# Information and Communication in Lean Product Development

Diploma Thesis
Technical University of Munich
Registration Code 1010

Martin Graebsch
January 2005

American Edition

# ABSTRACT

In this thesis, the implications and influences that information and communication impose on lean product development in general, as well as the development of a lean Product Development Value Stream Display (lean PDVSD) in specific, are discussed theoretically, studied and analyzed.

First, the concepts of information and communication are discussed theoretically from a lean perspective. Definitions are provided and aspects of importance to lean processes are deduced. Furthermore, requirements for an envisioned lean PDVSD are gathered systematically.

Existing Value Stream Mapping tools are introduced and shortly discussed, and the current development of the envisioned lean PDVSD is briefly reported. A preliminary, paper-based version is provided.

In order to test assumptions, and to generally foster the understanding of information value and waste in product development processes, a field study is conducted. The study is set in two product development projects of an MIT course for senior students of mechanical engineering. With the previously mentioned paper-based PDVSD as a tool, information transfers are observed and analyzed according to waste drivers, means of communication and other aspects of importance to lean processes.

Ultimately, based upon the theoretical elucidations and results from the study, recommendations for future product development projects are provided that potentially help to realize lