* and *differences in the productivity of the operators*.

The essential point in this issue is, that *greater variability will always result in greater levels of WIP or rather queues*, even in steady state, and *thus greater cycle times* (MORGAN, 2002, p. 156). But also the point in time when the variation is occurring plays a major role. In particular it could be established that high variability early in the process would have a greater impact on cycle times and WIP than it would later in the process (MORGAN, 2002, p. 156).

- Exceeding capacity utilization

The *capacity utilization, also called system loading, is the quotient of demand and capacity* (REINERTSEN, 1997, p. 51). As opposed to manufacturing where it would never be considered loading the system over 85 or 90 percents, in product development capacity utilization rates over 100 percents are not rare, even if this area is quite less deterministic than manufacturing. However, the price of multiple projects is high, and highly increased queuing times and accordingly cycle times will be the result (MORGAN, 2002, p. 156).

A good illustration of the dependency between the capacity utilization and the relative time in a queue is provided by the following figure (Reinertsen, 1997, p 47). The underlying assumption is a M/M/1/∞ queuing system, which according to the nomenclature works with Markovian arrivals, Markovian task durations, a single server, and the potential for infinite queue length. The curve shows that the queue time will be relatively low as long as the capacity utilization does not exceed about 60 percents of utilization. But once it does, the queue time in system increases in a highly non-linear fashion. More precisely, it doubles with a decreasing increment i.e. when going from 60 to 80, from 80 to 90, and from 90 to 95 percents utilization (Reinertsen, 1997, p 47).

The insights provided by this curve or the queuing theory in general are in stark contrast to most people's deterministic view of the world and how things are happening. In this way, most people would not expect any system overload or delays as long as there still is excess capacity or no full utilization. However, reality is different, it is not deterministic but more stochastic. The queuing theory, which is based on the latter, teaches that there will be some delays in the system despite of excess capacity (Reinertsen, 1997, p. 47).

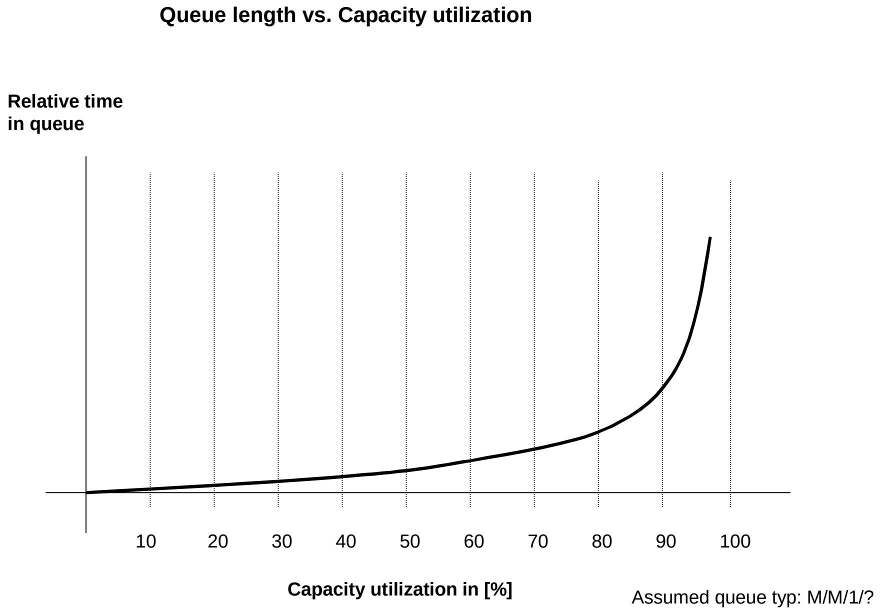


Figure D 3-3: Queue length vs. capacity utilization

A further critical and often underestimated point in this issue, suggested by Morgan (1998, p. 156), concerns the *expediting of single projects of a product development program due to time delays*. In most cases the resulting costs of that proceeding are much higher than expected since the whole product development system was destabilized and has to be re-coordinated to a certain extent. Corresponding to Morgan's remarks, the cost drivers basically are the 'hidden effects such as premium paid for not only the expedited job but for all those jobs it has displaced in the system'. Very close connected to this issue again is the ➲ Stop and go tasks/ Task switching effect with its negative impacts.

- Large batch sizes

  The third influencing factor of a queue is the batch size, which describes the amount of information that is passed on from an up to a downstream process. According to queuing theory, larger batches will lead to longer queues and thus will increase the cycle times.

  In practice, this often occurs when functional organizations are completing all their work and then hand on the whole ‘package’ to the downstream function. If the capacity of that function is very limited in addition, the built-up of large queues is obvious and inevitable (MORGAN, 2002, p. 156).

  The reasons for large batch sizes can be directly associated with the organization of development projects and in particular with the creation of and work to milestones, data release events or check points within the process (MORGAN, 2002, p. 156). These ‘gates’ act as kind of a barrage and result in a big conglomeration of development information, which is retained from downstream processes until all requirements and sub-targets linked with the respective gate are accomplished.

  As long as gates and milestones are very useful tools to manage projects, especially in terms of risk management, the total elimination of queues from this point of view is questionable but also unrealistic at the same time. However, the benefits of small batch sizes persist and must be targeted further on. A major role will also be played by an adequate synchronization of up and downstream processes, which often constitutes a bigger problem in practice (➲ Overproduction/ Unsynchronized processes).

D 3.2.6 Overproduction/ Unsynchronized processes

Production

Producing more than is required or producing before it is required, are the two basic characteristics of overproduction waste in manufacturing (LEAN AEROSPACE INITIATIVE, 2003, p. 76).

As established in the section before (➲ Inventory), the reason for this can be seen in a poor synchronization of up and downstream processes regarding to the factors amount, time and capacity, that is to say a great deal of work performed is pushed by upstream processes irrespective of what the needs of the downstream processes or the next stakeholders in the value stream especially are (SLACK, 1998, p. 39).

Since the logical result of this issue will always be increased inventories, its close relation to inventory waste is evident.

Product Development

Overproduction in product development occurs as well as it does in manufacturing. The symptoms are similar and can be attributed to the same root cause established before, which is a lack of synchronization of up and downstream processes. This refers to the stage of planning and the project execution as well. However, due to the different nature of product development like its high uncertainty, the central role of information and its low repetitiveness, some of the aspects associated with synchronization have to be re-thought such as the application of the pull concept. In contrast, other aspects have to be added. An example is the *excessive distribution of information*, which is more important for information creating processes like product development but less important for manufacturing (MCMANUS, 2004, p. 50).

Since the extent of overproduction is a direct result of the quality of the process synchronization, it is more reasonable to further concentrate on different aspects associated with synchronization. Hereby, the concept of *synchronization includes not only the* *synchronization of processes/tasks in terms of time, but also the synchronization as regards contents, quantity and capacity*. Synchronization regarding to these aspects is the core concept of concurrent engineering.

- Poor synchronization as regards contents

  As mentioned above, the application of the 'real' pull concept to the area of product development is critical since product development's purpose is to develop a new product and some kind of 'recipe' for manufacturing the product, but not to manufacture the exemplar again and again. The conventional pull principle however is exactly based on determined procedures, on repeating it a lot of times and pull exactly and only these parts or information from the upstream process which is necessary to accomplish the process at hand. In contrast, there is no totally predetermined way of developing the product. Downstream functions cannot really pull the information from upstream functions as they do not know the final output of the work they are supposed to do, not to mention the final product with all its specifications.

  However, there is also some predetermination of and in developing processes since the overall process but also the work of functional organizations for instance follow certain logical orders and is not performed in an arbitrary manner. Furthermore, there is the experience from the last project and especially from other simultaneously ongoing development projects that gives the engineers of functional departments a good idea of required input information and deliverable output information of their job.

  These facts actually provide a good basis for introducing some kind of pull concept also to the area of product development. However in practice, this potential is rarely used since the participants of up and downstream processes do not talk about each other's process and its requirements. Thereby they miss the chance of leaving their prevailing thinking in functional terms for the benefit of a more holistic view of the process with a much greater potential of straight-lining their sub-processes, producing exactly the information needed and so maximize the processes efficiency.

  But as mentioned before, practice still looks different and so *upstream processes are still pushing data and information irrespective of what the downstream processes special needs are*. Creating too much and unnecessary information in order to meet all possible requirements of downstream functions right at the first time, even if it exceeds the minimal possible effort by far, or forwarding incomplete information with the result of rework required and enormous time delay, will both surpass the minimal possible effort achievable with better synchronization of the processes as regards to contents. The resultant waste is obvious and much of the value of concurrent engineering is lost.

  The whole problem is mainly caused by a lack of process view as a consequence thereof strongly hierarchical organization structures and missing cross-functional teams. This can be aggravated by a low readiness to cooperate on the part of the process participants.

- Poor synchronization as regards time and capacity

  A further aspect of poor synchronization regards to the alignment of contents with time and capacity available.

  It is not unusual that *tasks or processes are processed more serial than parallel* (McManus, 2004, p. 50) even if there exists no obvious reason for doing so such as special dependencies between tasks of capacity limits. But this evidently is unnecessary and finally results in a considerable loss in cycle time. A poor understanding of concurrent engineering's capabilities by the engineers often is the underlying reason for it (McManus, 2004, p. 50).

  But even if functional department's processes are aligned well with the tasks of prior processes, what in turn automatically leads to a higher grade of concurrency regarding tasks performed, a *great part of the value of concurrent processing will be endangered if* *those tasks are not embedded in a reasonable and practicable frame as regards time and capacity available*. The result then are ‘unrealistic’ and inefficient processes where some tasks are done prior to maturity but others cannot be finished in time. Either way is critical, since producing information before needed always bears a high risk of rework, and otherwise slipped dates always require additional coordination effort and often result in destabilized processes and project time delays.

Insufficient transparency of functional organization’s capacities and unrealistic planning by project managers count among the root causes of this problem. The situation is exacerbated by low commitment to hold schedules on the part of the process participants (➲ Lack of system discipline).

- Over-dissemination of information

The *widespread dissemination of information especially of emails according to the principle ‘all information to everyone’* instead of a selective distribution, is a further issue with synchronization (MCMANUS, 2004, p. 51). On the one hand, it costs people quite a time to sort through the whole messages to just pick out the relevant ones. On the other hand, the danger of information overload arises which means that messages are not read any more or even deleted immediately after receiving with the potential that important information is missed (SLACK, 1998, p. 39).

The underlying reason for this problem often is a poor understanding and overview of the process by single process participants. This particularly refers to the different roles, responsibilities and rights (➲ Lack of system discipline) and the resultant information requirements of the process members.

- Redundant tasks

Redundant tasks are a result of poor synchronization as regards contents and just mean that tasks are repeated within functions but more often across functions or even across enterprises associated with suppliers, but without any significant differences in their results.

A good example for tasks repeated across functions, provided by SLACK (1998, p. 37), is the definition of the requirements for a purchase order by the engineering department. Instead of sending the order to the vendor, the requirements have to be forwarded to the purchasing department where they get rewritten for the ‘final’ order. The result of this procedure is pure waste as additional effort is spent on a task, that does not add any value at all but rather increases the risk of errors (➲ Defects) when rewriting.

Multiple inspection points also count among redundant tasks across functions (MORGAN, 2002, p. 77).

Another example refers to redundant tasks repeated across enterprises and especially to the integration of supplier processes. Additional and unnecessary effort emerges when the contractor conducts tests on a component part, which has already been scrutinized by the supplier (SLACK, 1998, p. 37). The reason for carrying the same tests out several times may just be based on pure ignorance by both up and downstream partners about each other’s processes. Different testing standards and scales in testing appear realistic as well. Especially for the last example it may bring savings when the supplier’s tests are modified in a way that enables the contractor to further use the data during his own and more comprehensive tests.

D 3.2.7 Defects

Production

In manufacturing this waste category is associated with component parts, materials, subassemblies or products which do not meet the quality requirements and thus have to be scrapped or reworked in order to correct these deficiencies. Defects may occur in the internal production as well as they do in supplier parts and materials, and often they get only detected during the final test or later after delivery by the customer. The reasons for defects in manufacturing are very various and reach from poor training and instructions to an insufficient consideration of process capabilities during the product design phase (LEAN AEROSPACE INITIATIVE, 2003, pp. 76, 79).

Product Development

Due to the differences between manufacturing and product development processes, the above concept of defects has to be reconsidered. As long as a product is well-established and the process i.e. the way how to come to there is fully determined like it is in manufacturing, the measurement of quality or rather the assessment of defects can be reduced to whether the specifications were met or not, even if the underlying ‘product’ is information. *Product development however is all about developing the new product and creating new information and finally working out those specifications*. In this information creating environment, the occurrence of failures, defects or deficiencies in information is much more frequent but also natural and inherent. Accordingly, the quality aspect in product development has not to focus on parts meeting the specifications but on working out accurate and error-free specifications, functionality and performance of the product.

Beside accuracy, there exist a couple of other information quality (IQ) attributes such as accessibility, relevancy, timeliness or interpretability. These may not all have a direct impact on an error-free product. But as they do effect people’s way of thinking, their assumptions and decisions in the development process, they represent quite important factors in this environment, and thus they are considerably responsible for the process efficiency.

The following sub-categories provide a better understanding of those aspects. An additional point concerns poor testing and verification. Even if it counts among the basic reasons for erroneous data and is mentioned in this context, it should be considered separately as it may entail enormous implications on product quality and the whole process.

- Deficiencies in IQ attributes

  Suggested by STRONG ET AL. (1997, p. 39) there are four major categories with a total of 15 different attributes describing information quality IQ (➲ C 1.3):

  Intrinsic IQ: Accuracy, objectivity, believability, reputation

  Accessibility IQ: Accessibility, security

  Contextual IQ: Relevancy, value-added, timeliness, completeness, amount of information

  Representational IQ: Interpretability, ease of understanding, concise representation, consistent representation

  Deficiencies in one or more of these attributes do not necessarily mean, that the information at hand lapse immediately and becomes useless, even it is not unlikely. Aside from that, the recognition of deficiencies depend on the individual, and some ‘lacks’ may even be compensated by the engineer’s individual experience learned from previous projects.

However, the fact is that deficiencies in IQ emerge as significant influence variables for engineers' work performed since they directly affect the way of their understanding, thinking, planning, deciding and last but not least acting. Dependent on the particular type of deficiency detected and the point in time occurring, the consequences for the process may be of different importance.

If the people notice a deficiency in IQ very early, it will be fairly easy to fix it in the majority of cases, even though it may take a good deal of rework. By doing so, the risk of a later defect caused by this lack can be reduced enormously. However, what turns out more chancy, is, if deficiencies are noticed but just ignored, or worse, if deficiencies are not recognized at all. Then the creation of new information with further proceeding in the process is based on misconceptions, inaccurate assumptions and incomplete pictures of the circumstances. This bears a high potential of generating erroneous information and consequently later problems and defects, which might require much higher levels of rework compared with when it is recognized and fixed immediately.

The reasons for IQ deficiencies occurring are as various as the describing attributes themselves. A few of them are explained more detailed in the following.

For example, deficiencies concerning the attribute *relevancy* often result from a poor synchronization as regards contents of up and downstream processes (➲ <u>Overproduction/ Unsynchronized processes</u>). But also a missing understanding of technical issues with the result of an insufficient focus on the essentials is realistic.

Accessibility of information is another example and closely linked with unnecessary ➲ <u>Movement</u>. What does it help if information is theoretically available in the 'system' but not easy accessible to the engineers which have to work with it? Instead of protracted information hunting, people rather continue their work based on assumptions even though this bears a higher potential of risk regarding rework and defects. The reasons of poor accessibility of information frequently arise from poor information systems, but also from a lack of disciplined data administration.

A further example concerns the aspect of *timeliness* of information. Information has to be available exactly when it is needed. Providing information too early is subject to the risk of becoming obsolete by the time needed, in contrast, too late available information will lead to some delays in the process. Poor synchronized processes but also frequent changes regarding to product and process mostly drive this problem.

Deficiencies in the *interpretability* of information mean that the representation of information is ambiguous. With different people looking at the information, there will emerge different interpretations and additional effort for discussing how to interpret the data. This problem is often caused by a lack of standardization for data representations and exacerbated by the different terminology of different departments for the same things.

- <u>Erroneous data and information</u>

Erroneous data and information just mean a lack of information accuracy, which is the result of IQ deficiencies occurring in previous process steps, of people's intelligence creating it, or even of failures in software tools. A special case in this point occurs, when the transfer of data from on place to another is erroneous and originally accurate information becomes inaccurate. In both cases however, the final result is erroneous information and thus the very beginning of defects arising.

SLACK (1998, p. 38) distinguishes two different types of defects regarding to their detection in a certain point in time.

The first are *engineering escapes*. These are defects detected during the process by testing and validation. They occur when 'requirements are overlooked […], appropriate analyses are not conducted, system interfaces are not adequately considered', 'standard processes are not followed or lessons learned are not captured'. Poorly designed input templates, undisciplined reviews, poor tests, validations and interpretation but also haste in processing are further reasons. The effort to correct the problems depends on the point in time, when the errors were made and finally detected. Also in this case the simple rule applies: The later, the worse.

The other type of defects is called *validation escapes* and refers to product defects, which are only detected by the end customer. The number, composition and matter of warranty issues serve as a useful metric for serial engineering in this concern. The root causes are similar with those from engineering escapes.

A very basic reason for both engineering and validation escapes is ➲ Poor testing and verification explained more detailed in the following.

- Poor testing and verification

Since uncertainty remains an immanent problem in product development, testing and verification in the different stages of development process is of high importance and indispensable because it enormously helps reducing the level of uncertainty and thus risk.

One of the major problems companies struggle with, are a great deal of product changes in the latter parts of the process, often a result of undetected problems with manufacturing. Since the solutions are already very elaborate in this stage, necessary changes in one part will squarely involve a couple of changes of related parts or even of the whole subsystem. This not only causes additional costs due to a lot of rework, but also significant time delays. The fact that many problems and errors can go unnoticed until late stages in the process, offers two possible explanations. Either there was no further testing and verification before the first physical prototype was built, or it was poorly performed.

In fact, engineers are often not aware about the usefulness and importance of testing and verification. A prevailed conception is, that testing only starts when a first physical prototype is build up. In reality however, testing sets in much earlier and a prototype already exists when its idea is created in the engineer's mind (WENZEL & BAUCH, 1996, p. 141). Irrespective whether it is an idea, a verbal description, a sketch, a drawing, a paper or a wooden model, each stage in the product development process has its particular types of prototypes, which can provide useful information (WENZEL & BAUCH, 1996, p. 141).

A very easy and cheap way of testing and verification is the communication of information and thoughts to other people even though these are in a pre-mature stage. Cross-functional teams can offer a very appropriate and fruitful environment to do that as they allow the assessment of an idea from different angles. A good example is the integration of people from manufacturing in the design phase in order to avoid later problems due to specific restrictions from this area. However, practice still turns out different and this approach is often impeded by factors such as competitive climate, incompetence-fear and disagreement-fear on the part of the single engineers, disturbed relationships, formal meetings, too elaborate solutions but also a focus on own problems (WENZEL & BAUCH, 1996, p. 142).

Another problem with testing and verification is related to 'wishful thinking' and a less realistic view of the engineers, which often results in a premature selection of alternatives, inadequate experiments but also excessive agreements in requirements regardless whether they are feasible or not (MILLARD, 2001, p. 28).

As important testing and verification is during the development as *important is it to exactly specify and plan the experiment and what should be achieved*. Aside from deficiencies in that concern, a lot of experiments conducted are characterized by *testing to specification and not testing to failure, which is more valuable* (MILLARD, 2001, p. 28).

This fact not only refers to single test parts but also to whole prototypes in the different stages of development process. Applying quality ensuring approaches such as Design of Experiments (DoE) to testing and verification can enormously improve the value of the results and decrease the costs simultaneously.

D 3.2.8 Re-invention

Production

The classical lean seven wastes provide no information about the problem with re-invention in the area of manufacturing.

Product Development

The re-use of already existing design solutions and experienced knowledge from previous projects in general, has a high potential to increase the quality and efficiency of product development.

However, companies and employees often seem not to realize this approach and its potential enough. Instead of starting the new project on the experience level of the last finished, they start their work on levels far below.

The classical symptom of this issue is the re-invention of processes, solutions, methods, and products which already exist or rather would only require some modifications to make them fit for the use at hand (MORGAN, 2002, p. 155).

- Poor design re-use

  No utilization of existing and reusable design solutions, no designing in existing components of a sub-assembly (MORGAN, 2002, p. 155), or the underutilization of valuable design knowledge of experts, especially regarding to costly parts (UGS PLM, 2004, p. 4), are examples for the re-invention problem in the design area, with the result of solving the same problems over and over again.

  When talking about the re-utilization of design solutions, it must also be clear, that modeling components have to be created re-usable (SLACK, 1998, p. 39). Even if there exist a couple of significant benefits such as their longer life-time within the product development program with thereby reduced maintenance costs, or the potential for a cross-program use (platform), the fact also is that the creation and test of reusable model components takes longer. However, this often disagrees with the short term budgeting in companies (SLACK, 1998, p. 39).

  A point just mentioned concerns the maintenance costs of models. Engineers are often insufficiently aware of the ‘real’ costs they cause by their acting. New models and parts cause not only additional engineering effort but can also arise high levels of additional costs over the product life cycle due to new tools required in manufacturing, or administration of the new parts.

  Two further factors that exacerbate the problem at hand, might be an insufficient system for the administration of design models etc. including special search functions, but also frequent job changes in the engineering area what prevents the engineers from getting an good overview of previous design solutions and more accountability with their work.

- Poor knowledge re-use

  The re-invention problem is not only limited to design solutions or modeling components. Quite the opposite, during a project a *great deal of experiences and knowledge is gained about the process itself and how it works best or not, and why.* Further, failures and problems occurred within the process provide valuable information for further improvement steps in this area. Since lessons and experiences from precedent projects are often documented poorly, and scarcely transferred to subsequent projects, the risk of solving the same problems repeatedly or making the same mistakes twice is obvious (MILLARD, 2001, p. 28).

As aforementioned, lost, discarded or unused knowledge is one of the basic reasons for re-invention occurring, mainly driven by poor knowledge and information management systems, and exacerbated by poorly defined, undisciplined product development processes (MORGAN, 2002, p. 155). The quality of such systems is a very critical factor and determined by the effort of feeding them with data, maintaining them and drawing the information needed. Databases that become too complicated in using and cannot quickly provide the relevant information required, will increasingly frustrate their users and lead them to refuse the future use, what in turn will lapse the whole system and effort spent so far. On the other side, the successful introduction of knowledge management approaches also depends on the engineers' commitment to use it consistently and on senior management's commitment to support that effort.

D 3.2.9 Lack of system discipline

System discipline embraces a couple of factors whose positive values are very basic and significant for the successful performance of a project. In contrast, negative values would result in 'disorganization' of the system. Going left in the root cause analysis of the above mentioned waste drivers points out, that these factors are often arranged at the very beginning of the 'root network' and thus are one of the elementary 'waste roots'.

The meaning of the following word 'unclear' is just the opposite of 'clear' which means in this context *few*, *simple*, *robust*, *verified* and *communicated* (WENZEL & BAUCH, 1996, p. 152).

- Unclear goals and objectives

  Goals and objectives appear at the different levels of the enterprise and constitute what has to be achieved without saying anything about the how. *Unclear goals and objectives basically mean that not everybody knows what the company is striving for in a long-term and short-term view* (WENZEL & BAUCH, 1996, p. 152). Related to the project at hand it might mean that the participants have not fully understood the particular project objectives (WENZEL & BAUCH, 1996, p. 152). This can be exacerbated when goals of a lower level are inconsistent among themselves or incompatible with the goals from the level above. The benefit of clear goals can be seen in the alignment of all team members performance into one direction and, as a result, in the much more efficient work since everybody pulls together. However, projects with unclear goals will not make it to this point and will waste a great deal of effort with compromising disagreements.

- Unclear roles, responsibilities and rights

  A complex project like product development requires that *each team member has a clear understanding of his own role and responsibility, but also of the roles of the others* (MORGAN, 2002, pp. 155, 156). For instance, person A is in charge of quality, person B for manufacturing integration, person C for change management, person D for supplier integration etc. Within a cross-functional core team with about 30 participants, which is not unusual for development projects in the car industry, the role structure can become complex very quickly. This is aggravated by the different rights of each team member to execute the role assigned. In many cases, problems arising refer not only to the team but also to the functional department behind each team member that supports his/her work.

  However, everybody who has worked in a team once, knows as well, that the concept 'role' does not only refer to expertise and responsibility but also to some personal aspects and skills of the single team members (WENZEL & BAUCH, 1996, p. 153). For example, person A has a talent to give presentations, person B analyses problems very fast, and another person creates very concise reports very quickly etc. Once it is clear what person has what preferences and strengths, and once the people begin to accept the different profiles of strengths and weaknesses, including their own, it will be easier for the team to work together efficiently (WENZEL & BAUCH, 1996, p. 153). Not only to get the right people on the bus, but also to put them on the right seats is the challenge for each new project beginning.

Unclear, not understood and unaccepted roles, responsibilities and rights in a project will result in a great deal of problems with overlapping competencies, of friction among the team members, and thus a high loss of efficiency.

- Unclear rules

Rules constitute some *kind of guidelines or principles for people's work in a company in order to achieve more efficient processes*. This can relate to very common contents like the careful entry of data in the different software systems, decision rules, but also to very specific points established by the individuals of a development team like early announcement of absence, usage of project internal templates, or not to cut team members off during discussions etc.

Further, it is important that rules are clear i.e. known, easy to understand, practicable, and accepted by all individuals of a group within they apply. If they are not, a great part of their benefits is lost.

- Poor schedule discipline

Unrealistic project plans might be one major reason for projects running out of time. Another often is a poor schedule discipline or rather *the missing willingness to meet the deadline on the part of the project participants*. This in turn may result from their poor awareness of the impacts of such acting (➲ High system variability) or from a poor commitment to their job due to low accountability caused by a lot of ➲ Handoffs.

- Insufficient readiness to cooperate

Insufficient readiness to cooperate represents a further and very critical factor within projects, departments and companies since people are *only interested in the success of their own work but not in the overall performance let alone making compromises.*

One of the reasons for this attitude driven issue may be seen in the social system in general, in which people are usually rewarded for their individual achievements. This already begins at school and continues at university and finally at work in form of a higher salary or another job that is higher in the hierarchy (WENZEL & BAUCH, 1996, p. 142).

A strongly hierarchical structure of a company, what is often associated with high levels of ➲ Handoffs and low levels of accountability, can be another reason as it aggravates people's thinking in functions or 'fragments' and people's focusing on their own business success, instead of providing them a more holistic view of the processes and making them aware of the overall performance.

However, people's unreadiness to cooperate does not prevail from the beginning in the majority of cases. Often the people rather experienced that others do not have the same understanding of readiness to cooperate and finally just take advantage of one's own engagement and effort. If there is no chance to criticize such a behavior in an open dialog and with prospects of betterment, people will reduce the level of their cooperation with others to a minimum very soon.

- Incompetence/ poor training

  Finally, all activities within a project or a company are conducted by single persons. The way i.e. the effectiveness, efficiency and quality of how they are performing their own tasks and integrating it in the super ordinate value stream, but also how they interact with the other people, is strongly depend on their *professional competence, competence in methods and soft skills*.

  Especially deficiencies in the latter turned out as critical, since they significantly effect how people get along with each other, and thus how efficiently their activities get coordinated. Another and often underestimated qualification are people's computer skills which are the basic tools for nowadays work. Poor proficiency can considerably reduce people's productivity.

  In order to keep pace with the highly dynamic changes in product complexity, decreasing product life cycles, global markets etc., it is necessary to continue with education and training once the people left school or university, and were incorporated in a company.

  Realizing this approach however necessitates willingness on two sides: Employees have to take it seriously and consider it as a chance to 'upgrade' their qualifications, employers have to provide these possibilities for professional development and regard it as a good way to improve the processes' efficiency.

  In practice, a lot of companies still seem to be not willing enough to go this path, even though it is only a question of time when they have to.

D 3.2.10 Limited IT resources

Even if the development of new information technologies and tools opened a total new world of possibilities to industry during the last 15 years, such as comprehensive databases, most diverse simulation programs etc., and accordingly allowed a lot of savings compared with conventional approaches, new problems were/are emerging on the other side. Some of them are among the above-discussed waste drivers.

The main reason for those problems lies in the big variety of existing IT components within information systems. In particular, this refers to hardware including computing resources and periphery (network), and software (operating systems and diverse applications/tools). Especially in earlier years, computing industry focused on isolated applications and the enforcement of company-internal standards. However, when it became important to provide not only mature special applications but also solutions, which allowed the further processing of data from upstream areas, these companies realized that they had to change their strategies towards more interoperability and integration.

From the view of IT technologies the challenge in the area of product development consists in mapping the whole development process with its results on integrated data models which should be useable by current software tools but also by future. This is significantly aggravated by new developments concerning software tools, operating systems and hardware systems. Parallel development processes using the 'same' systems might also make it difficult to simply stop and replace certain software tools as they are always used by other processes.

In the whole, there were found three major aspects regarding IT resources, why problems might occur: Poor compatibility, capability and capacity. Many of the above-discussed waste drivers have their roots in one, two or three of the following aspects.

- Poor compatibility

  Incompatibility and missing interoperability of hardware with software systems leads to a great deal of additional effort and rework. Re-formatting, extra converting or re-entering of data are all indicators for problems in this area. One of the most popular examples from the area of product development is the switching of computers (CAD to PC) in order to access the data or information needed (MCMANUS, 2004, p. 51).

- Poor capability

  An efficient work of engineers in product development requires capable software and hardware. Capable in this context means dedicated, high speed, reliable, ergonomic and up-to-date. In practice, there is still wasted a lot of time with complicated data retrieval or creation, waiting until the computer has opened files, ➲ Information hunting, or comparing data due to multiple and/or redundant sources. These are typical symptoms for insufficient capability and point out a major deficiency of obsolete software tools and hardware, or rather of integrated software tools for an efficient administration of data, information or knowledge. Deficiencies in information quality i.e. in the attributes accuracy, accessibility and security are closely linked with the capability issue.

- Low capacity (availability)

  Low capacity of the IT network of a company is one of the biggest sources of waste since it dramatically reduces the access to information and thus the productivity of the people waiting for (➲ Waiting). This is especially true for product development where the data traffic is innately high due to the high number of analysis results or the big data size of CAD models, sketches, etc. transferred.

  Another point in this issue refers to the often *sparely available computer or workstations equipped with special design tools*. If engineers cannot access the data needed immediately, or if they have to sign up to use the particular computer or workstation in a certain time slot, the chance, that they will not perform the original task, increases enormously. This in turn means a higher risk of creating flawed information and defects arising.

The high variety of existing IT components within an information system was already established as the main reason for problems in this area. Another factor responsible for those problems often is a poor awareness by management of the importance of powerful IT resources, which finally form the backbone of nowadays whole business processes and significantly determine the efficiency of people's work. Of course, the purchasing of new hardware or software has always to be discussed in economical terms, but fact also is, that IT resources innately are a low-budget priority in many cases, driven by a poor understanding of its critical impacts on the processes.

Since there will always be offered newer, faster and better software or computers with higher band-width communication lines on the market, it is hardly possible to be up-to-date always. However, what has turned out as very useful, is to develop some 'upgrade policies' for the own company which provides, that IT components are upgraded in certain intervals to the prevailing standards (STRONG, 1997, p. 46). This prevents a too big variability of different old IT system technologies used and thus a lot of problems due to restrictions with outdated systems.

A third factor in this context concerns people's competence in new IT resources. That is to say, a lot of problems in this area might only occur, because people are not well trained in the basic tools they need for their work (➲ Incompetence/ poor training). In many cases that already starts with deficient skills, for instance, in MS Office applications needed for simple secretarial jobs, and ends up in poor skills in converting or linking systems on the part of engineers. And even if employees are trained in such tools, low motivation often contributes, that acquired knowledge is not applied, not communicated to other colleagues, and eventually lost. As a result of the example at hand, a big part of the potential of available IT resources in a company remains unused and thus is wasted, because people just do not know how to use it.

D 3.3 Evaluation of the new waste system

The reorganized and extended waste system provides some a number of significant benefits but also exhibits limitations.

Benefits

The reorganized and extended waste system provides some significant benefits:

- Higher awareness of and transparency about the difference between waste and waste drivers, and the whole network of problem causes and impacts
- Relatively comprehensive set of relevant waste drivers through the reorganization and conglomeration of different people's work in this area including the author's own re-interpretations
- Workable and manageable set of waste drivers to eliminate the 'big fishes'
- Elimination of inconsistencies in the re-interpretations of the lean seven waste types to product development made by different authors
- Better understanding of waste drivers for the people themselves
- Set of waste drivers as kind of a common reference for people's analyses and communication (no different languages within departments)
- Current set of waste drivers was applied by a team member dealing with value stream mapping, and assessed as more comprehensive and precise with waste definitions compared with the other approaches
- Set of waste drivers is a diagnosis tool and can be used as a checklist within reviews to detect waste occurring during the development project

Shortcomings and problems

- Set of waste drivers is comprehensive and thus it requires some setup time for the people to understand and work with it
- Some waste drivers' definitions have slight overlapping with others regarding to the aspects they specify
- Some of the waste drivers are not completely equal to the others
- The might be some other and additional waste driver

D 3.4 Evaluation of the transferability of the lean seven types of waste

The investigation of waste within product development has shown that the re-interpretation of the lean seven types of manufacturing waste to product development with respect to information and information flow respectively is possible to the greatest possible extent and can offer useful results. In this point, the focus on information is not limited to files converted or excessive data storage but the whole information creation process. Consequently, this also includes the information processing activities performed by the single engineer as well as the design and synchronization of the process, or the area of people's communication.

The investigation yielded that precedent re-interpretations of other authors sometimes were very fragmentary. However, starting with the description of the lean seven types of waste *and* the research results of other people in this area helped the author to develop his own re-interpretations.

Comparing the different existing approaches also made obvious, that the re-interpretations of the manufacturing types of waste to product development are not able to completely describe development waste. For this reason, the author has introduced three further categories, which address quite specific issues resulting in decreased performance of development processes:

- *Re-invention*, including
  - Poor design re-use
  - Poor knowledge re-use
- *Lack of system discipline*, concerning
  - Unclear goals and objectives
  - Unclear roles, responsibilities and rights
  - Unclear rules
  - Insufficient readiness to cooperate
  - Poor schedule discipline
  - Incompetence/ poor training
- *Limit IT resources*, including
  - Poor compatibility
  - Poor capability
  - Low capacity

In order to provide the whole waste thinking with more ‘grip’, the author established some further significant sub-categories for each of the other main categories like *Waiting*, *Transport/ Handoffs* or *Movement*.

D 4 Sequence of waste elimination

When going through the above listing of waste drivers (main categories and sub-categories), it already became clear that there are a couple of relations among the waste drivers or rather problem fields in product development themselves. When considering one of the project targets, which is to find an approach for efficient waste elimination, the question arises where to start with the elimination or rather with what waste driver(s). The only intuitive consideration of this question does not seem to be target-oriented since human capacity in reasoning is limited to a certain number of different factors. 37 different factors however overreach this boundary by far. This requires another and more systematic way in analyzing.

D 4.1 Cause-effect analysis

A systematic way to get a better understanding of relations and interdependencies with a big number of factors is the cause-effect analysis method. What it exactly is, what you might expect from doing so and how to perform, is briefly explained in the following section.

D 4.1.1 Background to cause-effect analysis

The initial point for the application of a cause-effect matrix is the fact that a system at hand is characterized by a high number of factors of influence. Even if some of the relations among them are known, it turns out as very difficult to see the whole picture of interdependencies and thus to draw any qualitatively reliable conclusions about the system.

The method at hand however suggests a very special way to map a system. It is applied in those cases when the target is to systematically expose essentials, to prioritize elements, to sequence things and to display interdependencies. The *qualitative analysis of the system* and its behavior stands in the front.

During this approach, the established influencing factors are entered in the rows and columns of a matrix. For instance, ten factors will lead to a matrix with 100 separate fields to assess. Starting at the first row, the effect of a single factor gets rated against each other: How does factor A effect factor B, factor C, etc. The thereby used grading reaches from 0 (independent), 1 (weak), 2 (strong) to 3 (tightly related). Repeating that procedure with all rows will result in a completely filled out matrix, except for the primary diagonal fields, which would describe the effect of a factor against itself. Further, the active and passive sum (AS, PS) of rows and accordingly columns can be determined, and thus the quotient Q (AS/PS) and the product P (AS*PS) of each factor. Thereby, the last both mentioned parameter describe the activity and criticality of a factor respectively.

For a better visualization of the results, the factors are plotted into a chart displaying their specific active and passive sums. According to LINDEMANN (2000, Chapter 1, Slide 15), the classification of the factors refers to the four quadrants of the chart and suggests the following interpretations:

Active element	Strongly influencing but weakly influenced *High quotient Q*: big active sum, low passive sum
Passive element	Strongly influenced but weakly influencing *Low quotient Q*: low active sum, high passive sum
Critical element	Strongly influencing and strongly influenced *High product P*: high active sum, high passive sum
Inactive (buffering) element	Weakly influencing and weakly influenced *Low product P*: low active sum, low passive sum

The classified factors might be treated regarding the following order:

- Active elements since those only have an impact on other factors
- Critical elements since they strongly influence other factors but are influenced strongly by others as well
- Passive elements since they are only influenced
- Inactive elements have a buffering nature and might be treated at the beginning or at the end

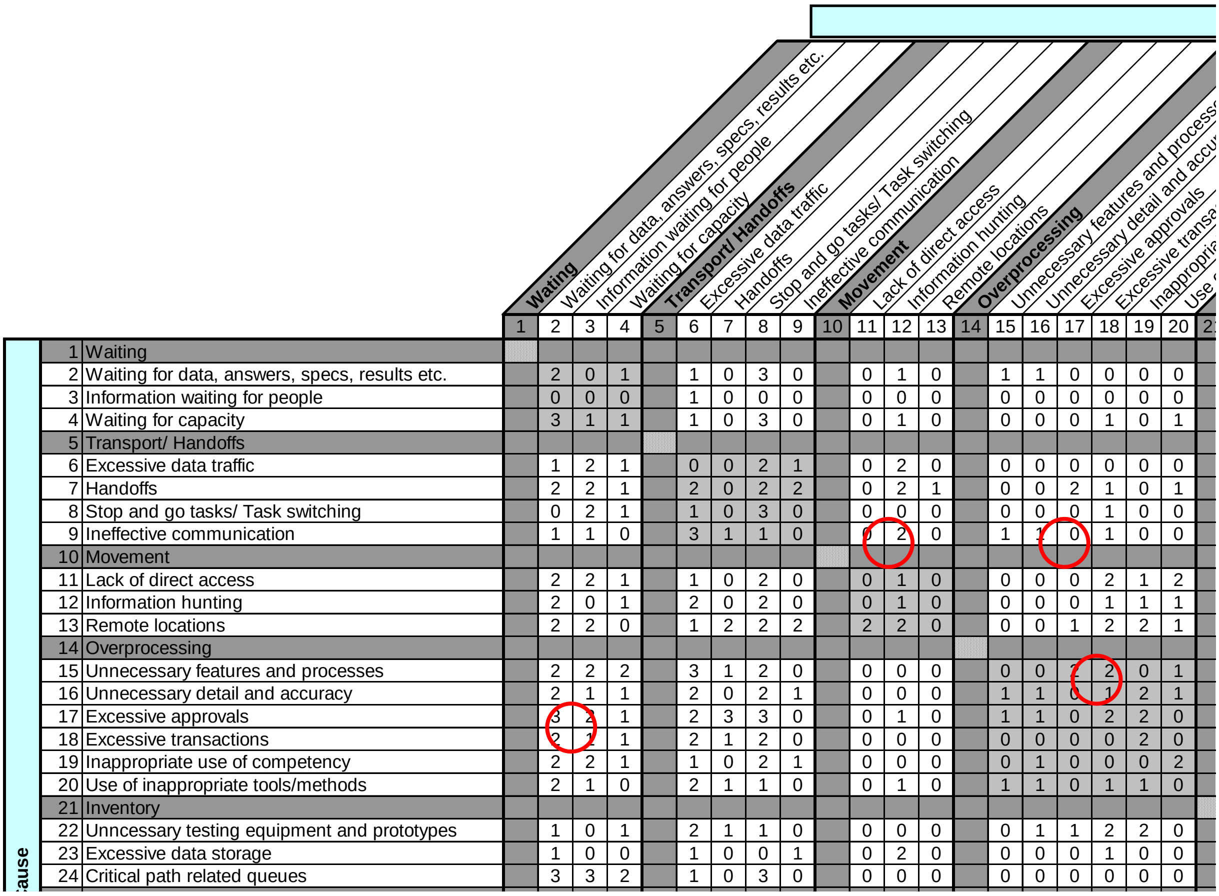
As mentioned above, the expected result when applying this method is more a qualitative than a quantitative classification of the influencing factors. Even if the result primarily must be considered as a clue, it makes an essential contribution to the better understanding and the handling of a multitude of influencing factors.

Persons, which are experienced with this method, can also confirm that inaccuracies in the assessment of the relations will compensate relatively well on the whole. The reason for this mainly lies in the number of stochastical inaccuracies over the total number of estimations.

Nevertheless, the performance of this method within a team is favored since circumstances and their interrelations are automatically considered more differentiated due to the different views of the team members. Simultaneously, this reduces the risk of an inaccurate estimation.

D 4.1.2 Procedure

Due to the large dimension of the matrix (37 x 37) and missing capacity on the part of the project team, the author decided to first perform the assessment of the cause-effect matrix on his own. However, to get a better sense of the informational value of the results, an empty matrix was given to another team member to repeat the assessment for some of the factors independently. When comparing both matrixes it turned out that there partially were bigger discrepancies not only in the final active and passive sums of the respective factors but also in the assessed relations themselves. During discussion it became clear that the reason for this mainly consisted in a different understanding of the waste categories. Direct and indirect dependencies of some factors were also assessed in a different way. Finally, since those deviations did not only lead to a 'uniform' change of factors' position in the diagram while sustaining its qualitative information, but also to some major changes in the pattern which could be justified with some relevant examples yet, the assessment of the whole matrix was repeated in a team of two students. For better understanding, a part of the cause-effect matrix is shown by ➲ Figure D 4-1, the complete matrix including each factor's active and passive sum and the derived classification can be found in appendix ➲ I 6.



		1 Waiting	2 Waiting for data, answers, specs, results etc.	3 Information waiting for people	4 Waiting for capacity	5 Transport/ Handoffs	6 Excessive data traffic	7 Handoffs	8 Stop and go tasks/ Task switching	9 Ineffective communication	10 Movement	11 Lack of direct access	12 Information hunting	13 Remote locations	14 Overprocessing	15 Unnecessary features and processe	16 Unnecessary detail and accu	17 Excessive approvals	18 Excessive transa	19 Inappropria	20 Use
1	Waiting																				
2	Waiting for data, answers, specs, results etc.		2	0	1		1	0	3	0		0	1	0		1	1	0	0	0	0
3	Information waiting for people		0	0	0		1	0	0	0		0	0	0		0	0	0	0	0	0
4	Waiting for capacity		3	1	1		1	0	3	0		0	1	0		0	0	0	1	0	1
5	Transport/ Handoffs																				
6	Excessive data traffic		1	2	1		0	0	2	1		0	2	0		0	0	0	0	0	0
7	Handoffs		2	2	1		2	0	2	2		0	2	1		0	0	2	1	0	1
8	Stop and go tasks/ Task switching		0	2	1		1	0	3	0		0	0	0		0	0	0	1	0	0
9	Ineffective communication		1	1	0		3	1	1	0		0	2	0		1	1	0	1	0	0
10	Movement																				
11	Lack of direct access		2	2	1		1	0	2	0		0	1	0		0	0	0	2	1	2
12	Information hunting		2	0	1		2	0	2	0		0	1	0		0	0	0	1	1	1
13	Remote locations		2	2	0		1	2	2	2		2	2	0		0	0	1	2	2	1
14	Overprocessing																				
15	Unnecessary features and processes		2	2	2		3	1	2	0		0	0	0		0	0	2	2	0	1
16	Unnecessary detail and accuracy		2	1	1		2	0	2	1		0	0	0		1	1	0	1	2	1
17	Excessive approvals		3	2	1		2	3	3	0		0	1	0		1	1	0	2	2	0
18	Excessive transactions		2	1	1		2	1	2	0		0	0	0		0	0	0	0	2	0
19	Inappropriate use of competency		2	2	1		1	0	2	1		0	0	0		0	1	0	0	0	2
20	Use of inappropriate tools/methods		2	1	0		2	1	1	0		0	1	0		1	1	0	1	1	0
21	Inventory																				
22	Unncessary testing equipment and prototypes		1	0	1		2	1	1	0		0	0	0		0	1	1	2	2	0
23	Excessive data storage		1	0	0		1	0	0	1		0	2	0		0	0	0	1	0	0
24	Critical path related queues		3	3	2		1	0	3	0		0	0	0		0	0	0	0	0	0

Figure D 4-1: Cause-effect matrix

D 4.1.3 Assessment of the matrix

Even if the cause-effect matrix at hand shows a dimension of 47 times 47, the effective dimension was 37 by 37 since only the waste sub-categories were assessed against each other. In contrast with the 'normal case', the assessment of primary diagonal fields partially made sense in the present case. Since product development processes consist of a whole network of linked tasks, occurring waste like waiting for data rarely remains limited to the task of only one person but often causes some waiting for diverse linked downstream tasks and their assigned people as well.

For the assessment of the cause-effect relations, the above-mentioned grading (0 to 3) was used. While in most cases relations with a grading of 0 or 3 were more obvious and easier to see, the assessment of relations with a grading of 1or 2 turned out more difficult. Especially those cases required a thorough consideration of the probability of an impact and of the grade of that impact from a practical point of view. Finally, it was taken into account, to what extent the different aspects of a sub-category effected/were effected the other/by the other sub-category. To ensure consistency within rows and columns also required to compare current assessments with previous ones and if necessary to adjust them. Doing so of course means a bigger effort but otherwise it is an important precondition for an adequate use of the grading and thus the calibration of the whole matrix.

For the reader's better understanding of the use of the grading and what kind of interpretations during the assessment have established, there will follow a few examples taken from the above figure (See marks in ➲ Figure D 4-1).

- 0, used for *independent* or *indirect 'could'* relations

  Ineffective communication, which means miscommunication or inaccurate communication due to non-standard terminology and meanings used by different departments, or a lack of communication such as ineffective feedbacks or insufficient discussions are not considered as a (possible) reason for the circumstance that information like user manuals often is not directly accessible from the workplace with the result that people have to walk for it. The coordinates of the current example in the above matrix are 9,11.

- 1, used for *obviously weak*, *indirect* or *direct 'could'* relations

  In some cases ineffective communication, which includes that things are not discussed adequately, might cause unnecessary detail and accuracy what means that features get over-engineered or information exchanged simply has more detail and accuracy than required. In many cases the latter however is driven by engineers' tendency to perfectionism, a lack of standardization or the need just to meet an individual's standard. Due to the ratio and weighting of those arguments, ineffective communication is supposed to only have a direct 'could' impact on the other sub-category. The coordinates of the current example in the above matrix are 9,16.

- 2, used for *strong*, and *direct 'normal'* relations

  Unnecessary features and processes against excessive approvals: Under constant conditions additional product features will almost automatically result in additional approvals. This applies even if the approval process per se is relatively simple and quick, and gets worse if the approval has to go through different levels of management before it can be released. The coordinates of the current example in the above matrix are 15,17.

- 3, used for *extra strong*, *closely related* and *immediately direct* relations

  An obvious example for this grading is given by the relation between excessive approvals and waiting for data, answers, decisions. Since engineering changes or other documents have to follow a certain path through different levels of management before downstream processes can use them, waiting time and thus interruptions in the workflow of ‘change owners’ or rather other engineers of downstream processes are pre-programmed. A grading of 3 can be justified by the fact that this kind of problem is still very prevalent in a lot of companies and furthermore almost always causes big delays for engineers’ work. The coordinates of the current example in the above matrix are 17,2.

The result of the cause-effect matrix performed is displayed in the following chart (➲ Figure D 4-2). A big size chart is provided in ➲ appendix I 7.

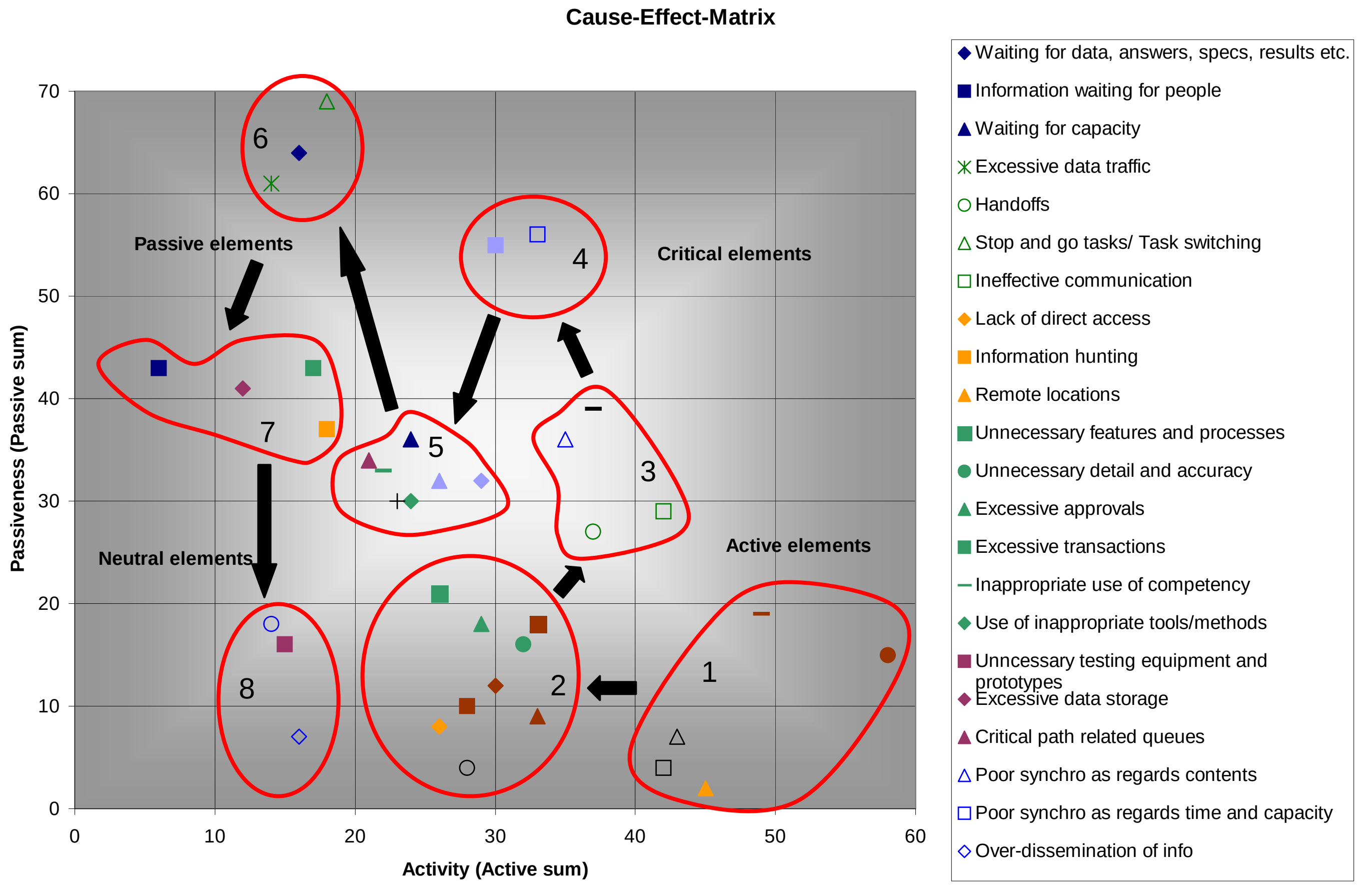


Figure D 4-2: Cause-effect chart

D 4.1.4 Verification

Plausibility check

During the assessment of the matrix, the team already developed a sense of some factors’ character. In general, the chart does not exhibit any significant mavericks. Of course, some factors’ position like that one of *Stop and go tasks/ Task switching* or *Low capacity* was supposed in a more active area, looking over the assessments of those factors in the matrix however made their positions more comprehensible.

Sensitivity analysis

In those cases where the team was not sure about the grading of some relations, a preliminary value was left in the field and marked for a second loop. A comparison the temporary and final assessment of those fields showed that there were only very small and thus negligible movements on the chart.

Another kind of sensitivity analysis performed consisted in replacing the numbers 2 and 3 in the matrix with 1 in order to get an idea what the chart would look like if the assessment of the relations was limited to a grading of ‘effect’ and ‘no effect’ (➲ appendix I 8). As a result, the spreading of elements on the chart was more straightened and many elements moved along or parallel with the 45° diagonal (➲ appendix I 9). This is especially true for the elements of cluster 5 (➲ Figure D 4-2), which almost all became then critical. Some elements with major changes are *Excessive transactions*, *Critical path related queues*, *Waiting for capacity*, *Unnecessary detail and accuracy* and *Handoffs*.

Even if the two different charts may in the whole show similar patterns, they also show that there are some differences. Reducing the assessment to 0 and 1 may very quickly give a first idea, but that also means that the characterization of factors is just driven by the number of interdependencies with other factors irrespective of their quality. Thus, more reliable information can only be obtained through the usage of a grading with a higher resolution, which allows a more differentiated assessment of the quality of those relations. The grading used in the above matrix can be considered as sufficient and adequate since the expected result is more of qualitative than quantitative nature. Any grading with a range of 0 to 5 or bigger would mean too much detail for a qualitative analysis and especially require much more time to perform it. According to the previous definitions, that would mean waste driven by ➲ Unnecessary detail and accuracy.

D 4.1.5 Defining clusters and clusters’ sequence for waste elimination

The analysis leads to a new categorization of the waste drivers dependent on their behavior in the whole system. Since the transitions between the suggested areas on the chart (active, critical, passive and neutral) should not be considered as discrete but rather fluid which is also more realistic, eight new clusters were identified in total, each containing elements with similar characteristics. According to the theory of the applied method, elements of cluster 1 or 2 for instance have to be treated with higher priority than ones of cluster 7 or 8. As a result, the order for waste elimination starts with elements of cluster 1 and ends up with ones of cluster 8.

In discussions it turned out that elements belonging to cluster 3 and 4 were supposed by different people to get eliminated before those of cluster 2 due to their high active and passive sum. Getting a problem solved in long-term however suggests to focus on the resolution of the root causes (➲ 5 Whys) and thus to gradually deprive the waste network of its ‘soil’. In the current case, significant root causes especially are elements characterized by high levels of activity but relatively low levels of passiveness. This exactly obtains to elements of cluster 1 but also those of cluster 2. In contrast, elements of cluster 3 and 4 not only exhibit a high level of activity but also of passiveness what indicates that they get also effected essentially by others. Eliminating them for long-term however suggests to first get rid of the system’s root causes which drive them in a direct or indirect way. Due to the relatively low passive sums, elements of cluster 2 rather represent the character of root causes than those of cluster 3 and 4 do.

What the careful reader might have noticed is that during the gradual elimination of waste elements, the above shown pattern of the elements (➲ Figure D 4-2) will not remain static. Quite the opposite, the elements will be moving on the chart. Each elimination of a waste element will result in a more or less new pattern with active, critical, passive and neutral elements. Thus, by continual eliminating the active elements in an iterative process that is to say the root causes of the current pattern, it is possible to gradually reduce waste within the system. Thereby, the above established and categorized elements generally move clockwise which means that, by rule of thumb, passive elements become critical, and critical elements become active during the next iterations of waste elimination. The ‘speed of movement’ and thus the change of an element’s originally category of course depends on the number of elements that were decided to eliminate within one iteration.

To get a better understanding of the movement of elements and how they open up a new pattern after the elimination of some elements, a simulation was performed (➲ I 10) which is based on 7 elimination cycles. It further presumes the complete elimination of a cluster’s elements per cycle run.

Even though this simulation strictly followed the above order of 1 to 8, it turned out that the elimination of previous clusters or rather their elements may have a deeper impact on the pattern and thus the order to further eliminate elements. Following the above rule of eliminating active elements first, cluster 5 then should be eliminated before cluster 4. This again results in some more changes regarding to the sequence of the elimination of the clusters remaining. In particular, the order is 1-2-3-5-8-4-7-6, the respective charts are provided in appendix ➲ I 11.

It is important to understand that the above-suggested sequence for waste elimination represents more a guideline than an absolute rule. How fast elements can be eliminated and which one have to be eliminated at all, depends on the special case and will finally effect the order essentially. The adjusted sequence also makes clear that waste elimination must not performed static following a plan defined once in a time. In contrast, it is essential to adjust the pattern again and again, since in reality waste elimination will only be able to happen step by step or rather element-by-element. Furthermore it will be necessary for companies to also quantify identified waste drivers occurring, and thus there might be an additional weighting for the elements with some impacts on the sequence for waste elimination.

D 4.1.6 Evaluation

Results and benefits

Starting with an intransparent network of relations between a big number of various factors, the application of this method yielded different things:

- First approach performed by a researcher that considers waste as a whole network of problems and tries to integrate this fact systematically for the waste elimination process
- Much better understanding and transparency of the factors’ interdependencies and characters provided by a qualitative classification in a visual, simple and easy way to understand
- More reliable results about relations than a purely intuitive approach may provide
- Based on the classification a prioritization of the factors that allows to sequence them properly on the way of waste elimination (order: active – critical – passive – neutral). In the above case, whole clusters may be worked on or rather eliminated in the order suggested by the numbers (1, 2, …, 8) in ➲ Figure D 4-2
- Approach for the setup of a checklist for waste elimination
- Revelation of new fields for improvement like the development of tools/ methods/ rules to ensure effective communication or information quality
- Good starting point to prioritize and weight specifications and necessary features for the display development since it should also help to prevent, to early detect and to display waste occurring

Problems and experiences

During the performance of the analysis there occurred some various problems:

- Definitions of the waste drivers were sometimes unclear and hard to remember for others (big scope of waste drivers)
- Assessment of the relations often is linked with an estimation of the probability and the grade of impact from a practical point of view
- The accomplishment of the assessment turned out as very time consuming as the matrix had a dimension of 37 times 37 which mean the assessment of 1369 relations
- To ensure the consistent usage of the grading sometimes required to look over the assessments of fields of some previous rows and if necessary to adjust them
- The application of the method was doubted as not to deliver enough meaningful results, the assessment of the relations was criticized as too vague
- The assessment in a team was helpful and prevented a too subjective view and estimation by the author
- Sometimes there was some overlapping in the meanings of some waste drivers
- Verification of results (plausibility check) turned out as critical and thus should be reviewed by people with high levels of practical experience

Limitations and suggestions for improvement

The assessment of the whole matrix was extensively discussed in a team made up of two students which themselves could look back on some practical experience in car industry and discussions with managers about different issues in this concern.

From the author’s point of view however it would be good to assess or, at least, to discuss the matrix within a bigger team consisting of people from different areas and hierarchical levels of product development with some good practical experience in this area. Another approach could be the performance of case studies. Both alternatives might provide higher levels of certainty in the results elaborated.

Above all, for a better use of the waste classification in practice it would be very useful to establish a system which not only allows a qualitative assessment of waste drivers within in the waste network but also a quantitative. Companies would benefit from a more differentiated assessment of house-internal waste drivers and thus a more specific procedure for waste elimination since problems and their extent may be different from company to company.

D 4.2 Checklist for waste elimination

Based on the results of the cause-effect analysis, a checklist was worked out as a guideline for waste elimination in practice (➲ Table 2). According to ➲ Figure D 4-2 it incorporates eight clusters for waste elimination starting with the cluster of highly active waste drivers and ending up with neutral. The matrix also shows a couple of different numbers that might help the reader to better navigate within the different charts that had to do with waste.

- *Serial number* (Waste overview) refers to the used numbering within the precedent waste overview established (➲ Figure D 3-2)
- *Serial number* (Waste matrix) refers to the waste drivers’ numbering within the cause-effect matrix (➲ Figure D 4-1, appendix I 6)
- *Serial number* (Waste elimination) just refers to the derived sequence of waste elimination of the particular waste drivers.

Integrated in the checklist, the reader can find a comparison between sequenced waste drivers (sub-categories) and the main categories of waste drivers they belong to. This provides some further information about the overall nature of the main categories. *Limited IT resources* and *Lack of system discipline* both are characterized by high levels of activity. In other words, regarding to the whole network of waste drivers both constitute two ‘big fishes’ or rather sources of waste happening (see also ➲ Figure D 2-2). In contrast, the result of other main categories like *Movement* is not that unequivocal.

At this point, the author would like to note, that not all of the terms may be self-explaining to the readers. The right and successful use of the checklist hence will depend on the thorough understanding of the nature of the waste drivers worked out (➲ D 3.2).

Furthermore, the sequence of waste elimination is not static. Quite contrary, eliminating some of the highly active waste drivers will result in more or less new positions of the factors in the above chart shown (➲ Figure D 4-2) what may also have some impact to the sequence. This is especially true for the categories 5 to 8.

				Waiting	Transport/ Handoffs	Movement	Overprocessing	Inventory	Overprod./ Unsynchr. Processes	Defects	Reinvention	Lack of system discipline	Limited IT resources
	Serial number (Waste elimination)		Serial number (Waste overview)	1	2	3	4	5	6	7	8	9	10
			Serial number (Waste matrix)	1	5	10	14	21	25	30	34	37	44
Highly active													
1	1	43	Incompetence/ poor training									x	
	2	42	Insufficient readiness to cooperate									x	
	3	46	Poor capability										x
	4	45	Poor compatibility										x
	5	13	Remote locations			x							
Active													
2	6	47	Low capacity										x
	7	11	Lack of direct access			x							
	8	40	Unclear rules									x	
	9	41	Poor schedule discipline									x	
	10	39	Unclear roles, responsibilities and rights									x	
	11	16	Unnecessary detail and accuracy				x						
	12	38	Unclear goals, objectives, strategies									x	
	13	17	Excessive approvals				x						
	14	15	Unnecessary features and processes				x						
Active-Critical													
3	15	9	Ineffective communication		x								
	16	7	Handoffs		x								
	17	26	Poor synchro as regards contents						x				
	18	36	Poor knowledge re-use								x		
Highly critical													
4	19	27	Poor synchro as regards time and capacity						x				
	20	31	Deficient info quality							x			
Middle risk													
5	21	32	Erroneous data and info							x			
	22	33	Poor testing and verification							x			
	23	20	Use of inappropriate tools/methods				x						
	24	35	Poor design re-use								x		
	25	19	Inappropriate use of competency				x						
	26	24	Critical path related queues					x					
	27	4	Waiting for capacity	x									
Highly passive													
6	28	8	Stop and go tasks/ Task switching		x								
	29	2	Waiting for data, answers, specs, results etc.	x									
	30	6	Excessive data traffic		x								
Medium passive													
7	31	12	Information hunting			x							
	32	18	Excessive transactions				x						
	33	23	Excessive data storage					x					
	34	3	Information waiting for people	x									
Neutral													
8	35	29	Redundant tasks						x				
	36	22	Unncessary testing equipment and prototypes					x					
	37	28	Over-dissemination of info						x				

Table 2: Checklist for waste elimination

D 5 List of open points and questions

The investigation performed was an important and very basic step waste elimination within product development. Improving the results established suggests a couple of further steps:

Verification of the results elaborated

Even if the results elaborated base on thorough analysis, further verification is needed. Two possible approaches include a review workshop within a multidisciplinary development team, and the performance of case studies with companies from industry.

Quantitative measure of waste

For a more differentiated assessment of and procedure for the elimination of house-internal waste drivers, the current qualitative system to measure waste should be connected with a quantitative system. The elaboration of characteristics based on cost and connecting a simple grading system (0 to 10) with project attributes like project size, duration etc. may be useful.

The targeted integration of those waste drivers into the display suggests to investigate some more aspects concerning waste. This includes the question about the different phases or levels of a development project the people can recognize waste. For example, *waiting* is a waste driver that each single engineer can experience and assess by his own. Other waste drivers like *unnecessary features and processes* might only be recognized in post-project reviews.

Linking waste drivers with waste types

In chapter ➲ D 1, the author has introduced definitions concerning waste drivers and waste types distinguishing between primary and secondary. The primary include the classical project targets like quality, time and costs to market, and resultant flexibility.

According to REINERTSEN (1997, pp. 198-200) each project has three primary constraints: Scope of work concerning requirements of product cost and performance, available resources and schedule. In practice, it only two of the three constraints can be kept constant. The third then acts as kind of a valve for the occurring variability of the first both. The determination which of those sides of the control triangle should be kept constant or rather should be the valve depends on the business. In medicine technology for instance, high product performance is a success factor for a company's business and thus has to be kept constant.

Coming back to the waste drivers it would be interesting, which of those are primarily linked with which project target (quality, time, …) and in what context. For a company that has to focus on quality and resources, the sequence of waste elimination may be different to a company that has to focus on schedule and resources.

Characterizing waste drivers against product development principles and tools used by Toyota

In order to learn more about Lean Product Development, the author suggested two different ways shown by the numbers in ➲ Figure A 3-3: the investigation of the transferability of lean manufacturing principles to product development, *or* an empirical approach by analyzing the principles and tools of the product development system at Toyota. Latter was performed by MORGAN. Characterizing the established set of waste drivers against those principles and tools used by Toyota can provide some additional hint how to overcome waste by focusing on guidelines for success. Furthermore, since even Toyota still is on its way to find out what lean product development really means, this can help to bring to the light *white fields* within the current system and thus show up potential and dimensions for further improvement.

E Display concept development

Thinking about the display concept in the context of *Lean* lead to a great deal of ideas and approaches, worth to analyze in more detail. However, due to time limitations of the author's participation in the project team and some unforeseen delays when working out the issues of the precedent chapters, the 'official' work on the display was limited to the problem analysis and first steps in searching for solutions. Thus, the following chapter is more an outline than a comprehensive description of the first results and ideas during the development of the targeted display.

Chapter ➲ E 1 briefly describes two results of the problem analysis: The definition of the display targets, and the preparation of a list of display specifications as basis for the further development.

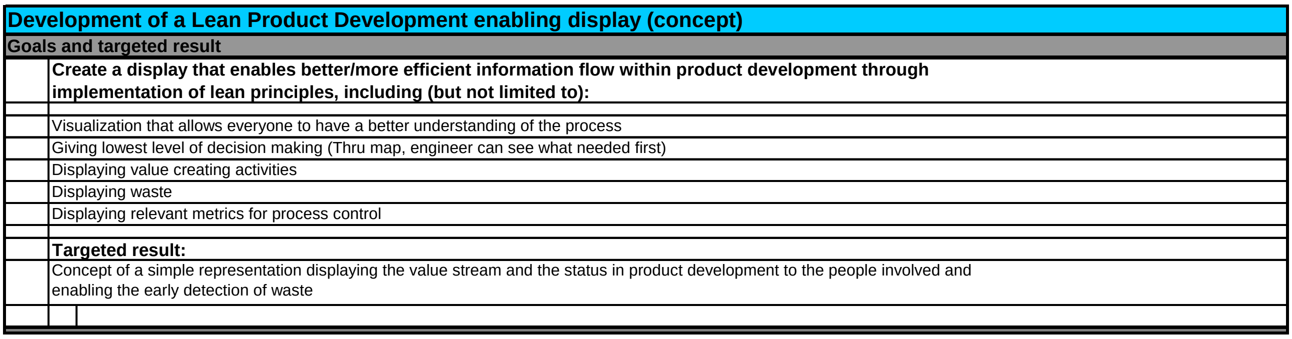
Chapter ➲ E 2 starts with the collection of possible aspects and contents concerning 'boxes' and 'arrows' as a possible approach for the targeted new value stream representation. Searching for new solutions suggests to also look at existing ones including a review of their strengths and weaknesses. In particular, regarding to alternative tools for displaying value streams, this was already performed by Millard (2001). The results of his work are very basic for the further development of the display and thus surveyed briefly in the second part of the chapter, including some conclusions for the current project.

A list of open questions collected during the development so far rounds off chapter ➲ E 2 and gives the reader some notion about future steps.

E 1 Problem Analysis

E 1.1 Defining display targets

In order to create a common sense among the team members about the development project and what has to be achieved, and to better align the subsequent development activities of the single persons, the team agreed on the project goals and targeted result, shown in ➲ Figure E 1-1.



Development of a Lean Product Development enabling display (concept)	
Goals and targeted result	
	Create a display that enables better/more efficient information flow within product development through implementation of lean principles, including (but not limited to):
	Visualization that allows everyone to have a better understanding of the process
	Giving lowest level of decision making (Thru map, engineer can see what needed first)
	Displaying value creating activities
	Displaying waste
	Displaying relevant metrics for process control
	Targeted result:
	Concept of a simple representation displaying the value stream and the status in product development to the people involved and enabling the early detection of waste

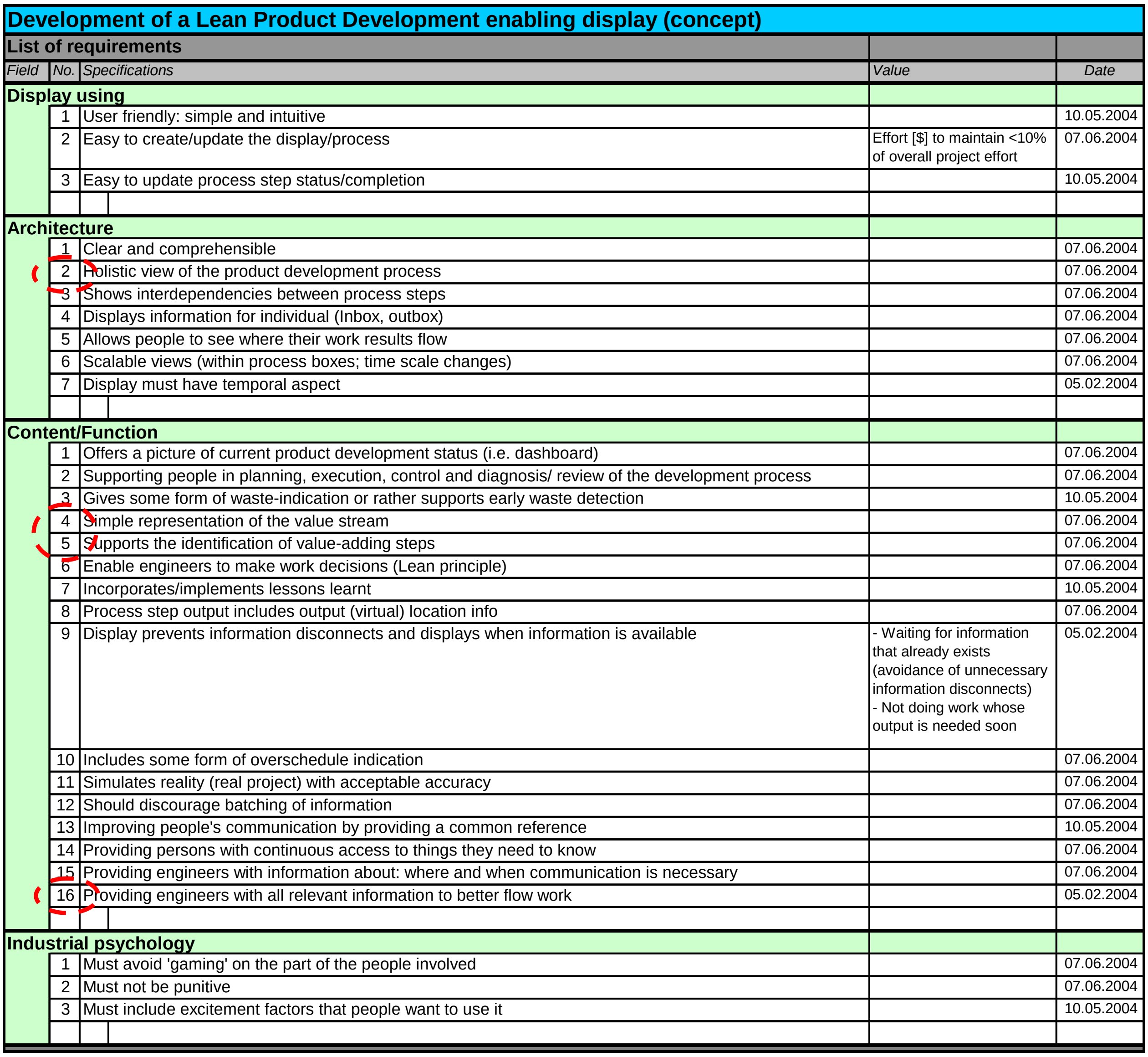
Figure E 1-1: Display goals and targeted result

The underlying motivation of and the targeted benefits associated with the development of such a display was already explained in detail at the beginning of the current thesis (➲ A 2).

E 1.2 List of requirements

As a result of the problem clarification and as basis for a targeted procedure for development, a list was worked out that accumulates all the different qualitative and quantitative specifications concerning the display. Changes in old requirements or even new requirements added over the project run time make the list dynamic.

According to ➲ Figure E 1-2, the display specifications fall into four different categories: display using, architecture, content/ function, and industrial psychology. Since the current subject is the development of a concept, the listed requirements mainly are of qualitative nature and thus have no entries in the ‘value’ column.



Development of a Lean Product Development enabling display (concept)				
List of requirements				
Field	*No.*	*Specifications*	*Value*	*Date*
Display using				
	1	User friendly: simple and intuitive		10.05.2004
	2	Easy to create/update the display/process	Effort [$] to maintain <10% of overall project effort	07.06.2004
	3	Easy to update process step status/completion		10.05.2004
Architecture				
	1	Clear and comprehensible		07.06.2004
	2	Holistic view of the product development process		07.06.2004
	3	Shows interdependencies between process steps		07.06.2004
	4	Displays information for individual (Inbox, outbox)		07.06.2004
	5	Allows people to see where their work results flow		07.06.2004
	6	Scalable views (within process boxes; time scale changes)		07.06.2004
	7	Display must have temporal aspect		05.02.2004
Content/Function				
	1	Offers a picture of current product development status (i.e. dashboard)		07.06.2004
	2	Supporting people in planning, execution, control and diagnosis/ review of the development process		07.06.2004
	3	Gives some form of waste-indication or rather supports early waste detection		10.05.2004
	4	Simple representation of the value stream		07.06.2004
	5	Supports the identification of value-adding steps		07.06.2004
	6	Enable engineers to make work decisions (Lean principle)		07.06.2004
	7	Incorporates/implements lessons learnt		10.05.2004
	8	Process step output includes output (virtual) location info		07.06.2004
	9	Display prevents information disconnects and displays when information is available	- Waiting for information that already exists (avoidance of unnecessary information disconnects) - Not doing work whose output is needed soon	05.02.2004
	10	Includes some form of overschedule indication		07.06.2004
	11	Simulates reality (real project) with acceptable accuracy		07.06.2004
	12	Should discourage batching of information		07.06.2004
	13	Improving people's communication by providing a common reference		10.05.2004
	14	Providing persons with continuous access to things they need to know		07.06.2004
	15	Providing engineers with information about: where and when communication is necessary		07.06.2004
	16	Providing engineers with all relevant information to better flow work		05.02.2004
Industrial psychology				
	1	Must avoid 'gaming' on the part of the people involved		07.06.2004
	2	Must not be punitive		07.06.2004
	3	Must include excitement factors that people want to use it		10.05.2004

Figure E 1-2: List of requirements

A big size view of ➲ Figure E 1-2 can be found in ➲ appendix I 12 that also displays some additional information about the ‘originator’ of the specifications listed.

E 2 Display development

Even though there is not such a specification, the team members early began to think in 'boxes' and 'arrows' regarding to the future display. The reason for this can mainly be seen in ordinary *Value Stream Maps (VSM)* where value creating activities are represented by boxes, or at least base on some kind of boxes, and arrows that connect those to a flow of activities. Also the targeted display aims at the representation of value streams. Furthermore, the use of boxes and arrows to depict the sequence of and dependencies between steps is very intuitive.

The two basic aspects within the next steps concern the questions *what information is useful for the representation* and *how can it be displayed*. This especially refers to the specifications A-2, C/F-4, C/F-5 and C/F-16, shown in ➲ Figure E 1-2. Hereby, the first letter specifies the category, the second one is the serial number of the specification.

E 2.1 Displayed information in the representation

The following two figures (➲ Figure E 2-1 and Figure E 2-2) show a list of aspects or rather factors that can be contained by arrows and boxes, or that should be considered within the next development steps. The sources of those collections are literature (NEGELE ET AL., 1999) but also team discussions and the author's own experience.

What can be contained by the arrows?		
Data exchange		
	Information/data/knowledge about tasks, issues, etc.	
	Category of info: product, process, project, business/ target information, factual information, operation information/ task relation information, context knowledge, control information	
	Specification of file types: .doc, .cad, .txt, .xls	
Synchronisation/Feedback		
	Importance, priority of connections	
	Punctuality: late, in time, premature	
	Processes linked and coordinated	
	Requests of other process participants, agreement in attributes, status of coordination	
	Different colours indicate coordination status between two process participants	
	Assessment of the information quality of exchanged information	
Interaction		
	Kind of direction: unidirectional/bidirectional/multidirectional	
	Duration : Interaction at one point in time, over a period of time	
	Type of interaction: Data exchange, reciprocal dialog/discussion, feedback, notification, program control, data releases	
	Type of info flow: pull or push	

Figure E 2-1: Information contained by arrows

What can be contained by the boxes?		
Process description		
	Classification within the process (phase)	
	Name of the process chain	
	Name of the process element	
	Process type	
	Description of the process element including inputs and outputs	
	Convergence rate (very slow – very fast)	
Scope of work		
	List of work packages, tasks, actions required/planned	
	Best practice procedure	
Targets		
	Process targets	
	Project goals/objectives	
	Project priority, task priority (high – low)	
Schedule		
	Target start and finish date	
	Actual start and finish date	
	Time before/after start of process	
	Cycle time/ In process time/ Duration	
Spent resources		
	Costs	
	Resources (human & non-human)	
	Work hours/ common hours	
	Used capacity and resources (money)	
Organization		
	Name of process owner including department/organization, phone, email	
	Roles, responsibilities rights	
	Organization	
	Hierarchy-info	
	Affected teams	
Synchronization		
	Information about coordination/link with process participants (traffic light as measure for synchronization)	
	Preliminary info in form of confidence intervals	
	Interface data ('I need'/'He needs')	
	Input and output boxes with required documents, models, specs, specific information	
Risk management		
	Level of criticality	
	Probability of rework, cost of delay	
	Critical factors	
	Bulletin board with 'top ten' problems	
Task performance		
	Description of used competence (Design experience, engineering, CAD skills, …)	
	Classification of the project: Individual project, group decision, milestone meeting	
	Overview of used tools/methods (Experimental equipment, CAD workstation, special software, …)	
Documentation		
	Docu thoroughness (none – total)	

Figure E 2-2: Information contained by the boxes

Based on these lists, it now is possible to create first drafts of how boxes may look like and how they get connected by the arrows. Before doing so, it might be beneficial to discuss those lists with project manager and engineers in order to verify those ideas and to add some new points that are relevant in practice. From the author’s point of view, it might also be helpful to learn more about communication structures within product development processes. Insights gained from those investigations could help to add more information to the arrows, compared with conventional value stream maps where arrows just specify the flow direction, and thus to supply the user of the display with much more details at the same time.

E 2.2 Analysis of existing Value Stream Mapping (VSM) tools

Searching for new representations of value streams suggests to look at existing tools first and to analyze their strengths and weaknesses and the environment they are used.

During research the team came across an analysis performed by MILLARD (2001), that characterizes six different value stream mapping tools against a number of criteria commonly used for analyzing business processes. The criteria are clustered into three major categories: *Time*, *Work* and *Structure* (➲ I 14). The VSM tools considered are *Gantt charts*, *Process flow charts*, *Design Structure Matrices (DSM)*, *Learning To See*, *Systems Dynamics*, and *Ward/LEI*. Short descriptions of the tools are provided in appendix ➲ I 13.

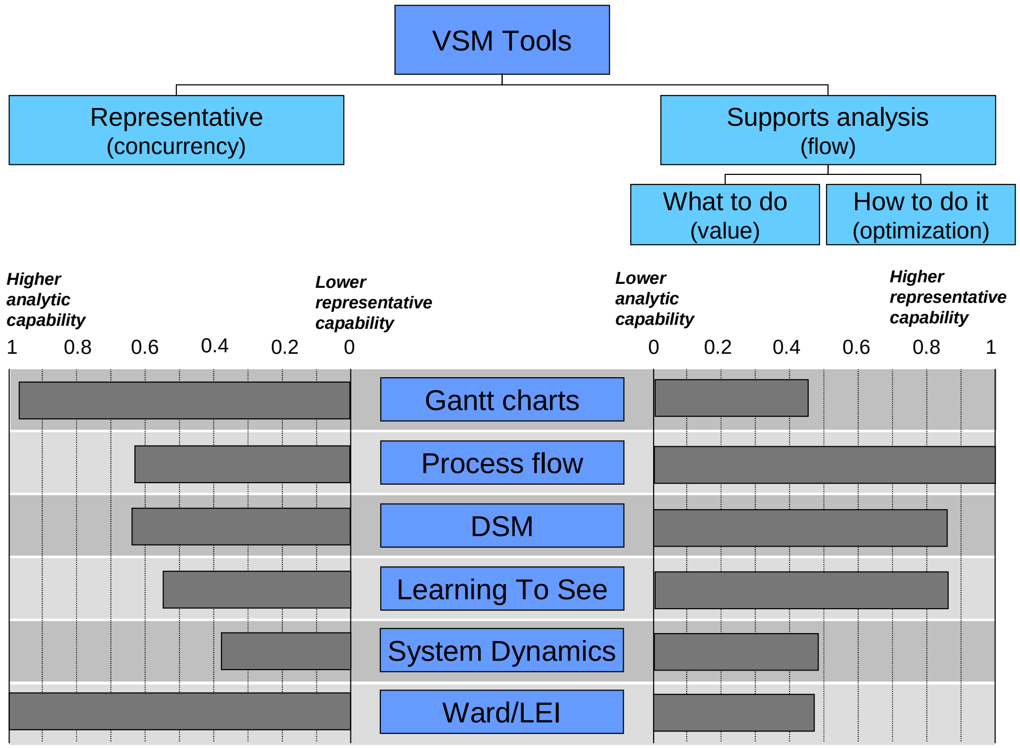
Results of the analysis performed by MILLARD

The analysis shows that VSM tools differ in their ability to accurately *represent* a process i.e. to capture its timing, versus their ability to support improvement *analysis* for the process i.e. to capture the flow and the value of activities required (➲ Figure E 2-3)(MILLARD, 2001, pp. 46-50). Tools of the first category are said to support the *communication of a process* to the process participants, while tools of the second category rather support people in *deciding how to make the process more efficient*.

With respect to the second category, MILLARD makes a further distinction in terms of whether a tool supports decision making in one of the both ways: *what to do* or *how to do it*.

The tools that best provide support in deciding *what to do*, primarily cover work criteria and try to describe the value of an activity embedded in a super ordinate process. This can be understood is a kind of functional analysis, and finding an answer to the question what is needed to fulfill the established requirements (MILLARD, 2001, p. 48).

The tools that focus on the support in determining *how to do it*, primarily cover the structure attributes of a process, and apply to the optimization of process steps in consideration of time, resources and current capabilities (MILLARD, 2001, p. 48).



Modified from MILLARD (2001, p. 48)

Figure E 2-3: VSM tool categorization and tool capability quantification

In order to better understand the VSM tools' capabilities, the previous qualitative characterization of the tools against the criteria was quantified. For this, Millard did two things: first, he weighted each criteria regarding to its importance in the representative and analytical aspect of value stream maps, and second, he quantified the ability of a tool to account for the different criteria.

The final result of this evaluation is the characterization of each tools capability expressed in two values, the representing value and the analysis value. The values were normalized to a rating of relative capability. The analysis shows that Ward/LEI maps, with a score of 1.0, and Gantt charts, with a score of 0.97, are best capable tools to represent a process. Process flow maps, with a score of 1.00, and DSMs, with a score of 0.86, best serve in analyzing processes (➲ Figure A 2-1).

Millard also explains that the derivation of improvement measure is largely driven by analysis-based aspects of a mapping tool (MILLARD, 2001, p. 50).

Conclusion

The analysis has shown that some VSM tools have higher analytical or representative capabilities than others do. It was said that tools of the representative category support the communication of the process to the people, while tools of the analytical category support in making decision about process improvements.

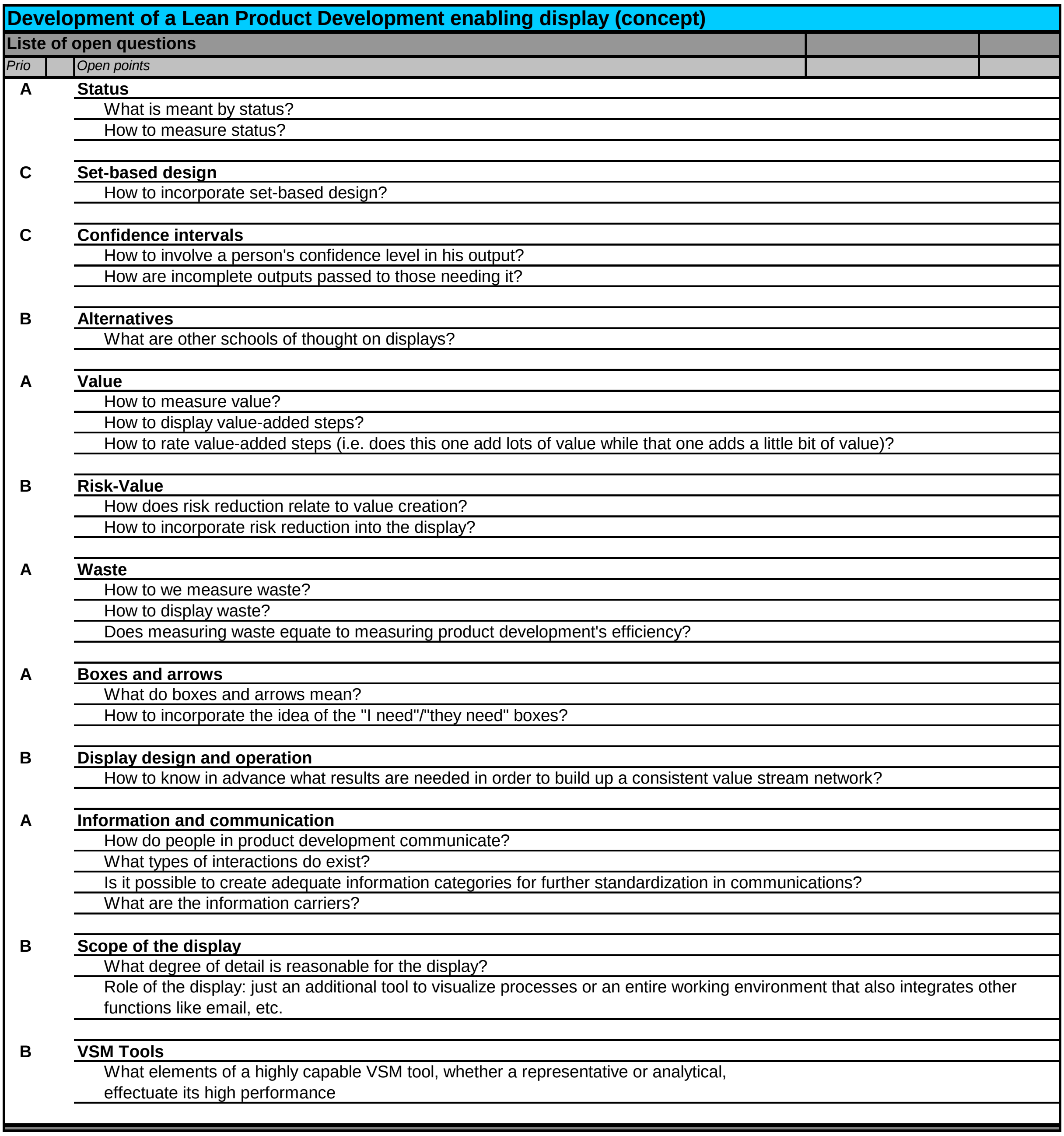
The introduction of this categorization and the fact that none of the analyzed tools is strong in both categories, let draw the following inference:

- The display specifications (➲ Figure E 1-2) demand both from the new display, enabling faster process improvements and facilitating engineer's communication and understanding of processes. This implies that different tools/views have to get integrated into or rather connected within the new display solution
- In order to benefit from the strengths of the strongest tools of a category, requires to learn why exactly some tools account best to a certain criteria. Understanding this, allows much more flexibility in the creation of a new value stream representation that can combine the benefits of both categories

E 2.3 List of open questions

When the author left the project, he was a member of for a couple of months, there were a good number of open questions that could not be investigated so far, but which have to get clarified during the next steps of the display development by the project team. Those are collected in a dynamic list (➲ Figure E 2-4).

Some of the questions are still of very basic nature for the development of a successful display. This includes aspects like *what value is* and how it *can be measured*. If all of those questions and problems can be solved step by step, or in several loops closely connected with the gradual specification of the display, future will show.



Development of a Lean Product Development enabling display (concept)

Liste of open questions

Prio		*Open points*		
A		**Status**		
		What is meant by status?		
		How to measure status?		
C		**Set-based design**		
		How to incorporate set-based design?		
C		**Confidence intervals**		
		How to involve a person's confidence level in his output?		
		How are incomplete outputs passed to those needing it?		
B		**Alternatives**		
		What are other schools of thought on displays?		
A		**Value**		
		How to measure value?		
		How to display value-added steps?		
		How to rate value-added steps (i.e. does this one add lots of value while that one adds a little bit of value)?		
B		**Risk-Value**		
		How does risk reduction relate to value creation?		
		How to incorporate risk reduction into the display?		
A		**Waste**		
		How to we measure waste?		
		How to display waste?		
		Does measuring waste equate to measuring product development's efficiency?		
A		**Boxes and arrows**		
		What do boxes and arrows mean?		
		How to incorporate the idea of the "I need"/"they need" boxes?		
B		**Display design and operation**		
		How to know in advance what results are needed in order to build up a consistent value stream network?		
A		**Information and communication**		
		How do people in product development communicate?		
		What types of interactions do exist?		
		Is it possible to create adequate information categories for further standardization in communications?		
		What are the information carriers?		
B		**Scope of the display**		
		What degree of detail is reasonable for the display?		
		Role of the display: just an additional tool to visualize processes or an entire working environment that also integrates other functions like email, etc.		
B		**VSM Tools**		
		What elements of a highly capable VSM tool, whether a representative or analytical, effectuate its high performance		

Figure E 2-4: List of open questions

F Project review

In the current thesis, ➲ Poor knowledge re-use was established as one of the waste drivers within product development. Enabling the re-use of knowledge not only asks for an adequate knowledge management system but also the readiness of people to review their projects and activities. Working out the problems and obstacles as well as the advances is basic for further improvement in any area, not only in product development.

In the following sub-chapters the author thus briefly evaluates his own project abroad from different points of views. This not only serves for the author's own knowledge management, but also provides some feedback for people involved, and might motivate and support students planning a similar project.

At this point, it has to be mentioned that the author will review the project very critically, to really extract the essentials for further improvement with future and similar projects. The two used symbols, ⬆ and ⬇, should be interpreted by the reader as '*was explicitly positive and beneficial*' or rather '*was critical and adverse*'.

F 1 Organization of project abroad

Writing the thesis abroad firstly demands the willingness of the single student to do so. The realization however also depends on other factors like finding the right contacts to a foreign university, ensuring enough funding for such a project, which is essential for the candidate's admittance there, and finally to put all these things together in a reasonable scope of time. In the current case, the contact to MIT was made about six months before the leaving date from Germany. The formal application at MIT and applications for scholarships and the visa could be completed within three months before departure. Positive or rather critical aspects during this phase of the project were in particular:

⬆ Establishing contact to Prof. Seering (MIT) by Prof. Lindemann (TUM)

⬆ Support by Gracia McGovern (MIT German Program) and Maria Brennan (International Students Office, MIT) during the application process

⬇ Long uncertainty concerning the realization of the project due to high dependency on scholarships for funding

F 2 Project work

Reviewing the thesis work actually can be broken down into two clear-cut phases, which were tightly connected with the initial organization of the project environment. The first one roughly regards to the first three months when a lot of new things had to get managed accompanied by some major obstacles. This begins with getting settled down (both apartment and office) and getting into a new field of study in a foreign language, to defining the individual project targets. After that was done, the individual project work became much more efficient and targeted. The chance to immediately discuss issues and ideas with another team member located in the same office made a big contribution to this. The list below outlines the most important aspects:

Getting started

⬇ Starting work at MIT during the IAP (Independent Activity Period) when a lot of people were absent

⬇ Setup of the project team lasted about one month

- 👎 Office only available after 3 months

Project definition

- 👍 Relatively free choice for the author concerning the specific subject of this research
- 👎 Team project targets were not explicitly worked out within the team
- 👎 Definition of the author's specific project targets only completed after two and a half month (March)

Project work

- 👍 At the beginning work was very theoretical, later it had much more grip
- 👍 The field of lean was completely new to the author and highly interesting to work on
- 👍 Largely independent working with regular feedback meetings together with Prof. Seering
- 👍 Work enabled a more holistic view of product development processes and showed up some fields for further improvement in this area beyond the scope of the thesis
- 👎 Seven months turned out as a short time to get used to a completely new field of study and do some research
- 👎 English skills of the author mainly were bottleneck for work progress in the first months

Project team

- 👍 Open-mindedness of other team members towards new ideas
- 👍 The later co-location with one team member in a single office facilitated the exchange and verification of ideas, and motivated each other
- 👎 Team only existed for the first three months, later the team members worked more independently
- 👎 Additional team meetings to discuss certain issues were always driven by the author
- 👎 Other team members were also very busy with taking courses compared with the author what generally meant obstacles for synchronizing tasks with them

F 3 Supervision

The author's work was supervised by Prof. Seering (MIT) and Dipl.-Ing. Stricker (MIT). Procedures, problems and ideas were discussed in team and face-to-face meetings with average intervals of 1.5 weeks, and in phone conferences with intervals of 2.5 weeks respectively. Positive and critical points established are listed below:

Supervision by Prof. Seering

- 👍 Transition to individual meetings around April rather allowed the discussion of individual issues
- 👍 Pleasant and uncomplicated working climate
- 👍 Direct supervision and feedback by a professor experienced in product development
- 👍 Openness towards proposals of the author concerning the thesis's subject of research
- 👍 Summarizing the results of a meeting, performed by the author and reviewed by the professor, turned out as a good way to prove and synchronize the understanding and expectations on both sides
- 👎 Vast team meetings at the beginning of the project did not allow many individual discussions about specific concerns of single students

- ⊖ Busy schedule of Prof. Seering during spring term sometimes made it difficult to meet regularly; spontaneous meetings due to specific issues arose were difficult

<u>Supervision by Dipl.-Ing. Stricker</u>

- ⊕ High openness to new approaches (lean philosophy) and proposals, fairly no constraints
- ⊕ Confidence in the author's way of procedure enabled independent working
- ⊕ High reliability in scheduled meetings
- ⊖ Partially irregular report intervals
- ⊖ Meetings had always to be 'pulled' by the author
- ⊖ Long distance between Boston and Munich made it partially difficult to discuss some issues in detail; thus phone meetings had to be more a kind of report meetings

F 4 Self-reflexion

When the author decided to do his thesis abroad, he surely was looking for a challenging task that would round off his study in mechanical engineering. In fact, it was. The last seven months have been full of new impressions, insights, ideas, experience, friendships and fun, closely connected with high levels of hard working, self-discipline and self-motivation. A couple of obstacles occurred and benefits gained, are shown below:

<u>Personal problems and obstacles</u>

- ⊖ Bad start with finding a place to stay (2 weeks)
- ⊖ Doing research and reading a lot of papers not sufficiently trains one's active English vocabulary. This especially bettered when having a office, which enabled to talk more with other students. Starting to write the thesis also was very advantageous in this point.
- ⊖ Language skills constrained personal appearance at the beginning
- ⊖ Additional English course for practicing the language skills would have been useful
- ⊖ Socializing with MIT students, except for the official events in the student dorm, was sometimes difficult since all of them were very busy with research or course homework
- ⊖ Seven months to get used to a completely new field and to do some research meant a tight time frame for the thesis
- ⊖ Striving for perfectionism and too high personal expectations concerning project results, combined with high expenses of the whole project, sometimes put the screws on the author
- ⊖ Working on issues which did not directly align with my project targets
- ⊖ Cold weather in January until late March prevented to cycle or travel around a little bit more; later, the time was already to short for this

<u>Personal benefits</u>

- ⊕ Improving my English skills in four dimensions (speaking, listening, reading and writing)
- ⊕ New understanding of the complexity of product development processes linked with a number of new ideas for potential improvement
- ⊕ More holistic view of business processes and enterprise networks (value streams)
- ⊕ Experience that progress is fast but possible to keep pace with
- ⊕ Awareness and appreciation of the German education system (no tuition)
- ⊕ Got to know a lot of interesting people, profiles and attitudes that motivated the author

- Increased open-mindedness towards other cultures, in particular people coming from Asian countries
- More sensitivity in respect to the challenge of integrating people from a different culture and a different language in the own society
- Motivation and new plans both job-related and private
- Revealing personal potential for improvement by learning about own limits in some specific aspects
- Fun with students from other cultures
- Trip to New York with sightseeing tour

F 5 Resume and recommendations

F 5.1 Resume

Looking back, the last seven months have been full of new impressions, insights and ideas about product development, the author himself and the world. Not every day was a sunshine day and accompanied by the one or other obstacle. Writing this thesis in English surely counted among the greatest challenges. Indeed not perfect and bearing potential for improvement, the effort to do this however was totally worth it. Getting used to a completely new field of study, the subject of lean, challenged the author in another way. It provided precious knowledge in a very current topic of research and opened a completely new view of product development processes showing up high potentials for future improvement. Taking all the benefits together, the current thesis was just the right thing to round off the study in mechanical engineering and to lay a solid basis for the next chapter in life.

F 5.2 Recommendations

- English skills

  In view of increasing internationalization of markets, English skills count among the basic skills in various businesses. Even though the Technical University of Munich offers a number of different English courses to its students, the majority of those courses is limited to listening or the reading of various articles. However, what is needed, are English courses in which students can train their speaking and writing skills in an active way in order to build up a sound basic vocabulary and to eliminate language barriers.

- Stays abroad

  Stays abroad should become a natural and integrated part within the study of each student. Such a project not only enhances language skills but also broadens the individual horizon in terms of expertise and social competence.

- Financial support

  Even though projects abroad are propagated by many sides as providing the just mentioned benefits, during the organization of such a project the student finally is left alone. A big percentage of those plans fail because of too high risks in and problems with funding. In the majority of cases there only is a little or no financial support at all on the part of the chairs. This also applies to term or thesis projects abroad which actually mean much more benefits for the chairs compared with a pure study times abroad when the student is exclusively engaged with courses.

- Exchange programs during high schools

  Exchange programs during high schools should be supported and funded more intensive. Even if the participation in such a program means the loss of one whole year to the students, in most cases the individual benefit especially concerning language skills is significant and invaluable. Furthermore, learning a new language in young age turns out as much easier than later.

G Summary and outlook

G 1 English

G 1.1 Summary

Time to market still proves to be one of the key factors for successful enterprises, beside quality and cost to market. In the majority of cases, time to market consists for the most part of the duration of the product development process. Long cycle times in the development process are often the result of high levels of rework and iterations caused by a large number of problems such as poor planning or deficient transparency as regards processes.

The primary target of the thesis is to investigate waste within product development, based on, but not limited to, the investigation of the *transferability* of the lean seven types of manufacturing waste established by Toyota to product development. The secondary target aims to an investigation of how to apply the lean principle transparency to product development.

As basis for the current research, the author worked out a concise overview of the lean philosophy existing of three major parts: five lean principles, Toyota's fundamental rules, and lean manufacturing tools, practices and flow techniques (➲ B 2).

Since the target is to investigate the applicability of lean manufacturing principles to product development, a basic step was to analyze the differences or analogies between them: product development is not interested in the transformation of physical material but in the creation of information (➲ B 3), thus, *product development is an information creation factory.*

After the analysis of some basic aspects of information, information creation was analyzed more detailed in terms of product development processes. All finding was a highly complex information flow. Thus, in order to better understand the information creation and to make that complexity more transparent, two different views were introduced: *micro level* and *macro level*. Hereby, the term micro level refers to the specific work of an engineer, the term macro level refers to the whole process and how the process elements build up the process network (➲ Figure C 2-1 and Figure C 2-2). Both models make aware of the big number of variables during information creation, and each of them represents a potential source of waste.

The following investigation of waste within product development has shown that the re-interpretation of the lean seven types of manufacturing waste to product development with respect to information and information flow respectively is possible to the greatest possible extent and can offer useful results. In this point, the focus on information in the re-interpretations is not limited to files converted or excessive data storage but refers to the whole information creation process.

The investigation yielded that precedent re-interpretations of other authors partially were very fragmentary, did not address the problem landscape adequately, exhibit some inconsistencies or were not very precise. Comparing the different existing approaches also made obvious, that the re-interpretations of the manufacturing types of waste to product development were not able to completely describe development waste. For this reason, a new waste system was created to eliminate all those weaknesses. The waste system is represented by the waste pyramid (➲ D 1).

The waste pyramid distinguishes between *waste types* and *waste drivers*. Waste types provide an answer to the question what can be wasted. Waste drivers refer to the question what the underlying causes are. Based on these definitions, the author also concluded that the lean seven types of manufacturing waste should be considered as waste drivers.

The new set of waste drivers established contains 10 main categories of waste drivers with 37 sub-categories in total (➲ appendix I 4). The sub-categories were introduced in order to furnish the whole waste system and 'waste thinking' with more grip, especially for the practical use. In addition to the original seven categories of manufacturing waste, the three following categories were introduced in order to better describe waste occurring in product development:

- *Re-invention*, including
  - Poor design re-use
  - Poor knowledge re-use
- *Lack of system discipline*, concerning
  - Unclear goals and objectives
  - Unclear roles, responsibilities and rights
  - Unclear rules
  - Insufficient readiness to cooperate
  - Poor schedule discipline
  - Incompetence/ poor training
- *Limit IT resources*, including
  - Poor compatibility
  - Poor capability
  - Low capacity

Working out the new set of waste drivers showed that there were a lot of interrelations between the waste drivers themselves, in fact, a whole cause-effect network. Thus, an easy elimination of those waste drivers within the company might be problematic, especially with such a large number of sub-categories. Finding the root-causes could not be done by just thinking about those interdependencies.

In order to solve this problem, a systematic cause-effect analysis (➲ D 4.1) was performed. Based on its results (➲ Figure D 4-2), a sequence for the elimination of those waste drivers could be derived, and was transferred into a checklist for waste elimination (➲ Table 2).

With respect to the secondary project target, the development of a display, a problem analysis was performed in order to define the exact project targets, targeted results, and to collect all necessary specifications. Some first development steps dealt with a search for adequate information 'attributes' contained by the future display. Further, an analysis of value stream mapping tools performed by MILLARD was discussed, including a conclusion for future development activities. All open questions were collected in a list.

G 1.2 Outlook

Even though the current thesis contains a detailed investigation of waste within product development, many questions remain unanswered, not only limited to the matter of waste. With respect to the subjects waste and display development, a list of open questions but also some concrete suggestions for further research in the particular field was added at the end of the respective chapter (Waste: ➲ D 5, Display development: ➲ E 2.3).

The following ideas are considered as very fruitful for the further display development from the author's point of view.

Going ahead with study of information categories and communication

The cause-effect matrix showed that ineffective communication and deficient information quality are active/critical or rather highly critical elements within the whole network of waste drivers. Since both play a major role for the display, it would be useful learning more about these two issues. With respect to the display development, those insights could help to add much more information to the targeted value stream representation.

Studying communication within development processes might also facilitate recognizing certain patterns and structures in communication, which then can be integrated into the display and with it providing maximum benefit to the users.

Furthermore, investigating the matter of information for example might give some insights in the frequency of the combinations of certain information types, information carriers, communication mediums used. In particular, this might reveal some common ‘information channels’, which in turn help to standardize companies’ internal communication processes.

Integrate rules of queuing theory into the display tool

According to REINERTSEN (1997, p. 64) there are two ways to monitor ‘the health’ of a development process. One method consists in monitoring cycle times through the process and aligns with what most companies do. The other method consists in monitoring the queues. In this point, LITTLE’S Law states that both approaches will give an identical answer (REINERTSEN, 1997, p. 64). However, it is said that monitoring queues has a significant advantage, since it provides *instant information* about the health of a process, and thus essentially contributes to display the current status of the development process. This exactly aligns with one of the most essential display specifications.

Development of a 3D value stream representation

Even if the targeted display focus on a 2D representation of the value stream, the next step in the development of process supporting tools might be the creation of a 3D model of the value stream that combines different lens like product, process and ‘people’ view. Bringing those three views together would be very beneficial, since this also addresses the way people are thinking within development processes in practice. Beyond that, 3D models have a much bigger potential concerning the amount of information displayed. Linked with some haptic devices like cyber gloves, teams members can manage their processes in virtual rooms by drag and drop.

Now this is not the end. It is not even the beginning of the end. But it is, perhaps, the end of the beginning.

- Winston Churchill

G 2 German

G 2.1 Zusammenfassung

Time to Market gilt auch weiterhin als einer der Schlüsselfaktoren für erfolgreiche Unternehmen, parallel mit *Quality to Market* und *Cost to Market*. In den allermeisten Fällen wird Time to Market zu einem Großteil von der Entwicklungsdauer eines Produktes bestimmt. Die Ursache für lange Produktentwicklungszeiten liegt oft darin, dass Aufgaben überarbeitet oder zusätzliche Iterationen vollzogen werden müssen. Der Grund dafür wiederum ist eine große Anzahl an Problemen wie beispielsweise ungenügende Planung oder ein niedriger Grad an Prozesstransparenz.

Das Primärziel der vorliegenden Diplomarbeit ist die Untersuchung von *Waste*, d.h. Verschwendung im Bereich der Produktentwicklung, basierend auf, aber nicht beschränkt auf die Untersuchung der *Übertragbarkeit* der 7 klassischen, von Toyota begründeten Waste-Kategorien aus dem Bereich *Lean Manufacturing* auf die Produktentwicklung. Das Sekundärziel betrifft ebenfalls eine Untersuchung, in welcher Weise das Lean-Prinzip Transparenz auf die Produktentwicklung angewendet werden kann.

Als Grundlage für die vorliegende Forschung, wurde zu Beginn eine kurze und prägnante Übersicht über die Lean-Philosophy ausgearbeitet, welche drei größere Bereiche beinhaltet: Die fünf Lean-Prinzipien, grundlegende Regeln bei Toyota, und Lean Manufacturing Werkzeuge, Praktiken und Flusstechniken (➲ B 2).

Da das Ziel darin besteht, die Anwendbarkeit von Lean Manufacturing-Prinzipien auf die Produktentwicklung zu untersuchen, besteht ein sehr grundlegender Schritt darin, die Unterschiede, aber auch Analogien zwischen beiden Bereichen zu analysieren: Produktentwicklung interessiert sich nicht für die physikalische Transformation von Materie, sondern die Generierung von Information (➲ B 3), aus diesem Grund, *Produktentwicklung ist eine informationsgenerierende Fabrik*.

Im Anschluss an die Analyse von einzelnen grundlegenden Aspekten bezüglich Information, wurde die Informationsgenerierung im Hinblick auf Produktentwicklungsprozesse ausführlicher betrachtet. Was gefunden wurde, war ein hoch komplexer Informationsfluss in diesem Bereich. Um die Informationsgenerierung besser zu verstehen und die erfahrene Komplexität transparenter zu machen, wurden vom Autor zwei verschiedene Sichtweisen eingeführt: *Micro Level* und *Macro Level*. Micro Level bezieht sich dabei auf die ganz spezielle Aufgabe eines Ingenieurs. Im Gegensatz dazu, bezieht sich der Begriff Macro Level auf den ganzen Prozess und darauf, wie die einzelnen Prozesselemente miteinander zum Prozessnetzwerk verbunden sind (➲ Figure C 2-1 and Figure C 2-2). Beide Sichtweisen bzw. Modelle verdeutlichen ganz besonders die große Anzahl an Variablen, die unter der Informationsgenerierung gelten. Jede davon eine potentielle Quelle von Waste dar.

Die folgende Untersuchung von Waste im Bereich der Produktentwicklung hat gezeigt, dass die Reinterpretation der 7 klassischen Waste-Kategorien von Lean Manufacturing auf die Produktentwicklung hinsichtlich Information bzw. Informationsfluss bis zu einem gewissen Maße möglich ist, und zu nützlichen Ergebnissen führen kann. Dabei sei erwähnt, dass der Fokus auf Information bei den Reinterpretationen nicht auf konvertierte Dateien oder übermäßige Datenspeicherung begrenzt ist, sondern den vollständigen Prozess der Informationsgenerierung in die Betrachtung mit einbezieht.

Die Untersuchung ergab, dass vorausgehende Reinterpretationen anderer Autoren teilweise sehr bruchstückhaft sind, die Problemlandschaft nicht ausreichend erfassen, Inkonsistenzen beinhalten oder in ihren Definitionen nicht sehr genau sind. Wenn man die verschiedenen bestehenden Ansätze mit einander vergleicht, fällt ebenso auf, die Reinterpretationen der 7 klassischen Waste-Kategorien aus dem Bereich Lean Manufacturing auf die Produktentwicklung nicht ausreichen, um Waste in der Produktentwicklung vollständig zu beschreiben. Genau aus diesem Grund wurde ein neues Waste-System entwickelt, welches all jene Schwächen nicht mehr aufweist. Das Waste-System wird durch eine Waste-Pyramide dargestellt (➲ D 1)

In der Waste-Pyramide wird zwischen *Waste-Typen* und *Waste-Drivern* (Waste-Verursachern) unterschieden. Während Waste-Typen eine Antwort auf die Frage liefern, was verschwendet werden kann, beziehen sich Waste-Driver auf die Frage, was die zugrundeliegenden Ursachen sind. Konsequenterweise sollten die 7 klassischen Waste-Kategorien aus dem Bereich Manufacturing zukünftig auch als Waste-Driver bezeichnet werden.

Das neue Set von Waste-Drivern, welches erstellt wurde, enthält insgesamt 10 Hauptkategorien von Waste-Drivern und insgesamt 37 Unterkategorien (➲ Anhang I 4). Der Grund für die Einführung von Subkategorien war die Absicht, das ganze Waste-System und Waste-Denken gerade für den praktischen Gebrauch mit mehr Grip auszustatten. Zu den 7 klassischen Waste-Kategorien aus dem Manufacturing-Bereich, wurden die drei folgenden Hauptkategorien mit den entsprechenden Unterkategorien hinzugefügt, um Waste in der Produktentwicklung besser benennen zu können.

- Neuerfindung, einschließlich
    - Geringe Wiederverwendung von Design-Lösungen
    - Geringe Wiederverwendung von Wissen
- Mangel an Systemdisziplin, einschließlich
    - Unklare Ziele
    - Unklare Rollen, Verantwortlichkeiten und Rechte
    - Unklare Regeln und Vereinbarungen
    - Mangelnde Kooperationsbereitschaft
    - Geringe Termineinhaltungs-Moral
    - Inkompetenz und schlechtes Training
- Begrenzte IT-Ressourcen, bestehend aus
    - Geringe Kompatibilität
    - Geringe Leistungsfähigkeit
    - Geringe Kapazität

Die Ausarbeitung eines neuen Sets von Waste-Drivern hat gezeigt, dass es zwischen den Waste-Drivern selbst eine Vielzahl an Abhängigkeiten und Wechselwirkungen gibt. In Wirklichkeit handelt es sich um ein ganzes Ursache-Wirkungs-Netzwerk. Genau aus diesem Grund scheint eine einfache Elimination von Waste-Drivern problematisch, und wird zusätzlich erschwert durch die große Zahl der Unterkategorien. Im vorliegenden Fall, konnten die Grundursachen nicht mehr nur durch einfaches Nachdenken über diese Abhängigkeiten gefunden werden.

Um dieses Problem zu lösen, wurde eine systematische Ursache-Wirkungs-Analyse durchgeführt (➲ D 4.1). Auf Basis der gewonnen Ergebnisse konnte dann eine Reihenfolge bei der Elimination von Waste-Drivern abgeleitet (➲ Figure D 4-2) und in Form einer Checkliste für die Elimination von Waste dargestellt werden (➲ Table 2).

In Bezug auf das sekundäre Projektziel, welches die Entwicklung eines Displays betrifft, wurde eine Problemanalyse durchgeführt, um die genauen Projektziele, geplanten Projektergebnisse festzulegen und alle notwendigen Spezifikationen zu sammeln. Erste Entwicklungsschritte befassten sich mit der Suche nach Informations-Attributen für das geplante Display. Des weiteren, wurde eine Analyse von Value Stream Mapping Tools, die von MILLARD durchgeführt worden war, diskutiert und daraus Schlussfolgerungen für zukünftige Entwicklungstätigkeiten abgeleitet. Alle offenen Fragen wurden in einer Liste gesammelt.

G 2.2 Ausblick

Auch wenn sich die vorliegende Diplomarbeit eingehend mit der Untersuchung von Waste in der Produktentwicklung beschäftigt hat, bleiben viele Fragen unbeantwortet, was sich jedoch nicht alleine auf Waste bezieht.

Hinsichtlich der Punkte Waste und Displayentwicklung, befindet sich jeweils eine Liste mit offenen Fragen, aber auch ganz konkreten Vorschlägen für weitere Untersuchungen am Ende des entsprechenden Kapitels (Waste: ➲ D 5, Displayentwicklung: ➲ E 2.3)

Die im folgenden dargestellten Ideen tragen nach Einschätzung des Autors für die weitere Entwicklung des Displays einen hohen Nutzen.

Fortsetzung der Untersuchung von Informationskategorien und Kommunikation

Die Ursache-Wirkungs-Analyse hat gezeigt, dass ineffektive Kommunikation und mangelhafte Informationsqualität aktiv/kritische bzw. hochkritische Elemente innerhalb des ganzen Netzwerks von Waste-Drivern darstellen. Da beide für das Display eine größere Rolle spielen, wäre es hilfreich, mehr über jene zwei Problempunkte herauszufinden. Im Hinblick auf die Displayentwicklung könnten jene Erkenntnisse dazu beitragen, viel mehr Information in die geplante Value Stream-Repräsentation zu packen.

Eine weitere Beschäftigung mit dem Thema Kommunikation in Produktentwicklungsprozessen könnte ermöglichen, bestimmte Muster und Strukturen bezüglich Kommunikation zu erkennen, welche dann wiederum in das Display integriert werden können und dem Benutzer so maximalen Nutzen bieten.

Darüber hinaus könnte zum Beispiel die Untersuchung des Themas Information neue Einblicke in die Häufigkeit von Kombinationen aus verwendeten spezifischen Informationstypen, Informationsträgern und Kommunikationsmedien ermöglichen. Dies könnte dazu beitragen bestimmte ‚Informationskanäle' zu identifizieren, und darauf aufbauend helfen, unternehmensinterne Kommunikationsprozesse zu standardisieren.

Integration der Schlangen-Theorie in das Display

Nach REINERTSEN (1997, p. 64) gibt es zwei Wege, um die ‚Gesundheit' eines Entwicklungsprozesses zu monitoren. Eine Methode besteht darin, die Durchlaufzeiten zu monitoren, und ist das, was die meisten Unternehmen durchführen. Die andere Methode besteht im Monitoren von Schlangen. Laut LITTLE'S LAW werden beide Ansätze zu einer gleicher Antwort führen (REINERTSEN, 1997, p. 64). Jedoch wird behauptet, dass das Monitoren von Schlagen einen bedeutenden Vorteil hat, da es *sofortige Information* über die Gesundheit eines Prozesses bietet, und damit eine ganz wesentliche Rolle spielt für die Anzeige des augenblicklichen Status des Produktentwicklungsprozesses. Dies wird genau von einer der wichtigsten Display-Spezifikationen verfolgt.

Entwicklung einer 3D Value Stream Darstellung

Auch wenn das geplante Display eine 2D Repräsentation des Value Streams sein wird, könnte der nächste Schritt in der Entwicklung eines prozessunterstützenden Tools die Generierung eines Models eines 3D Value Streams sein, welches unterschiedliche Perspektiven wie beispielsweise Produktsicht, Prozesssicht, und Organisationssicht miteinander verbindet. Die Verknüpfung dieser drei Sichtweisen wäre sehr vorteilhaft, da es größtenteils auch der Art und Weise entspricht, wie Leute aus der Praxis über Produktentwicklungsprozesse denken. Davon abgesehen hat ein 3D Modell ein viel größeres Potential in der Menge der Information, die angezeigt werden kann. Verbindet man dies mit haptischen Vorrichtungen wie beispielsweise *cyber gloves*, können Teammitglieder ihre Prozesse in virtuellen Räumen durch *drag and drop* managen.

Now this is not the end. It is not even the beginning of the end. But it is, perhaps, the end of the beginning.

- Winston Churchill

H Indexes

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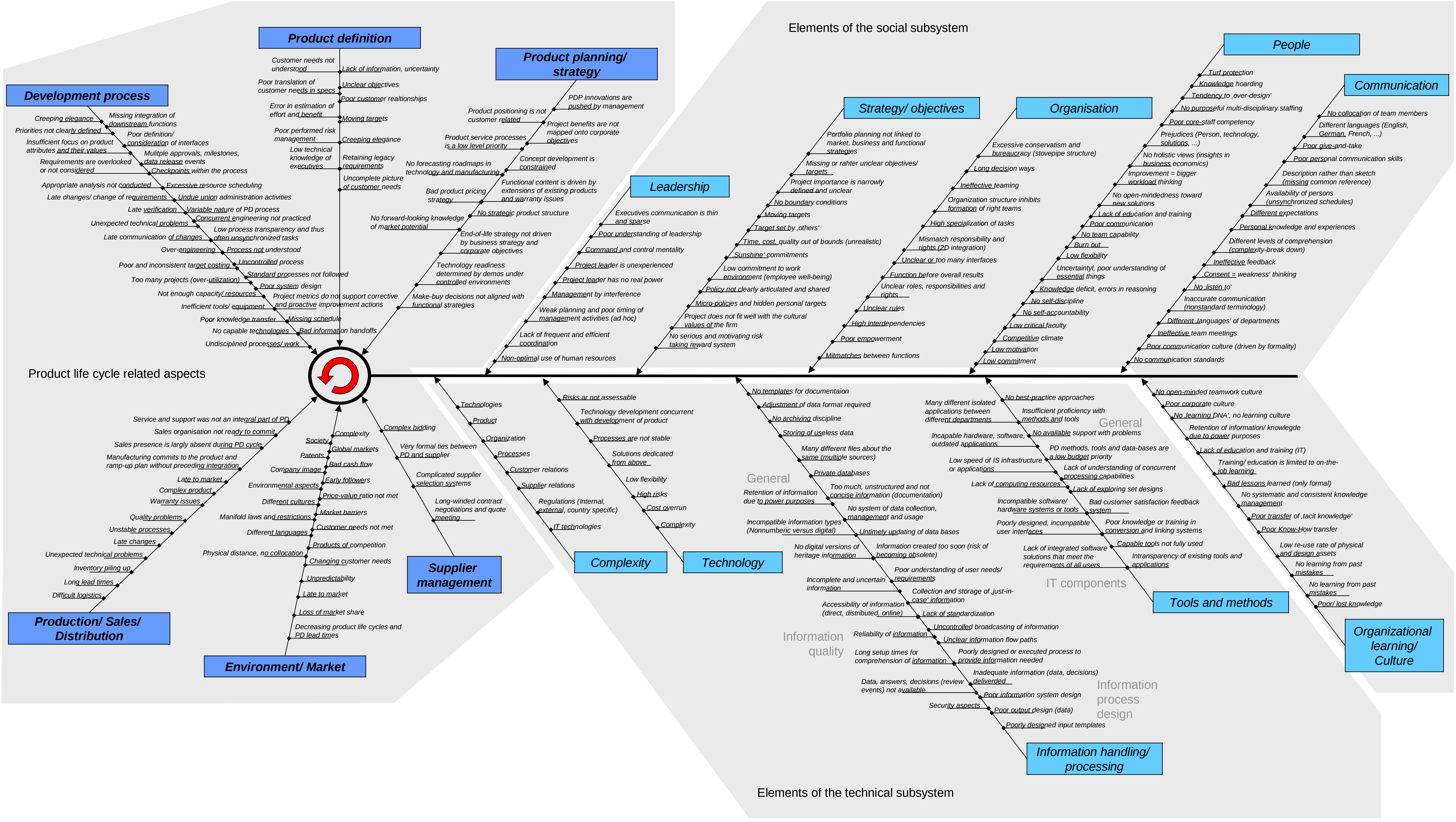
I Appendix

I 1 Fishbone diagram: Problems within Product Development



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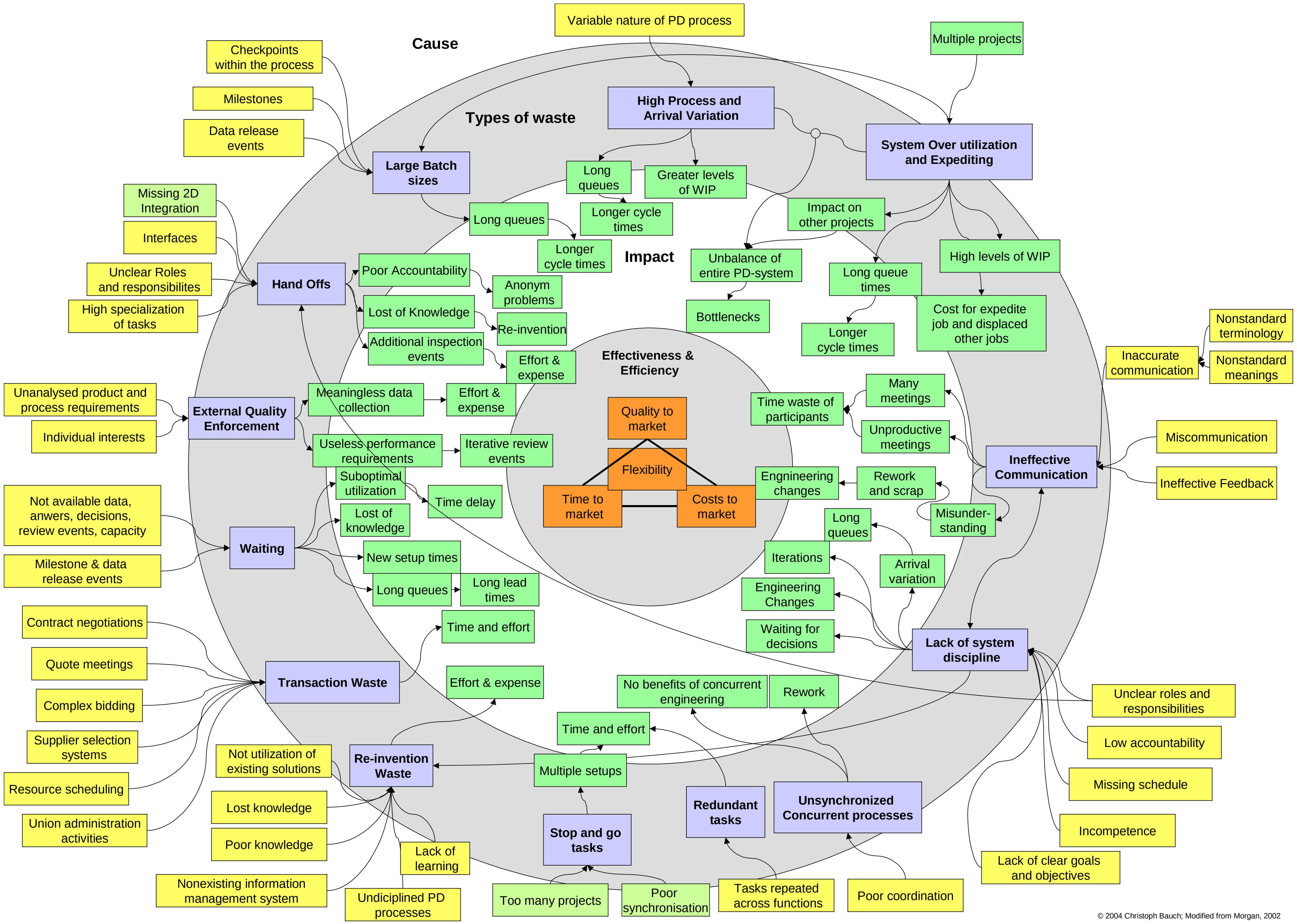
I 2 Mapping cause-effect chains (Referring to MORGAN, 2002)



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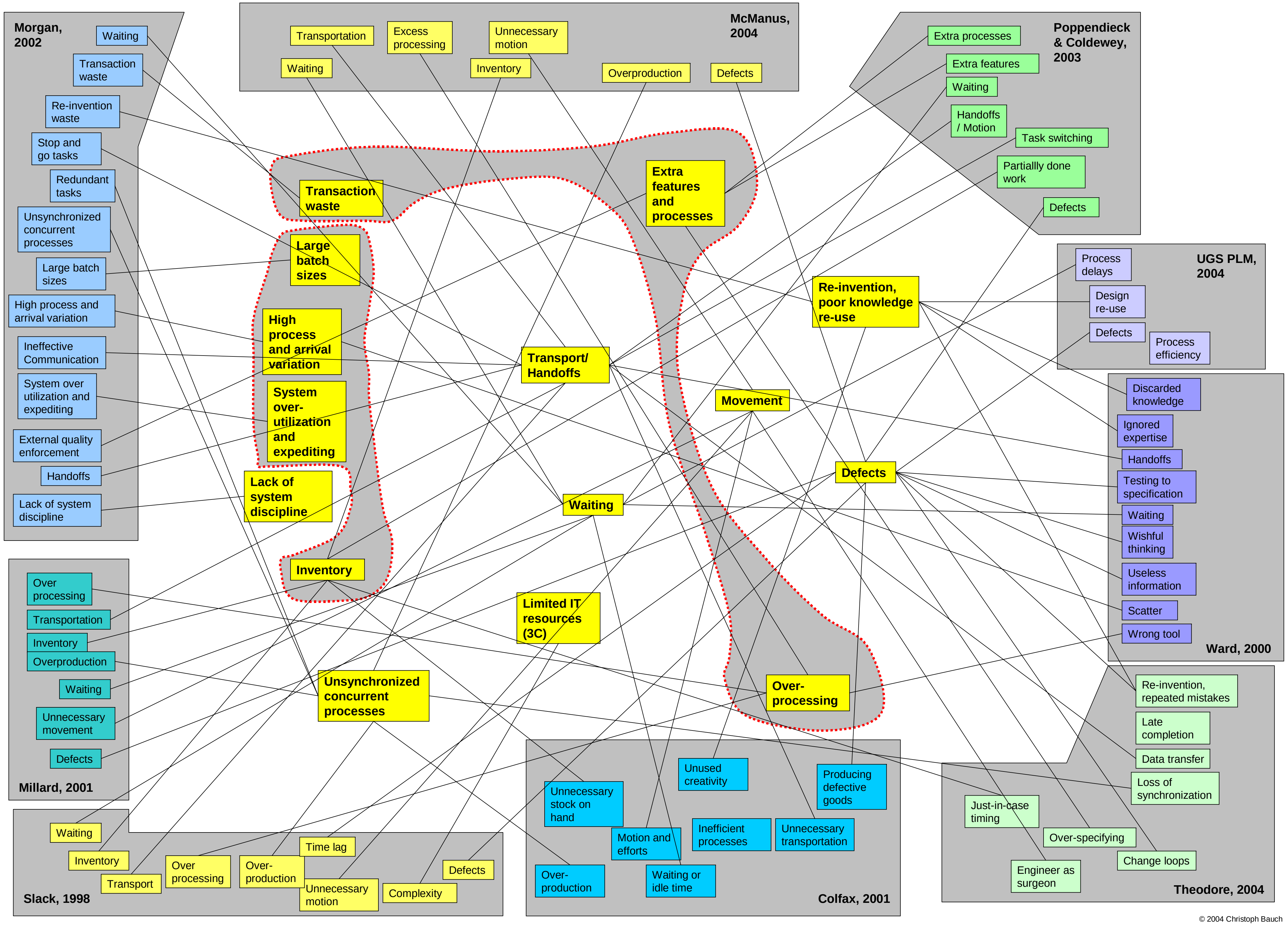
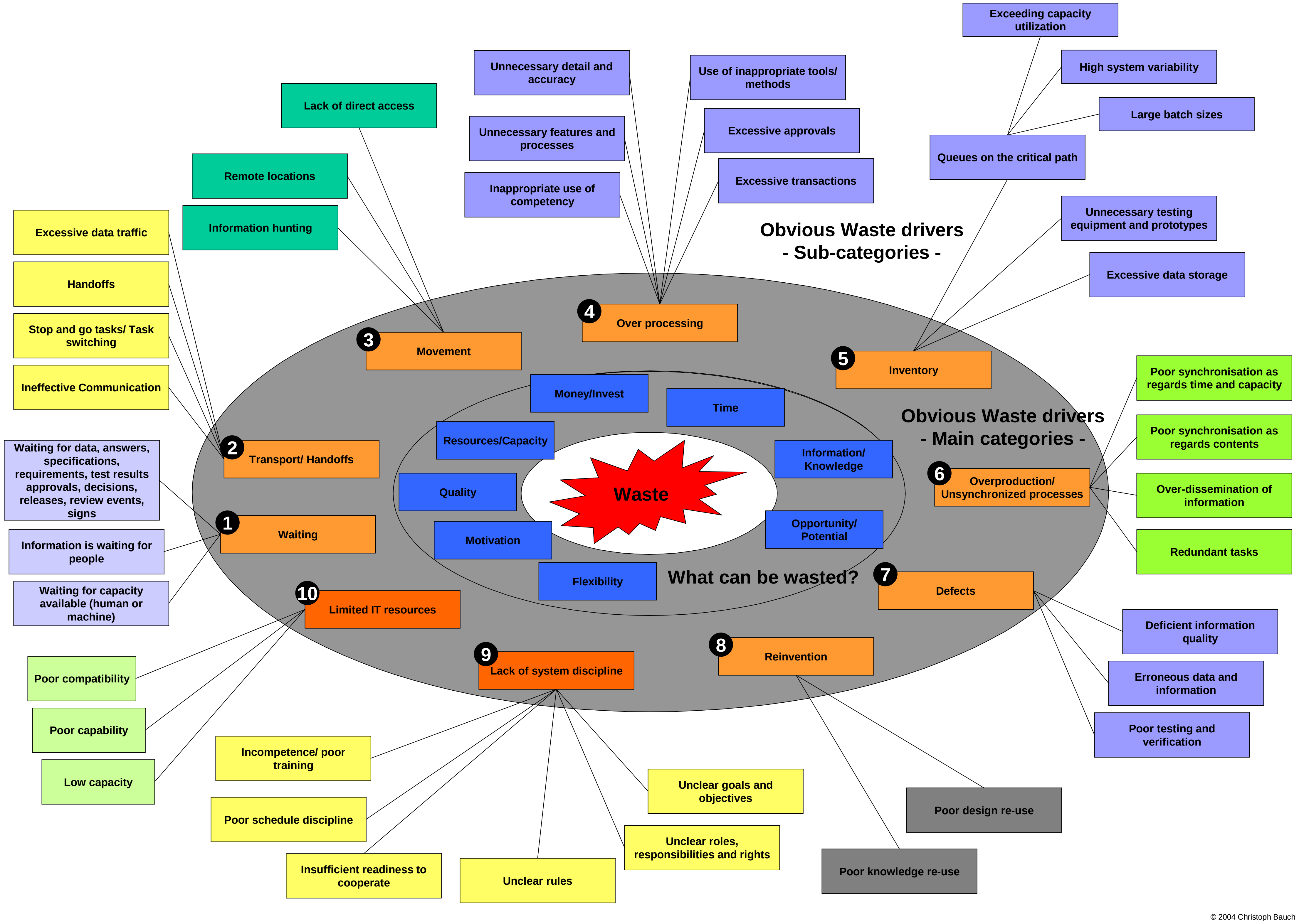
I 3 Waste categories of different authors



I 4 Overview of waste drivers



I 5 Work chart of waste drivers including sub-categories

Main categories	Sub-categories	Description/ Example	Causes	Effects
Waiting		Idle time due to unavailable information, manpower or computing resources	- Deficiencies in IT tools - Poor project planning and execution	
	Waiting for data, answers, specifications, requirements, test results, approvals, etc.		- Poor project management skills - Low knowledge of the benefits of concurrent engineering - Bad planned and scheduled milestone and data release events - Lack of access - Multiple authorizing signatures - Extensive approval of engineering change documents	- Prevents downstream processes from starting or continuing with work - Interrupts in the information flow (stop and go taksks) - Mental setup times required
	Information is waiting for people	--	Insufficient synchronization of processes (Unsynchronized processes)	Risk of obsolesence and rework (Defects)
	Waiting for capacity available (human or machine)	Capactiy needed is not available: - Waiting for different people to discuss a problem - Sparely available computer/ workstations equipped with special design tools like FEM, Heat analysis, etc.	- Poor scheduling - Different task priority of different people - Lack of computing capacity (Limited IT resources)	- Time delay - Risk that original task is not conducted
Transport/ Handoffs		- Inefficient transmittal of information (papers where files are needed) but also the unnecessary movement of information (data transfer) - Number of handoffs	--	--
	Excessive data traffic	- Transfer of converted or re-formatted data itself, but also the whole underlying communication effort getting these things done - Additional communication effort in form of emails, papers, files, etc. due to unsynchronized processes	- Missing interoperability and incompatibility of the different software and hardware systems and tools (Limited IT resources) - Converting, re-formatting or even re-entering data (Overprocessing) - Unsynchronized processes	- Time and effort wasted - Wasted IT capacity
	Handoffs	Responsibility for a product or process gets transferred from one person or group to another within or between functional departments	- High specialization of tasks - Low process view	- Valuable knowledge and time is lost each time - Low accountability
		Separate group is responsible for the quality which finally takes the ownership away from a person or group	- Unclear roles and responsibilities	- Additional inspection events (Excessive Approvals)
		Information is handled by multiple people before arriving at the right user	- Unclear information paths	- Additional time and effort
		Multiple authorizing signatures		
	Stop and go tasks/ Task switching	Engineer has to reorient himself to a certain task	- Poor synchronization of tasks - Too many running projects	- Multiple mental setup times - Loss in productivity
	Ineffective communication	- Miscommunication, inaccurate communication - Insufficient communication	- Miscommunication, inaccurate communication owing to non-standard terminology and meanings used by different departments - Lack of communication e.g. ineffective feedbacks, inadequate discussions of project objectives - Unclear goals and objectives, rules and roles	- Misunderstandings - Team members' time spent in the meetings - Risk of rework, scrap - Unnecessary engineering changes
Movement		Any human movement necessitated by a lack of direct access to information and communication		
	Lack of direct access (information)	Information needed is available but not directly accessible from the workplace - Retrieving of printed materials - Switching computers (CAD to PC) - Walking to a terminal to access internet data	- Lack of direct access, i.e. distributed (paper) or online access (digital files) - Poor information system design (Limited IT resources)	- Walk to distant central information access points
	Information hunting	Information or data needed is theoretically available and accessible but people have to go searching for - Directly asking people - Searching through project directory structure	- Unclear and thus poor performed rules in handling and naming files - Lack of clear information paths - Unclear roles and responsibilities - Lack of clear information creating processes (Unsynchronized processes)	- Time and effort for searching exactly that piece of information needed
	Remote locations	Local distance of departments and facilities such as test stations	- Physical restrictions of company buildings - Obsolete organization structures - Poor awareness of creating a success enabling project environment	- Loss of time - Less spontaneous communication opportunities - Preventing formation of right teams

Overview of waster drivers including sub-categories – part 1

Main categories	Sub-categories	Description/ Example	Causes	Effects
Overprocessing		Processing beyond the requirements		
	Unnecessary features and processes	Product provides more features that the customer needs	- Unanalysed or rather not understood product or process requirements - Tendency of carrying-over of requirements from the last product - Individual interests of system participants	- Wasted time and effort expended for data collection - Unnecessary costs
	Unnecessary detail and accuracy	- Features get over-engineered and finally exhibit more technical finesse that was expected and necessary - Information exchanged has too much detail and accuracy - Excessive and custom formatting of data or information	- Engineer's tendency to perfectionism - Poor insights and feedback in business economics and life-cycle costs - Lack of standardization - Just to meet an individuals' standard	- Unnecessary time and effort
	Excessive approvals	Information such as engineering changes or other documents has to go through different levels of management before it can be released to the downstream process	- Old and strongly hierarchical organization structures with no or poor cross-functional teams - Prevalent command and control mentality - Turf protection - Failure of defining some significant business cases for approvals	- Interrupts (Stop and go tasks) - Waiting time (Waiting) - Long throughput times
	Excessive transactions	Spent time and effort on non-value added steps which are necessary to get the primary tasks done - Contract negotiations, quote meetings, complex supplier bidding and supplier selection systems - Resource scheduling, union administration action	- Complex supplier structure - No win-win-relations with suppliers	- Time and effort wasted
	Inappropriate use of competency	- Necessary but not value adding activities conducted by engineers instead of lower qualified people - People are not skilled enough for the task at hand	- Poor insights in time management - Insufficient support from management regarding the employment of students/ assistants	- Time and effort wasted - Poor focus on core tasks - Use of wrong tools/ methods produces inadequate results
	Use of inappropriate tools/ methods	Use of inappropriate tools/methods, which necessitate additional processing steps in order to accomplish the result and thereby cause longer processing times than would be required with a proper tool/method. Re-formatting, re-converting and re-entering data are very characteristic for this category.	- Incompatibility and poor interoperability of software and hardware systems - Incompatible information types - Lack of availability, knowledge or training in conversion and linking systems - Poor knowledge/experience with methods	- Time and effort consumed - Deficiencies in quality of generated information
		Multiple conversions of model data for simulation purposes	Different departments use different tools	
		Use of antiquated IT technology, especially of mainframe software systems	- Data cannot be transferred from the old to a new system due to various incompatibilities (Limited IT resources) - Poor farsightedness of executives in respect of the potential of IT technology	
		Excessive keyboard or mouse operations	- Deficiency in training - Poorly designed and incompatible user interfaces - Incompatible software suites - Too huge amounts of information to sort through	
		Inappropriate use of methods	- Poor knowledge or experience - Prejudices versus new or not before used approaches	
Inventory		-Information that is kept unnecessary, or is WIP on the critical path - Unnecessary testing equipment/ prototypes		

Overview of waster drivers including sub-categories – part 2

Main categories	Sub-categories	Description/ Example	Causes	Effects
Inventory		-Information that is kept unnecessary, or is WIP on the critical path - Unnecessary testing equipment/ prototypes		
	Excessive data storage	In the information system used, whether it is an electronic or not, more information is being kept than needed	- Tremendous increase in computing systems over the last 15 years - Tremendous increase in electronic file traffic, size, and storage - Little effort in managing and conserving these kind of resources due to an insufficient awareness of this kind of waste	- Memory space but also network capacity consumed - Longer search times for information - More frequent searching
		Multiple and redundant sources	Lack of integrated information systems (Limited IT resources)	
		Numerous and fragmented reports which could actually be merged	Inadequate standards and practices concerning the administration of data and information	Poor overview of documents (Information hunting)
		- Outdated and obsolete data and files - Designs which has never been used, completed or delivered	Lack of a disciplined system (Lack of system discipline) for updating new and purging old files	- A lot of memory consumed - Extended search times for files
		'Just-in-case' data and information	- Overengineering - General uncertainty with development processes - Missing understanding of the essential things in development - Bad experience with executives focussing on negligible issues	- Time and effort wasted
	Critical path related queues	Queues on the critical path will delay the project and instantly increase the cycle time, and dependent on the extent of that delay, the costs might be enormous	- High system variability - Exceeding capacity utilization - Large batch sizes	- Increased cycle time - Increased costs - Stop and go effects
		High system variability depends on (> Causes)	Arrival rate of the tasks but also on their duration, which is again effected by - Differences in the contents - Differences in the productivity of the operators	- Greater levels of WIP or rather queues - Greater cycle times
		Exceeding capacity utilization/ system loading	- Multiple projects - Poor awareness of system behaviour (queuing theory) - Expediting of single projects of a product development program due to time delays	- Increased queuing times - Increased cycle times - Product development system was destabilized and has to be re-coordinated - Stop and go effects
		Large batch sizes: Amount of information that is passed on from a up to a downstream process	- Organisation of development projects: Creation of and work to milestones, data release events or check points within the process - Inadequate synchronisation of up and downstream processes	- Long queues - Increased cycle times
Overproduction/ Unsynchronized pro		Producing, distributing more information needed due to poor synchronisation as regards contents, time and capacity		
	Poor synchronisation as regards contents	Upstream processes push data and information irrespective of what the downstream processes special needs are	- Participants of up and downstream processes do not talk about each other's process and its requirements - No holistic view of the process due to: - Strongly hierarchical organisation structures - Missing cross-functional teams - Poor readiness to cooperate (Lack of system discipline)	- No straight-lined sub-processes, - Resending data/information to upstream processes - Increased risk of rework (e.g. data conversion) - Waste time and effort
	Poor synchronisation as regards time and capacity	Tasks or processes are processed more serial than parallel	- Poor understanding of concurrent engineering's capabilities	- Loss in cycle time
		- Tasks are not embedded in a reasonable and practicable frame as regards time and capacity available - Taks are bad synchronized	- Insufficient transparency of functional organisation's capacities - Unrealistic planning by project managers - Insufficient communication - Low commitment to hold schedules (Lack of system discipline)	Unrealistic and inefficient processes due to: - Some tasks are done prior to maturity - Others cannot be finished in time - High risk of rework - Additional coordination effort due to slipped dates - Destabilized processes - Project time delays
	Over-dissemination of information	Widespread dissemination of information especially of emails instead of a selective distribution	- Poor understanding and overview of the process by single process participants - Unclear roles, responsibilities and rights (Lack in system discipline) and the resultant information requirements of the process members	- Quite a time to sort through the whole messages - Danger of information overload with potential that important information is missed

Overview of waster drivers including sub-categories – part 3

Main categories	Sub-categories	Description/ Example	Causes	Effects
Overproduction/ Unsynchronized pro		Producing, distributing more information needed due to poor synchronisation as regards contents, time and capacity		
	Redundant tasks	Tasks repeated within functions, across functions or even across enterprises associated with suppliers, but without any significant differences in their results (tasks) - Requirements of a purchase order by engineering is rewritten by purchasing - Multiple inspection points - Redundant tests on a component part conducted by customer and supplier	- Poor synchronisation as regards contents - No holistic view of the value stream - Different testing standards and scales in testing	- Unnecessary time, effort and costs
Defects		Generating erroneous information or information with poor information quality		
	Deficient information quality IQ	- Intrinsic IQ: Accuracy, objectivity, believability, reputation - Accessibility IQ: Accessibility, security - Contextual IQ: Relevancy, value-added, timeliness, completeness, amount of information - Representational IQ: Interpretability, ease of understanding, concise representation, consistent representation	- Poor synchronisation as regards contents of up and downstream processes (Unsynchronized processes) - Missing understanding of technical issues	- Deficiencies in IQ emerge as significant influence variables for engineer's work performed since they directly affect the way of their understanding, thinking, planning, deciding and last but not least acting - High risk of rework - High potential of generating erroneous information and consequently later problems and defects
		Poor accessibility	- Poor information systems - Lack of disciplined data administration	- Information hunting - People rather continue their work based on assumptions - Higher potential of risk regarding rework and defects
		Poor timeliness	- Poor synchronized processes - Frequent changes regarding to product and process	- Risk that information becomes obsolete by the time needed - Delays in the process
		Bad interpretability	- Lack of standardization for data representations - Different terminology of different departments for the same things	- Additional effort for discussing ambiguous information - Risk of later rework due to information creation based on wrong interpretation
	Erroneus data and information	Lack of information accuracy which is the result of IQ deficiencies occurring in previous process steps, of people's intelligence creating/transfering it, or even of failures in software tools	- Requirements overlooked - Appropriate analyses not conducted - System interfaces not adequately considered - Standard processes not followed - Lessons learned are not captured - Poorly designed input templates - Undisciplined reviews - Poor tests, validations and interpretation - Haste	- Engineering escapes: Defects detected later by testing - Validation escapes: Defects escaped to the customer - High effort to correct the problem - Time delay
	Poor testing and verification	- Insufficient testing and verification in the different stages of development process does not reduce uncertainty and risk	- Low awareness of testing and verification - Testing is often limited to the first physical prototyp built up - Insufficient test of thoughts and ideas in the early stages of the process due to: - Competitive climate - Incompetence-fear and disagreement-fear on the part of the single engineers - Disturbed relationships - Formal meetings - Too elaborate solutions - Focus on own problems	- Additional costs due to a lot of rework - Significant time delays - Many defect unnoticed until late phases
			'Wishful thinking' and a less realistic view of the engineer	- Premature selection of alternatives - Inadequate experiments - Excessive agreements in requirements regardless whether they are feasible or not
		- Bad planning of the experiment conducted - Testing to specification and not testing to failure which is more valuable	- Low knowledge with systematic testing as suggested by Design of Experiments DoE - 'Quick and dirty' experiments due to short-term problems	- Unnecessary testing results or rather results that could have been achieved in less time and with less effort
Reinvention		Poor re-use of already existing solutions and experienced knowledge from previous projects		

Overview of waster drivers including sub-categories – part 4

Main categories	Sub-categories	Description/ Example	Causes	Effects
Reinvention		Poor re-use of already existing solutions and experienced knowledge from previous projects		
	Poor design re-use	No utilization of existing and reusable design solutions, no designing in existing components of a sub-assembly, or the underutilization of valuable design knowledge of experts	- Modelling components were not created re-usable - Insufficient awareness of the 'real' costs engineers cause by their acting - Inadequate system with special functions for the administration of design models (part families) - Engineers poor overview of previous designs due to frequent job changes	- Solving the same problems over and over again - Additional engineering effort - Additional costs over the product life cycle when designing new parts
	Poor knowledge re-use	- A great deal of experiences and knowledge gained from previous projects is unused or lost - Knowledge from upstream processes is unused within the current project - Problem solving knowledge from previous projects is unused - Lost knowledge due to long waiting times	- Lessons and experiences from precedent projects are often documented bad, and scarcely transferred to subsequent projects - Poor knowledge and information management systems - Poorly defined, undisciplined product development processes - Multiple handoffs - Poor accountability	- Effort and time wasted for solving the problems repeatedly - Increased risk of repeating mistakes - Loss of knowledge
Lack of system discipline		Undermining the framework for a successful project performance		
	Unclear goals and objectives	Unclear goals and objectives basically mean that not everybody knows what the company is striving for in a long-term and short-term view	- Poor insights into the factors of successful project management - Lack of communication	- Team members work not aligned into one direction - Effort with compromising disagreements and different conception of the project goals
	Unclear roles, responsibilities and rights	Not each team member has a clear understanding of his own role and responsibility, or of the roles of the others; that also includes some personal aspects and skills of the single team members	- Poor focus on the framework or rather the preconditions for successful project management - Insufficient readiness on part of the team participants to accept the own role and the roles of the others - Lack of communication	- Problems with overlapping competencies - Friction among the team members - High loss of efficiency
	Unclear rules	Rules are not understood, accepted or performed by some team members e.g. - Careful data entry in information systems - Usage of templates - Not cutting team members off during discussions	- Poor awareness of the usefullness of such rules - Focus on the effort instead of the benefit of that approach - Rules are not open communicated, everybody has his own standard - Lack of communication	- Bad climate among team members - Excessive data storage - Poor reliability of information systems due to gaps within datasets - etc.
	Poor schedule discipline	Missing willingness to meet the deadline on the part of the project participants	- Poor awareness of the impacts of such acting (High process variability) - Poor commitment to the job due to low accountability caused by a lot of handoffs	- Time delays
	Insufficient readiness to cooperate	Only interested in the success of the own work but not in the overall performance let alone making compromises	- Social system in general, in which people are usually rewarded for their individual achievements - Hierarchical structure of a company, often associated with high levels of handoffs and low levels of accountability - Some people's readiness to cooperate was misused by other team members	- People's thinking in functions or 'fragments' - People's focussing on their own business success - Poor awareness of the overall performance - Reducing the level of cooperation with others to a minimum
	Incompetence/ poor training	Deficiencies regarding to: - Professional competence - Competency in methods - Social competence	- Unwillingness of employers to offer regular training - Unwillingness of employees to take it as a chance	- Poor performance of own tasks and their integration in the superordinate value stream - Poor interaction with other people - Low productivity

Overview of waster drivers including sub-categories – part 5

Main categories	Sub-categories	Description/ Example	Causes	Effects
Limited IT resources		Use of outdated and less powerful information technology causes a lot of problems and obstacles in the process	- High variety of existing IT components within an information system - Poor awareness by management of the importance of powerful IT resources - High variability of different old IT system technologies - Restrictions with outdated systems - People's competence in new IT resources - Acquired knowledge is not applied, communicated due to low motivation of the people	- Low efficiency of people's work - Additional effort and rework due to non-integrated data models
	Poor compatibility	Incompatibility and missing interoperability of hardware (computer, network) with software systems (operating systems, applications/tools)	Big variety of existing IT components within information systems	Additional effort and rework due to: - Re-formatting - Re-entering - Extra converting
	Poor capability	Incapable hardware and software tools to accomplish the assigned tasks effiently: Not dedicated, not high-speed, not reliable, not ergonomic '- Obsolete software tools and hardware - Deficiency of integrated software tools for an efficient administration of data, information or knowledge	- IT resources are a low budget priority	Waste of time due to: - Complicated data retrieval or creation - Waiting until the computer has opened files - Information hunting - Comparing data due to multiple and/or redundant sources
	Low capacity	- Low capacity of the IT network (low band-width) - Sparely available computer/ workstations equipped with special design tools like FEM, Heat analysis, etc.	- IT resources innately are a low-budget priority - Expensive software licenses - Outdated band-width communication lines	- Reduction of the access to information and thus the productivity of the people waiting for (Waiting) - Increased risk of not performing the original task - Higher risk of creating flawed information and defects arising

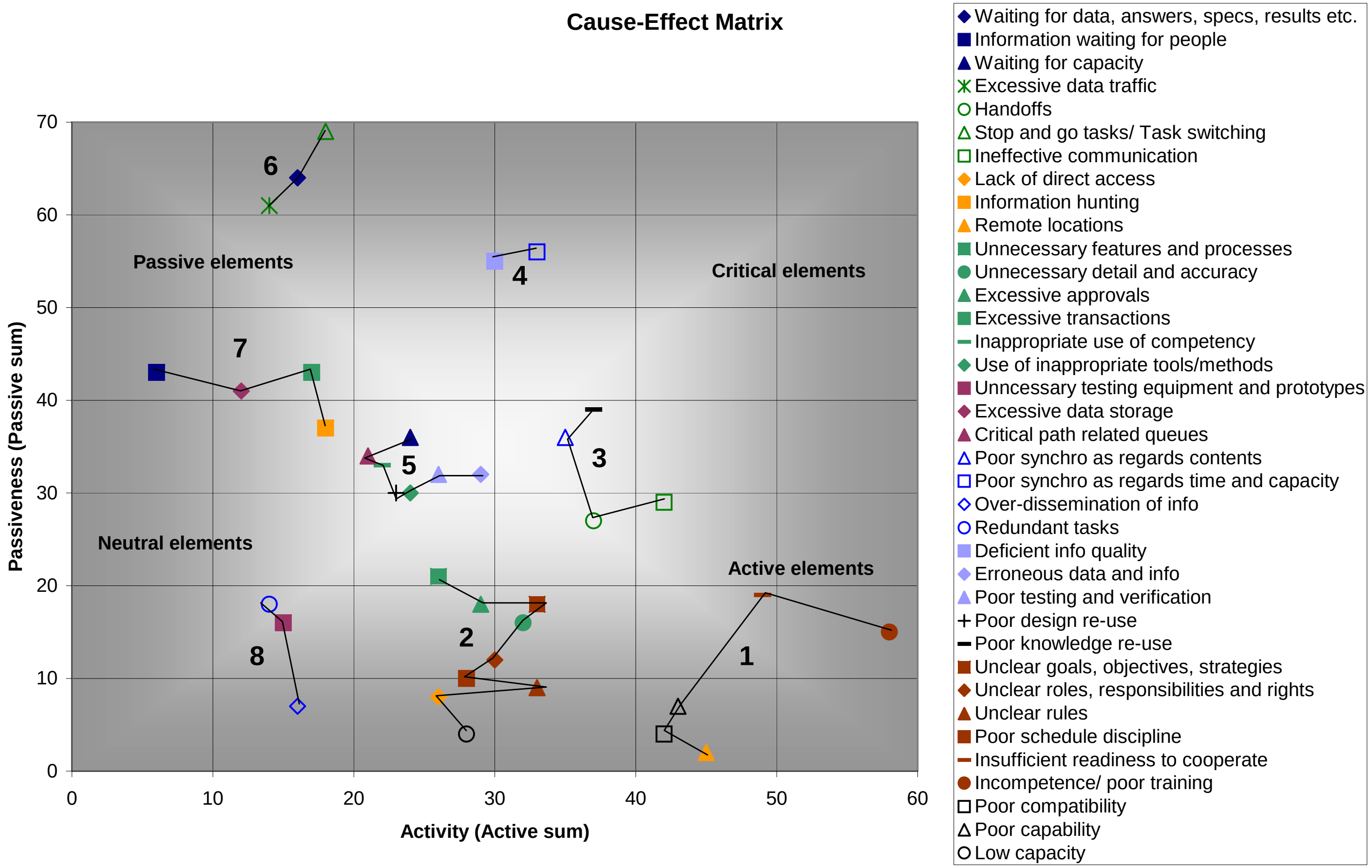
Overview of waster drivers including sub-categories – part 6

I 6 Cause-effect matrix

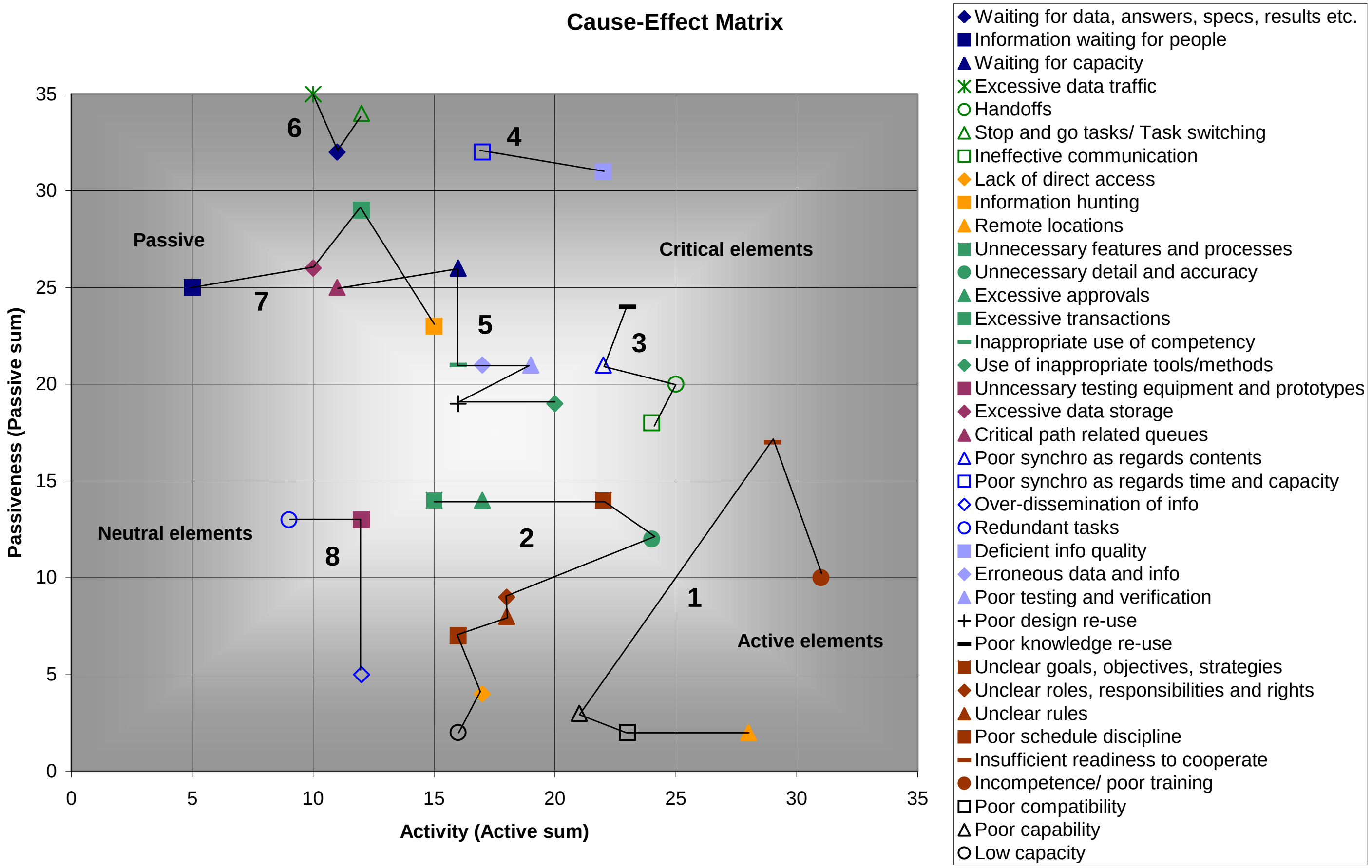
Cause		Effect																																																			
		Waiting	Waiting for data, answers, specs, results etc.	Information waiting for people	Waiting for capacity	Transport/ Handoffs	Excessive data traffic	Handoffs	Stop and go tasks/ Task switching	Ineffective communication	Movement	Lack of direct access	Information hunting	Remote locations	Overprocessing	Unnecessary features and processes	Unnecessary detail and accuracy	Excessive approvals	Excessive transactions	Inappropriate use of competency	Use of inappropriate tools/methods	Inventory	Unnecessary testing equipment and prototypes	Excessive data storage	Critical path related queues	Overproduction/ Unsynchr. Processes	Poor synchro as regards contents	Poor synchro as regards time and capacity	Over-dissemination of info	Redundant tasks	Defects	Deficient info quality	Erroneous data and info	Poor testing and verification	Reinvention	Poor design re-use	Poor knowledge re-use	Lack of system discipline	Unclear goals and objectives	Unclear roles, responsibilities and rights	Unclear rules	Poor schedule discipline	Insufficient readiness to cooperate	Incompetence/ poor training	Limited IT resources	Poor compatibility	Poor capability	Low capacity	Active sum AS	Passive sum PS	Quotient Q ((=AS/PS)*100)	Product P (=AS*PS)	Element
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47					
1	Waiting																																																0	0	#DIV/0!	0	
2	Waiting for data, answers, specs, results etc.		2	0	1		1	0	3	0		0	1	0		1	1	0	0	0	0		0	0	2		0	2	0	0		0	0	0		0	0		1	0	0	0	1	0		0	0	0	16	64	25	1024	p
3	Information waiting for people		0	0	0		1	0	0	0		0	0	0		0	0	0	0	0	0		0	0	1		0	2	0	0		1	0	1		0	0		0	0	0	0	0	0		0	0	0	6	43	14	258	p
4	Waiting for capacity		3	1	1		1	0	3	0		0	1	0		0	0	0	1	0	1		0	0	1		2	2	0	0		2	1	2		0	1		0	0	0	0	1	0		0	0	0	24	36	67	864	p
5	Transport/ Handoffs																																																0	0	#DIV/0!	0	
6	Excessive data traffic		1	2	1		0	0	2	1		0	2	0		0	0	0	0	0	0		0	2	1		0	1	0	0		1	0	0		0	0		0	0	0	0	0	0		0	0	0	14	61	23	854	p
7	Handoffs		2	2	1		2	0	2	2		0	2	1		0	0	2	1	0	1		0	2	1		2	2	1	1		1	1	0		0	2		1	1	1	2	1	0		0	0	0	37	27	137	999	a
8	Stop and go tasks/ Task switching		0	2	1		1	0	3	0		0	0	0		0	0	0	1	0	0		0	0	2		1	2	0	1		2	1	0		0	1		0	0	0	0	0	0		0	0	0	18	69	26	1242	p
9	Ineffective communication		1	1	0		3	1	1	0		0	2	0		1	1	0	1	0	0		0	1	2		3	3	0	2		3	2	2		1	2		2	2	2	0	1	2		0	0	0	42	29	145	1218	a
10	Movement																																																0	0	#DIV/0!	0	
11	Lack of direct access		2	2	1		1	0	2	0		0	1	0		0	0	0	2	1	2		0	2	0		1	0	0	0		2	1	1		2	2		0	0	0	0	0	1		0	0	0	26	8	325	208	n
12	Information hunting		2	0	1		2	0	2	0		0	1	0		0	0	0	1	1	1		0	0	1		0	1	1	0		0	1	0		1	1		0	0	0	0	1	0		0	0	0	18	37	49	666	p
13	Remote locations		2	2	0		1	2	2	2		2	2	0		0	0	1	2	2	1		1	2	1		2	2	0	2		2	0	2		1	2		1	1	1	0	1	2		1	0	0	45	2	2250	90	a
14	Overprocessing																																																0	0	#DIV/0!	0	
15	Unnecessary features and processes		2	2	2		3	1	2	0		0	0	0		0	0	2	2	0	1		2	1	2		1	2	0	0		0	0	0		0	0		0	0	0	0	1	0		0	0	0	26	21	124	546	n
16	Unnecessary detail and accuracy		2	1	1		2	0	2	1		0	0	0		1	1	0	1	2	1		1	2	1		0	1	0	0		2	0	1		1	2		1	2	1	1	1	0		0	0	0	32	16	200	512	a
17	Excessive approvals		3	2	1		2	3	3	0		0	1	0		1	1	0	2	2	0		0	1	2		2	1	0	1		0	0	0		0	0		0	1	0	0	0	0		0	0	0	29	18	161	522	a
18	Excessive transactions		2	1	1		2	1	2	0		0	0	0		0	0	0	0	2	0		0	1	1		0	2	0	0		1	0	0		0	0		0	0	0	0	1	0		0	0	0	17	43	40	731	p
19	Inappropriate use of competency		2	2	1		1	0	2	1		0	0	0		0	1	0	0	0	2		0	0	1		1	1	0	0		2	2	0		1	1		0	0	0	0	1	0		0	0	0	22	33	67	726	n
20	Use of inappropriate tools/methods		2	1	0		2	1	1	0		0	1	0		1	1	0	1	1	0		0	1	1		0	2	0	1		2	1	1		1	1		0	0	0	0	1	0		0	0	0	24	30	80	720	n
21	Inventory																																																0	0	#DIV/0!	0	
22	Unncessary testing equipment and prototypes		1	0	1		2	1	1	0		0	0	0		0	1	1	2	2	0		0	1	1		0	1	0	0		0	0	0		0	0		0	0	0	0	0	0		0	0	0	15	16	94	240	n
23	Excessive data storage		1	0	0		1	0	0	1		0	2	0		0	0	0	1	0	0		0	1	0		0	0	0	0		2	1	0		0	1		1	0	0	0	0	0		0	0	0	12	41	29	492	p
24	Critical path related queues		3	3	2		1	0	3	0		0	0	0		0	0	0	0	0	0		0	0	2		1	2	0	0		2	0	1		0	0		0	0	0	0	1	0		0	0	0	21	34	62	714	p
25	Overproduction/ Unsynchr. Processes																																																0	0	#DIV/0!	0	
26	Poor synchro as regards contents		3	0	0		3	2	2	0		0	2	0		1	2	1	1	0	1		1	2	1		0	2	0	2		2	1	1		1	2		1	0	0	0	0	1		0	0	0	35	36	97	1260	c
27	Poor synchro as regards time and capacity		3	3	3		1	1	3	1		0	0	0		0	0	1	3	1	0		0	0	3		2	3	0	0		1	1	2		0	1		0	0	0	0	0	0		0	0	0	33	56	59	1848	c
28	Over-dissemination of info		0	2	1		3	0	1	1		0	1	0		0	0	0	0	1	0		0	2	0		0	0	1	1		1	0	0		0	0		1	0	0	0	0	0		0	0	0	16	7	229	112	n
29	Redundant tasks		1	0	0		2	1	2	0		0	0	0		0	0	1	2	1	0		1	3	0		0	0	0	0		0	0	0		0	0		0	0	0	0	0	0		0	0	0	14	18	78	252	n
30	Defects																																																0	0	#DIV/0!	0	
31	Deficient info quality		2	0	1		2	1	2	2		0	1	0		1	0	0	1	0	1		0	1	1		1	2	0	0		2	1	1		2	2		1	1	1	0	0	0		0	0	0	30	55	55	1650	c
32	Erroneous data and info		2	1	1		3	1	2	1		0	1	0		2	0	2	2	0	0		0	1	1		0	3	0	0		3	2	1		0	0		0	0	0	0	0	0		0	0	0	29	32	91	928	a
33	Poor testing and verification		0	0	0		1	1	1	1		0	1	0		2	0	1	1	0	1		1	0	1		0	2	0	0		3	3	0		1	1		1	1	0	0	0	2		0	0	0	26	32	81	832	n
34	Reinvention																																																0	0	#DIV/0!	0	
35	Poor design re-use		1	2	0		2	1	1	0		0	0	0		2	0	1	1	2	0		2	2	0		0	0	0	0		1	1	0		1	2		0	0	0	0	0	1		0	0	0	23	30	77	690	n
36	Poor knowledge re-use		1	2	0		2	1	1	0		0	0	0		3	2	1	1	2	2		1	1	0		2	1	1	2		1	3	2		2	1		0	0	0	0	0	2		0	0	0	37	39	95	1443	c
37	Lack of system discipline																																																0	0	#DIV/0!	0	
38	Unclear goals, objectives, strategies		1	0	0		1	1	2	3		0	0	0		3	2	1	1	0	2		1	1	0		2	1	0	1		2	0	2		1	1		2	0	0	1	1	0		0	0	0	33	18	183	594	a
39	Unclear roles, responsibilities and rights		1	0	1		2	2	3	2		0	3	0		0	0	0	1	1	0		0	1	0		2	1	3	2		1	0	1		0	0		0	0	0	2	1	0		0	0	0	30	12	250	360	a
40	Unclear rules		0	0	1		1	0	0	2		0	3	0		0	1	0	2	1	2		2	3	0		0	1	0	0		3	0	2		3	3		1	0	1	1	0	0		0	0	0	33	9	367	297	a
41	Poor schedule discipline		3	2	3		2	0	2	0		0	1	0		0	0	1	2	1	0		0	0	2		1	3	0	0		1	0	1		0	0		0	0	0	2	1	0		0	0	0	28	10	280	280	n
42	Insufficient readiness to cooperate		2	2	3		1	1	1	3		1	3	0		1	0	0	2	1	1		0	2	1		3	2	0	1		2	1	3		2	2		2	1	1	1	2	1		0	0	0	49	19	258	931	a
43	Incompetence/ poor training		3	1	1		2	2	2	3		0	1	1		1	2	2	2	2	3		1	1	1		3	3	0	0		3	3	2		1	1		2	2	1	0	2	2		0	2	0	58	15	387	870	a
44	Limited IT resources																																																0	0	#DIV/0!	0	
45	Poor compatibility		2	2	1		3	2	2	1		2	1	0		0	0	0	2	2	3		1	2	0		2	1	0	1		2	2	0		2	1		0	0	0	0	0	0		0	3	2	42	4	1050	168	a
46	Poor capability		3	1	2		1	0	3	0		3	3	0		0	0	0	1	2	3		1	2	0		1	1	0	0		1	2	2		3	3		0	0	0	0	0	0		3	0	2	43	7	614	301	a
47	Low capacity		3	1	2		0	0	3	1		0	0	0		0	0	0	0	3	1		0	0	0		1	1	0	0		1	1	1		3	3		0	0	0	0	0	1		0	2	0	28	4	700	112	n
	Passive sum PS		64	43	36		61	27	69	29		8	37	2		21	16	18	43	33	30		16	41	34		36	56	7	18		55	32	32		30	39		18	12	9	10	19	15		4	7	4					

Score		Character of elements	
0	independent	a	active
1	weak	p	passive
2	strong	c	critical
3	tightly related	n	neutral

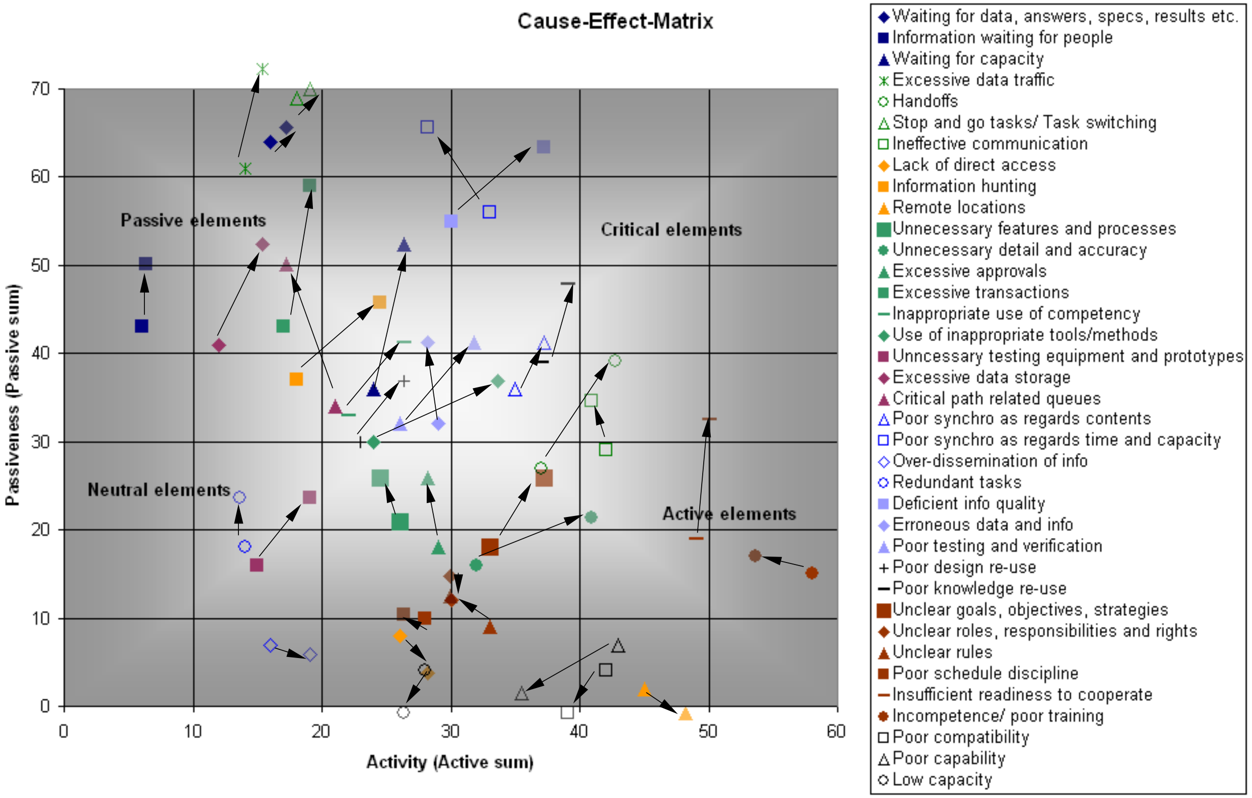
I 7 Cause-effect diagram



I 8 Cause-effect diagram with restricted grading



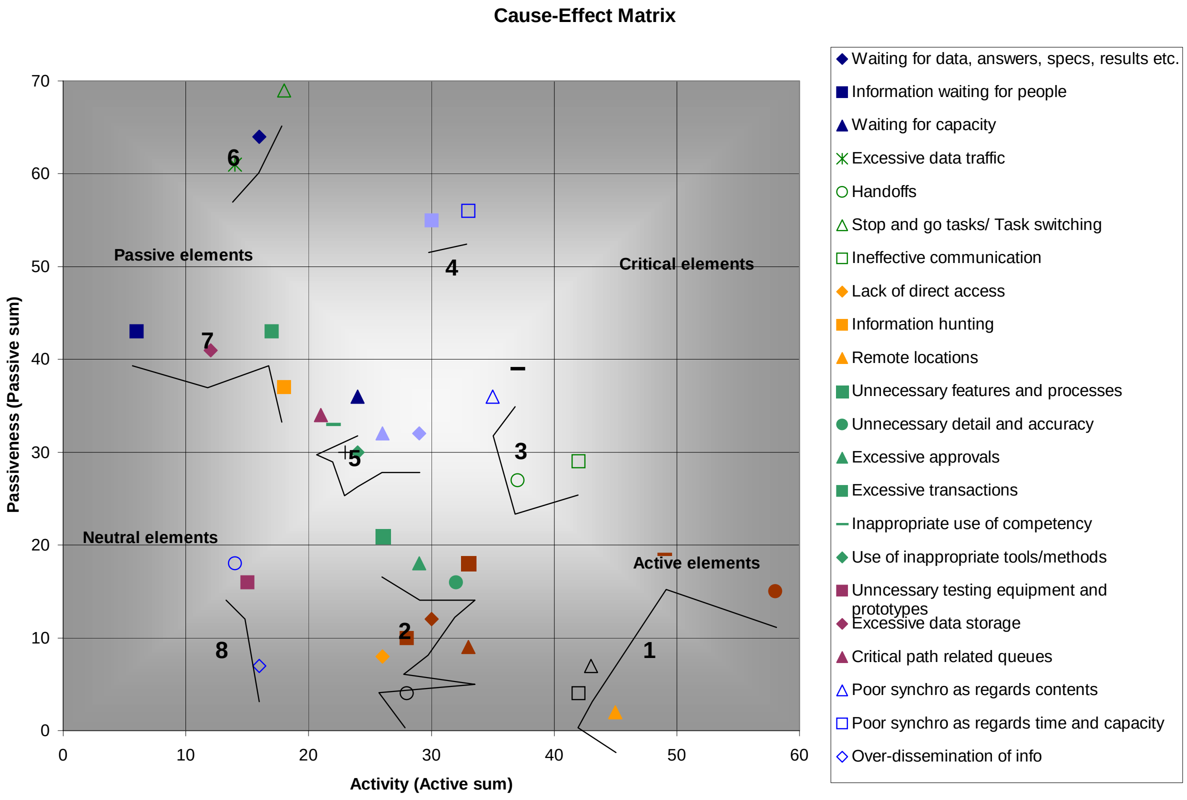
I 9 Comparison of cause-effect diagrams



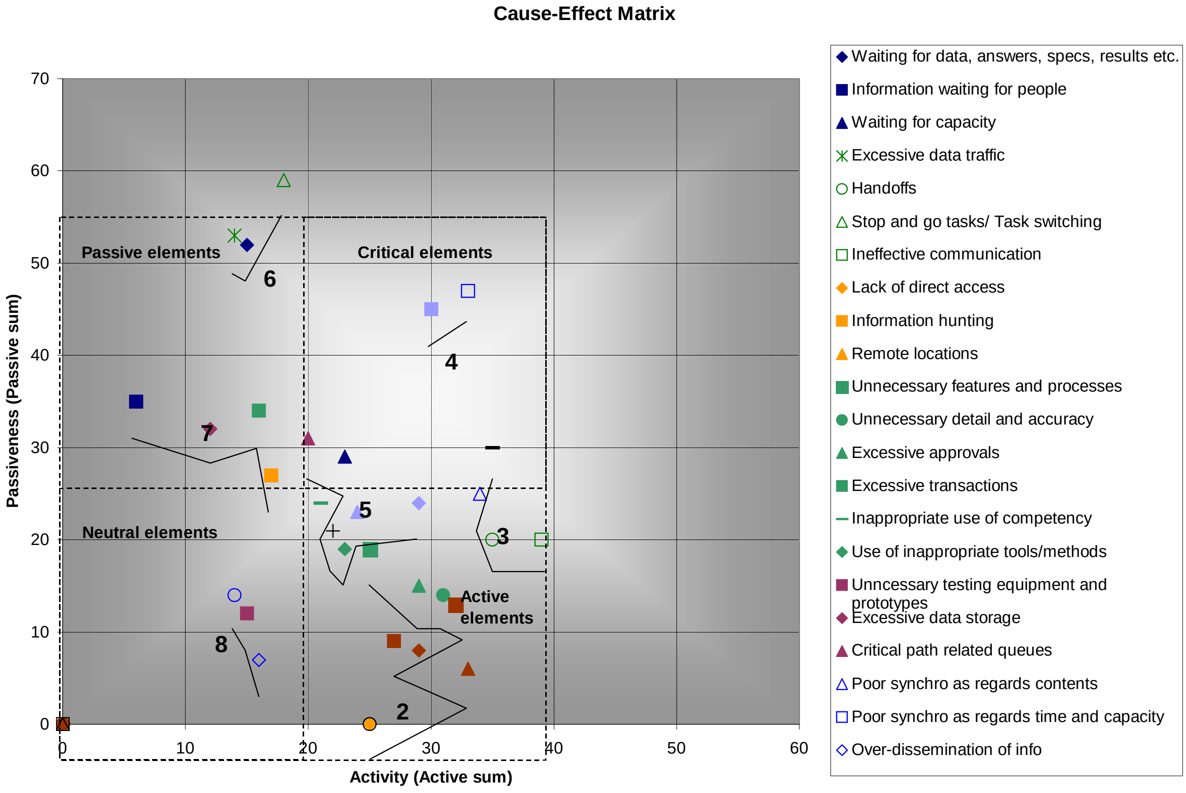
- Cause-effect chart 1 (with grading 0 to 3) and cause-effect chart 2 (with grading 0 and 1) were overlayed
- Only the relative structural movement of elements are to consider (values of displayed scaling refer to chart 1)

I 10 Simulation of waste elimination - I

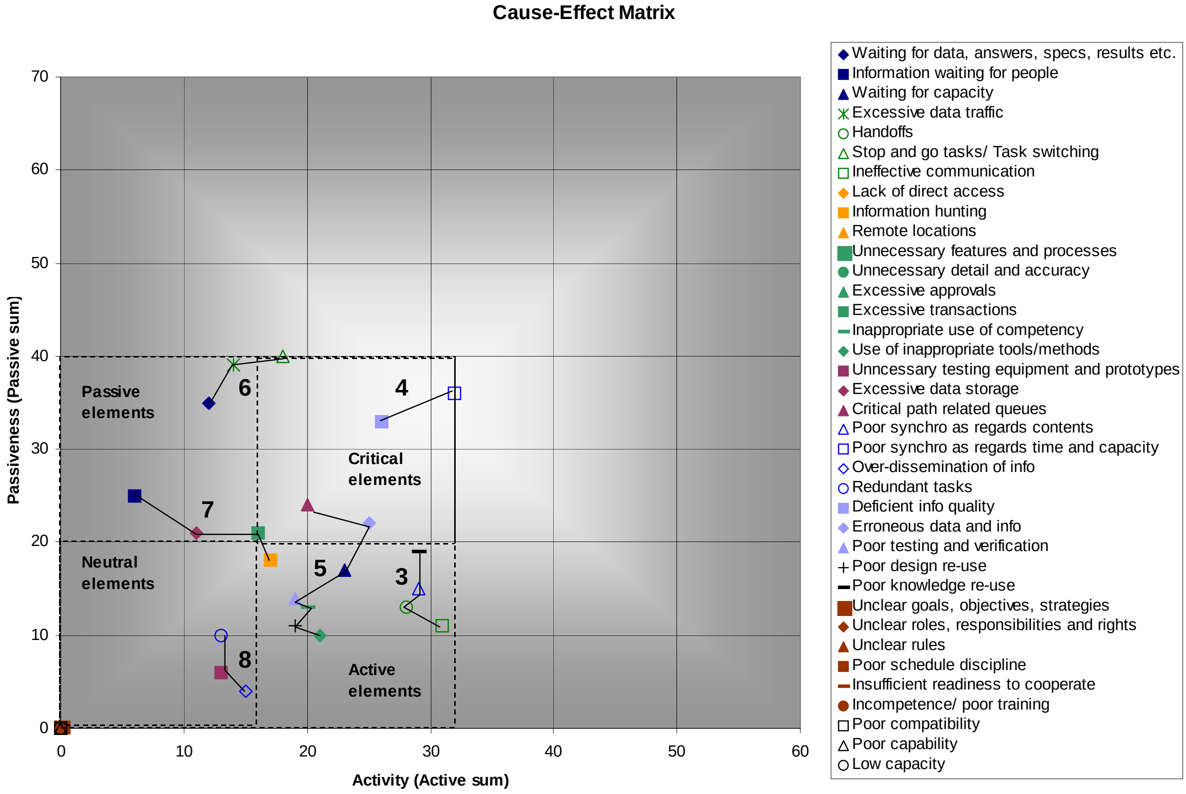
Elimination - I: Eliminating clusters step by step (1 to 8)



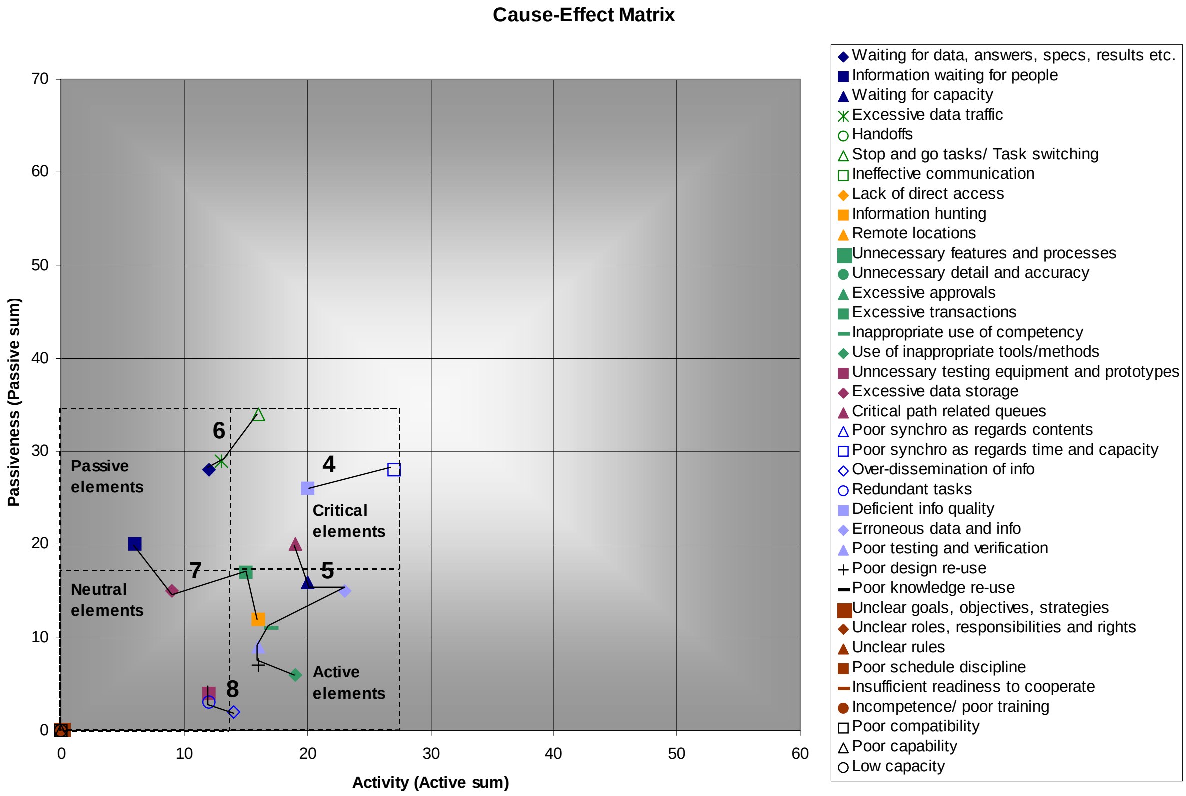
Initial position



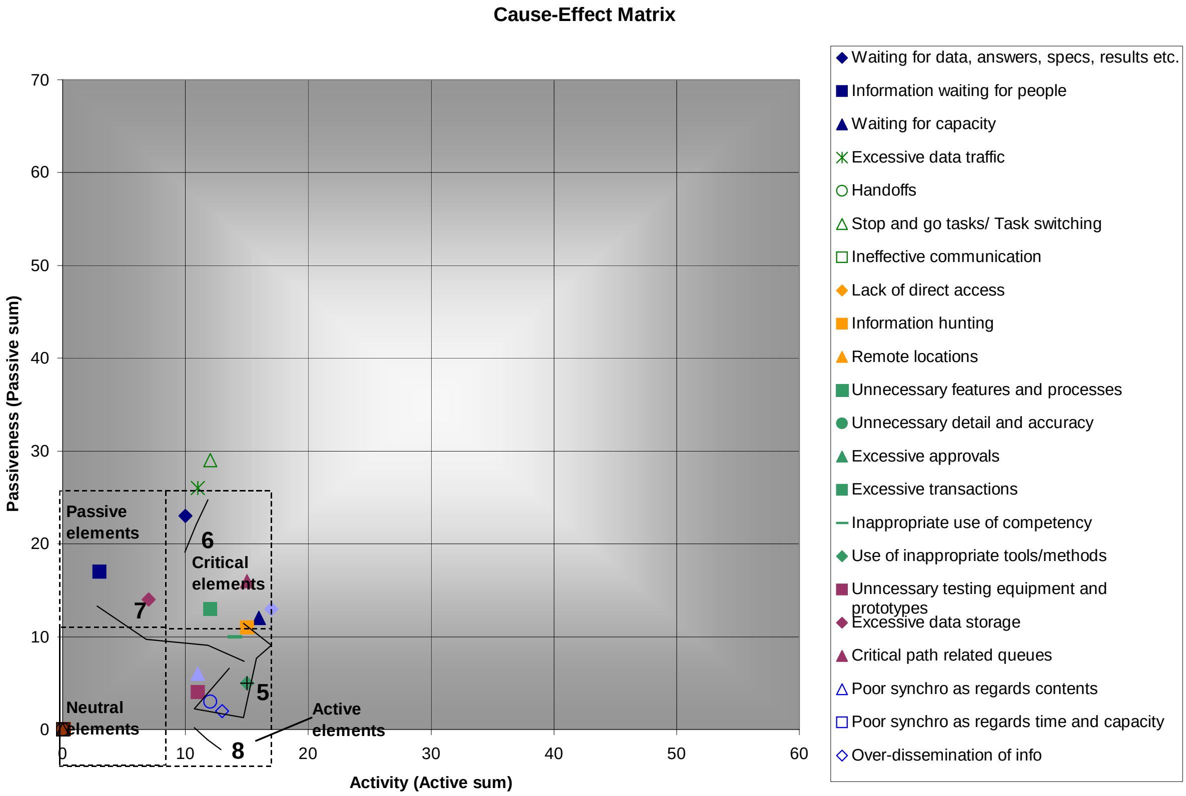
Graph after the elimination of cluster 1



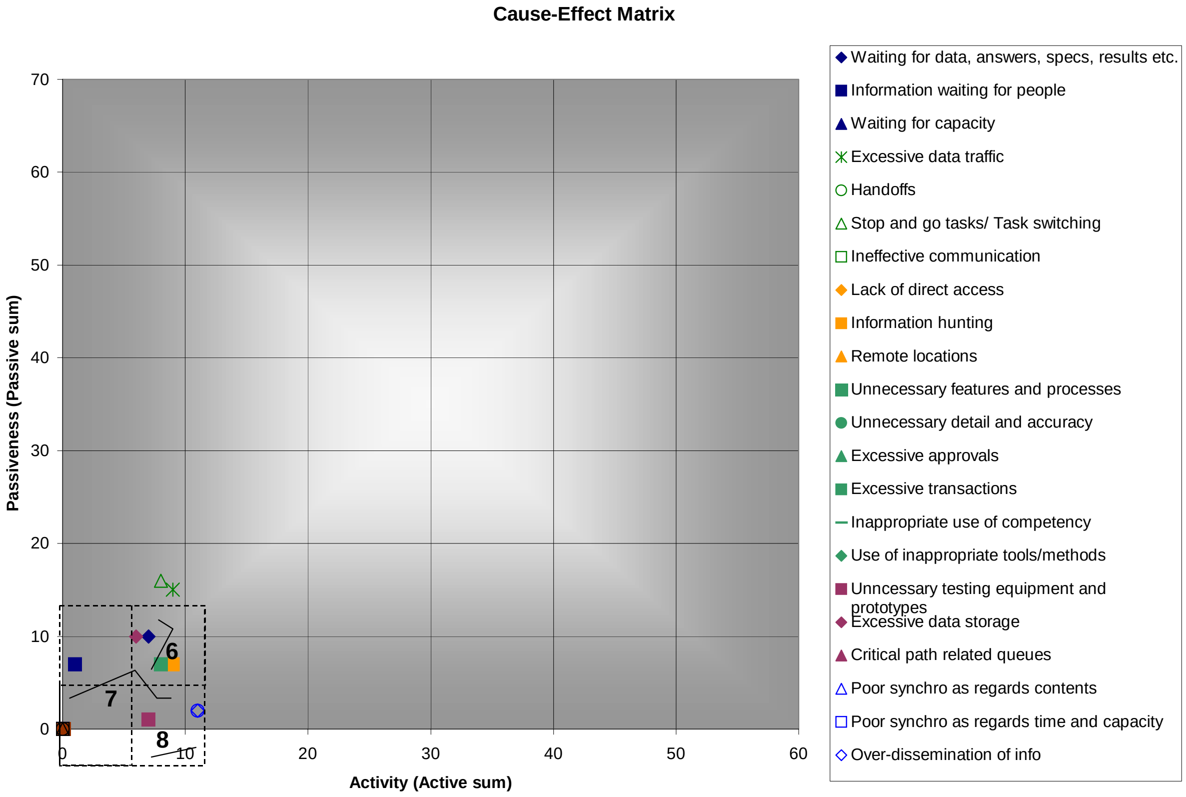
Graph after the elimination of cluster 2



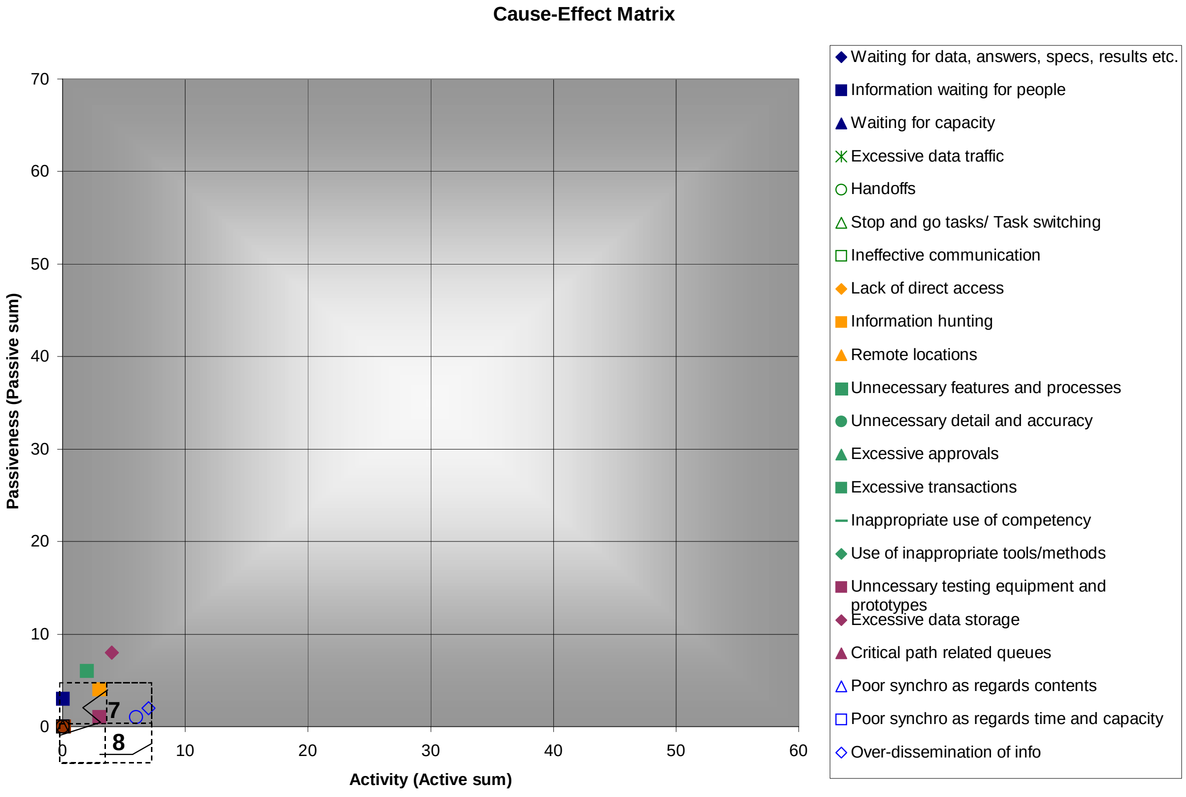
Graph after the elimination of cluster 3



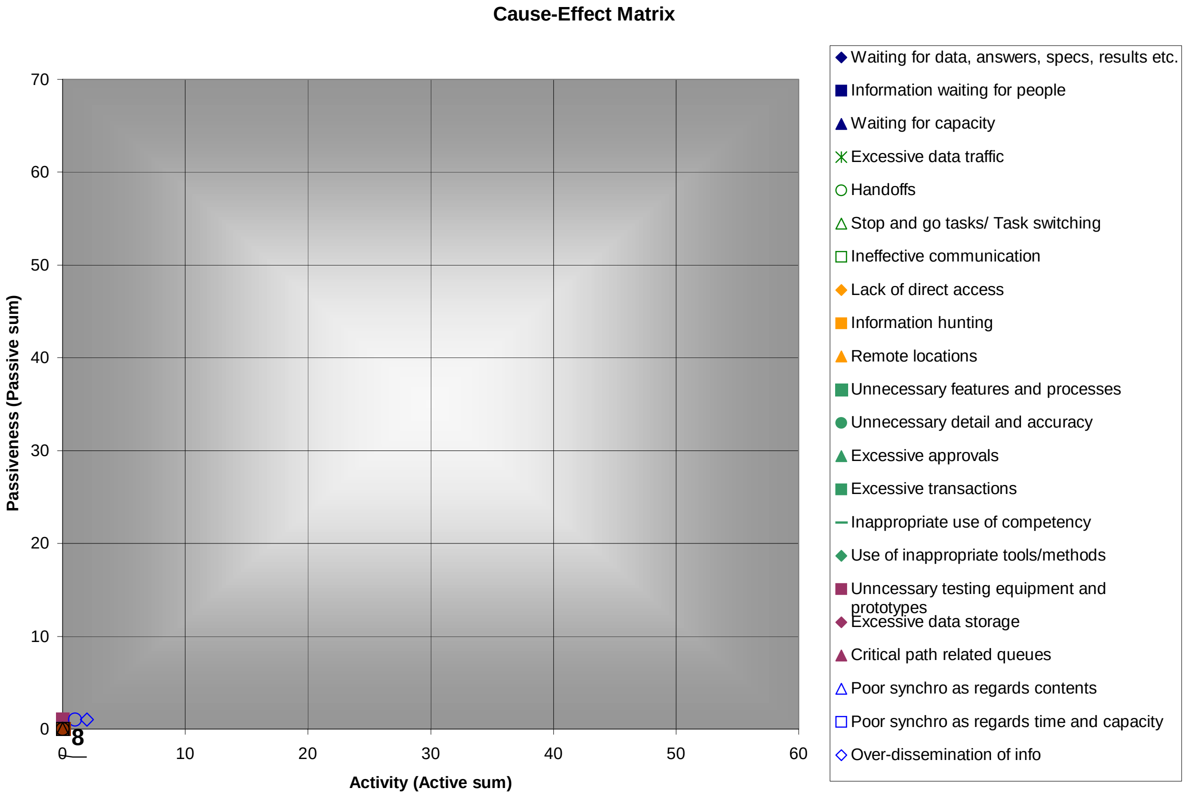
Graph after the elimination of cluster 4



Graph after the elimination of cluster 5



Graph after the elimination of cluster 6

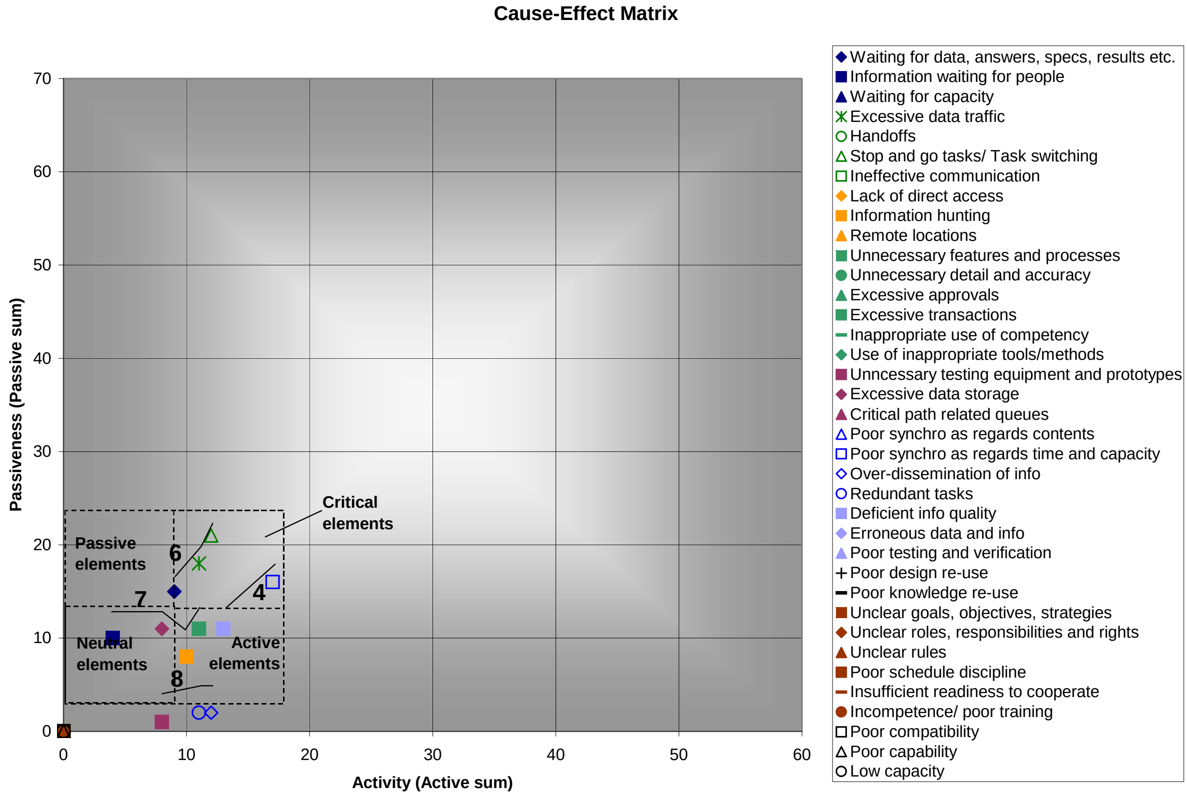


Graph after the elimination of cluster 7

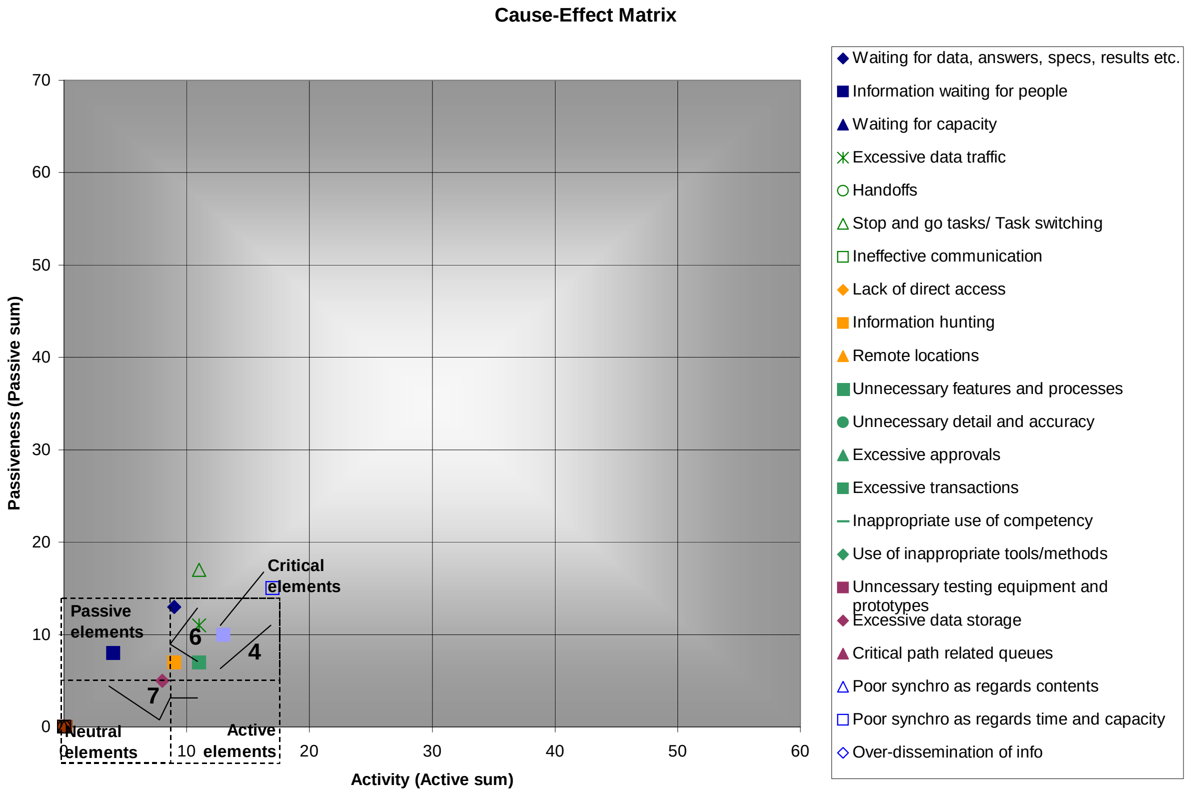
I 11 Simulation of waste elimination - II

Elimination - II: Eliminating clusters step by step

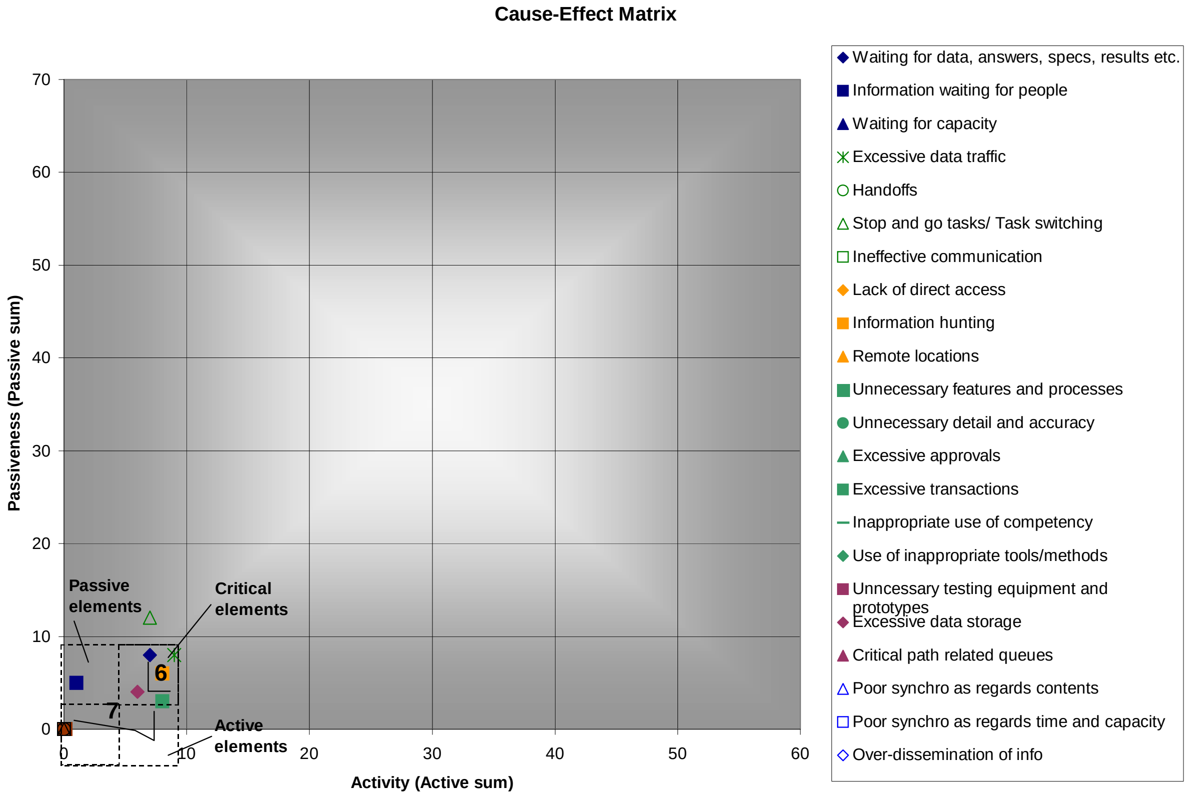
- 1 to 3 as shown in appendix ➲ I 10
- 4 to 8 adjusted, for instance 5 before 4



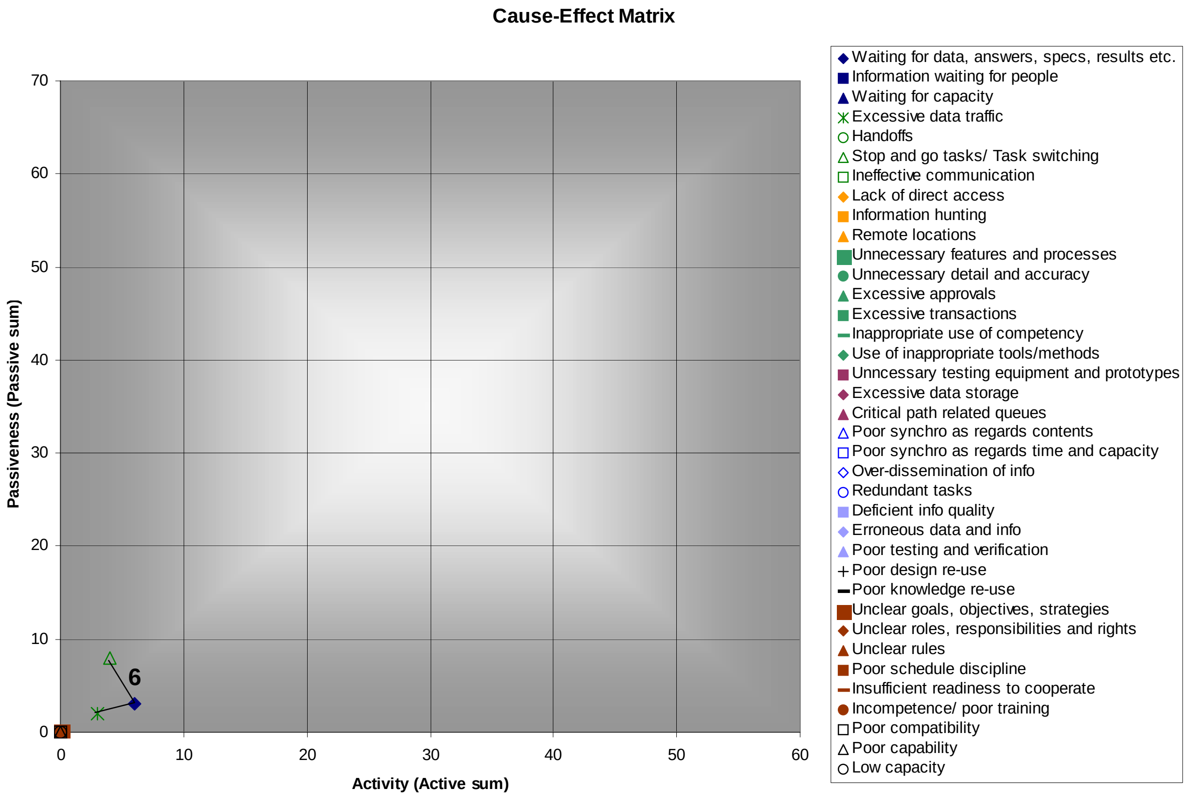
Graph after the elimination of cluster 5 (before 4)



Graph after the elimination of cluster 8



Graph after the elimination of cluster 4



Graph after the elimination of cluster 7

I 12 Display project targets and list of requirements

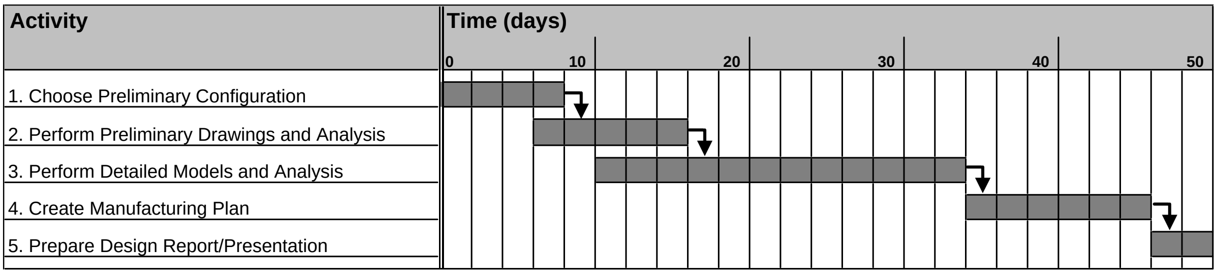
Development of a Lean Product Development enabling display (concept)						
Goals and targeted result						
		Create a display that enables better/more efficient information flow within product development through implementation of lean principles, including (but not limited to):				
		Visualization that allows everyone to have a better understanding of the process				
		Giving lowest level of decision making (Thru map, engineer can see what needed first)				
		Displaying value creating activities				
		Displaying waste				
		Displaying relevant metrics for process control				
		Targeted result:				
		Concept of a simple representation displaying the value stream and the status in product development to the people involved and enabling the early detection of waste				
List of requirements						
Field	*No.*	*Specifications*	*Value*	*Comment*	*Name*	*Date*
Display using						
	1	User friendly: simple and intuitive			Whitaker, Bauch	10.05.2004
	2	Easy to create/update the display/process	Effort [$] to maintain <10% of overall project effort	Value by Whitaker	Whitaker, Bauch	07.06.2004
	3	Easy to update process step status/completion			Whitaker, Bauch	10.05.2004
Architecture						
	1	Clear and comprehensible			Whitaker, Bauch	07.06.2004
	2	Holistic view of the product development process			Whitaker, Bauch	07.06.2004
	3	Shows interdependencies between process steps			Whitaker, Bauch	07.06.2004
	4	Displays information for individual (Inbox, outbox)			Whitaker, Bauch	07.06.2004
	5	Allows people to see where their work results flow			Whitaker, Bauch	07.06.2004
	6	Scalable views (within process boxes; time scale changes)			Whitaker, Bauch	07.06.2004
	7	Display must have temporal aspect			Seering	05.02.2004
Content/Function						
	1	Offers a picture of current product development status (i.e. dashboard)			Whitaker, Bauch	07.06.2004
	2	Supporting people in planning, execution, control and diagnosis/ review of the development process			Bauch	07.06.2004
	3	Gives some form of waste-indication or rather supports early waste detection			Bauch	10.05.2004
	4	Simple representation of the value stream			Bauch	07.06.2004
	5	Supports the identification of value-adding steps			Whitaker, Bauch	07.06.2004
	6	Enable engineers to make work decisions (Lean principle)			Whitaker, Bauch	07.06.2004
	7	Incorporates/implements lessons learnt			Bauch	10.05.2004
	8	Process step output includes output (virtual) location info			Whitaker, Bauch	07.06.2004
	9	Display prevents information disconnects and displays when information is available	- Waiting for information that already exists (avoidance of unnecessary information disconnects) - Not doing work whose output is needed soon		Seering, Bauch	05.02.2004
	10	Includes some form of overschedule indication			Whitaker, Bauch	07.06.2004
	11	Simulates reality (real project) with acceptable accuracy			Whitaker, Bauch	07.06.2004
	12	Should discourage batching of information			Bauch	07.06.2004
	13	Improving people's communication by providing a common reference			Bauch	10.05.2004
	14	Providing persons with continuous access to things they need to know			Whitaker, Bauch	07.06.2004
	15	Providing engineers with information about: where and when communication is necessary			Whitaker, Bauch	07.06.2004
	16	Providing engineers with all relevant information to better flow work			Seering, Bauch	05.02.2004
Industrial psychology						
	1	Must avoid 'gaming' on the part of the people involved			Whitaker	07.06.2004
	2	Must not be punitive			Whitaker, Bauch	07.06.2004
	3	Must include excitement factors that people want to use it			Bauch	10.05.2004

I 13 Examples of Value Stream Mapping (VSM) Tools

On the whole, there exists a number of different possible representations of value streams. The difference can be seen in their ability to represent the timing of a process, or their ability to support improvement analysis by capturing the flow and value of work within the process (Millard, 2001, p. 89). The following pictures are directly taken from McManus (2004).

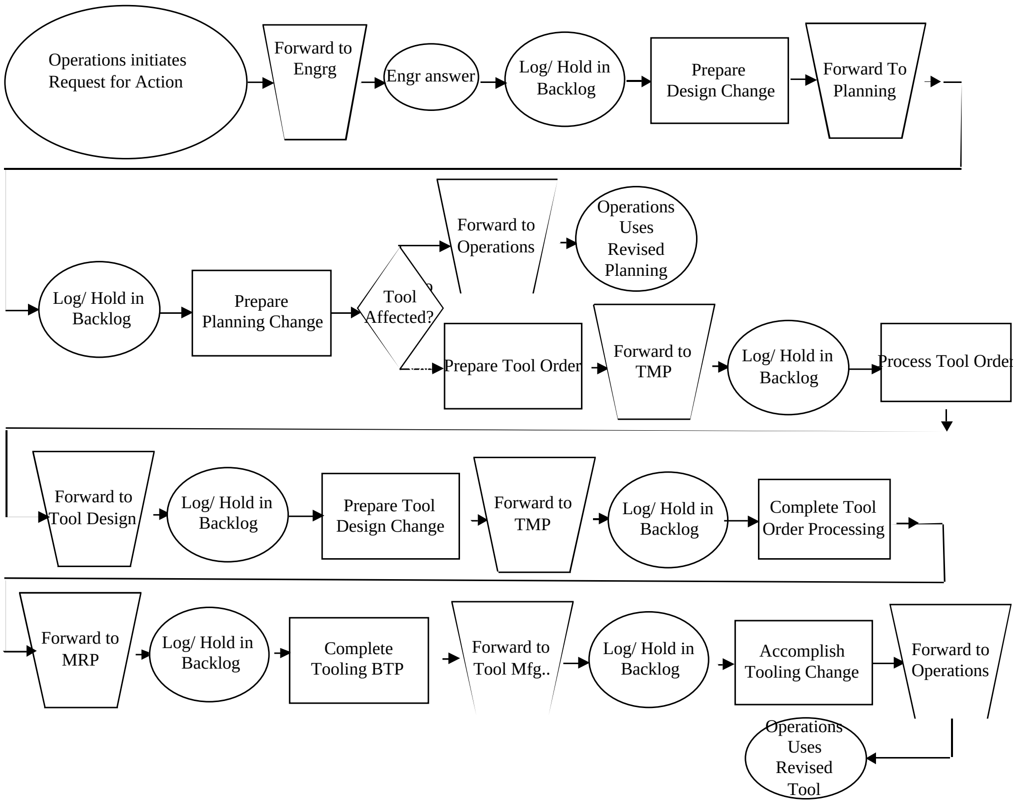
I 13.1 Gantt charts

A Gantt chart is a very traditional way to display schedule, sequence, duration of and dependencies between the different project tasks, and is mainly used on the abstract level of project management.



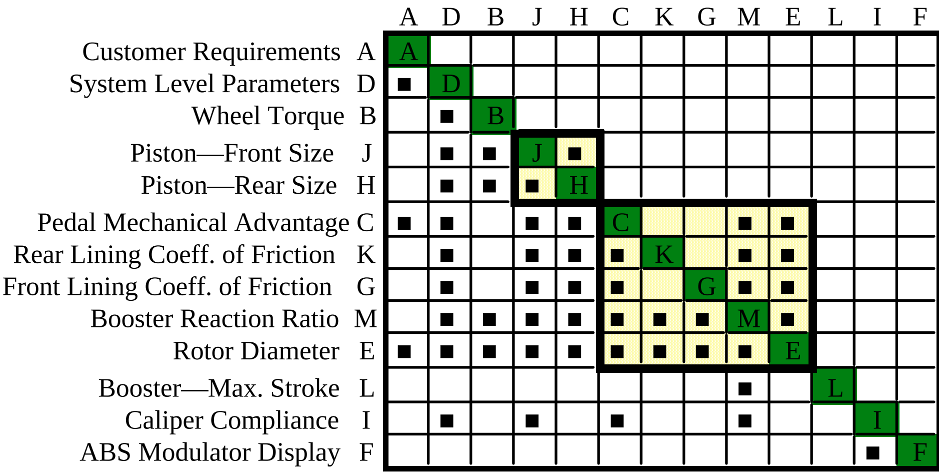
I 13.2 Process flow maps

Process flow maps focus on the sequence of process steps and are often used to highlight waste and areas for improvement. The method uses standard symbols connected by arrows to describe the process flow. Identified non-value adding steps can easily be displayed by the use of different colors (McManus, 2004, p. 74). In general, process flow maps applies to both high and low level of process analysis.



I 13.3 Design Structure Matrix (DSM)

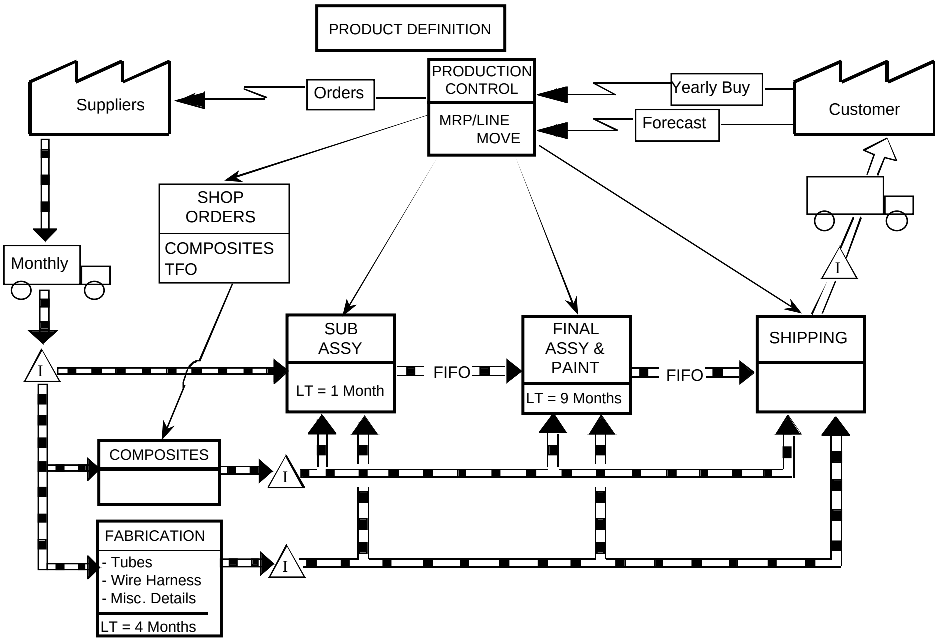
‘The DSM technique is a well-developed method for analyzing the sequences of, and information flows between, the tasks in a process. An ‘n-squared’ matrix is used to depict the information flows from one task to another. The matrix can be numerically optimized to minimize iterations and maximize the potential for concurrent work’ (MCMANUS, 2004, p. 77).



		A	D	B	J	H	C	K	G	M	E	L	I	F
Customer Requirements	A	A												
System Level Parameters	D	■	D											
Wheel Torque	B		■	B										
Piston—Front Size	J		■	■	J	■								
Piston—Rear Size	H		■	■	■	H								
Pedal Mechanical Advantage	C	■	■		■	■	C			■	■			
Rear Lining Coeff. of Friction	K		■		■	■	■	K		■	■			
Front Lining Coeff. of Friction	G		■		■	■	■		G	■	■			
Booster Reaction Ratio	M		■	■	■	■	■	■	■	M	■			
Rotor Diameter	E	■	■	■	■	■	■	■	■	■	E			
Booster—Max. Stroke	L									■		L		
Caliper Compliance	I		■		■		■			■			I	
ABS Modulator Display	F												■	F

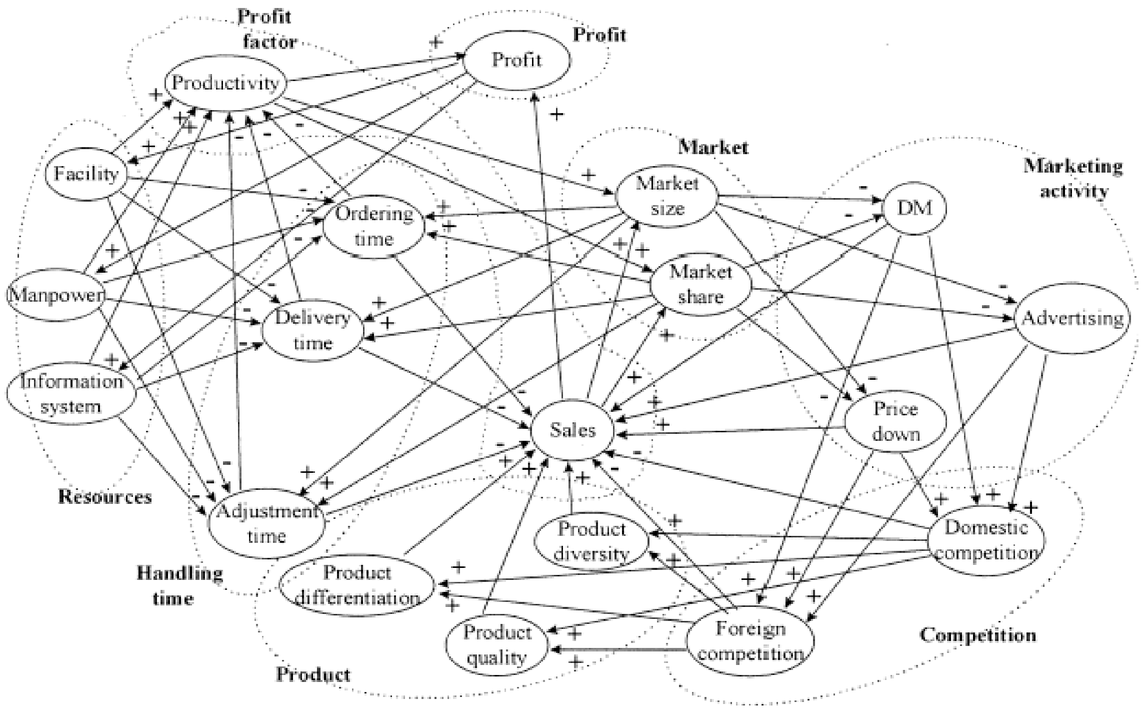
I 13.4 Learning To See

Learning To See, a method developed by ROTHER & SHOOK, is based on factory floor mapping and represents the most proven tool for lean-based value stream mapping so far. In general it uses boxes and arrows with different meanings. Once it is clear how lean principles such as value, waste and flow translate to product development, it will also be possible to use it in this environment (MCMANUS, 2004, p. 76).



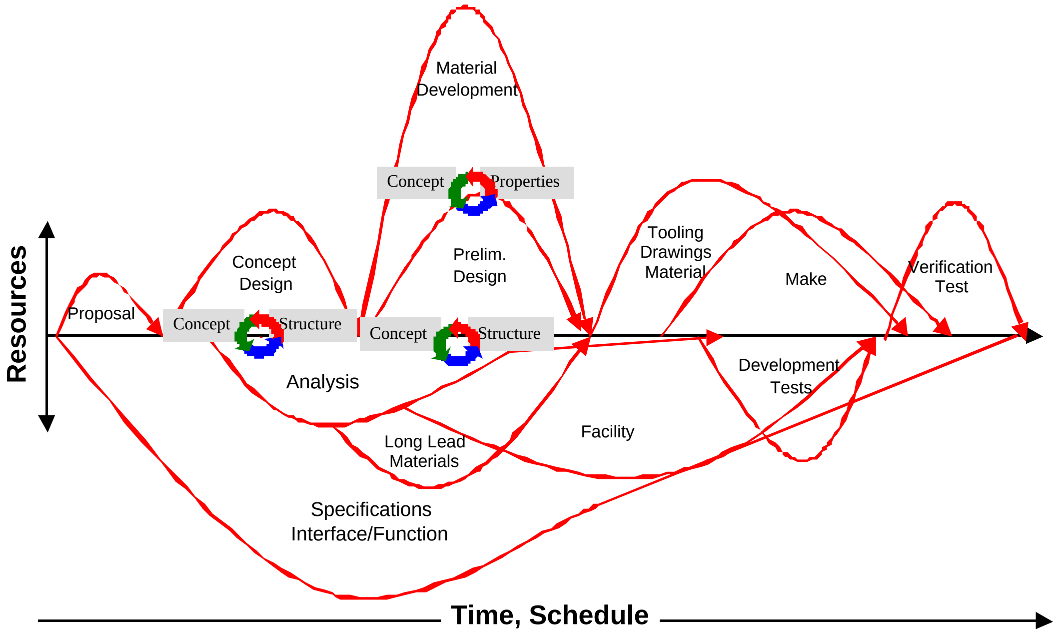
I 13.5 System Dynamics

System dynamics modeling is no ordinary VSM method but can be very helpful in the context of lean improvement activities. A certain number of different factors get assessed in terms of the quality of their relations each other. Discussing all factors may result in a complex network that visualizes active and passive factors of the system considered.



I 13.6 Ward/LEI

Alan Ward of Ward Synthesis, Inc., is the originator of a map, which focuses on the concurrency, milestones, and the cyclic nature of product development processes. As shown in the example, the map displays time along the horizontal axis, and the magnitude of resources required to accomplish a certain task on the vertical axis (McManus, 2004, p. 73).



I 14 VSM Tool Categorization Matrix

	Process Attributes		Gantt	Process Flow	DSM	Learning To See	System Dynamics	Ward/LEI
Time	Concurrency		✓		✓		✓	✓
	Start/stop times		✓		(✓)			✓
	Task duration		✓					✓
Work	Decision branching			✓				
	Feedback				✓		✓	
	Flow							
		'product' info		✓	✓			
		command info		✓		✓		
		material		✓		✓		
	Inputs/outputs			✓		✓	✓	
	Iteration				✓		✓	✓
	Metrics			(✓)		(✓)		(✓)
	Task precedence		✓	✓	✓		✓	✓
	Tasks		✓	✓	✓	✓		✓
	Resources							
		generalized						✓
		specific	(✓)	(✓)	(✓)	(✓)	(✓)	
	Value			(✓)		(✓)		(✓)
Structure	Geography			(✓)		✓		
	Grouping/teaming				✓			
	Milestones		✓					✓
	Organizations				✓	(✓)		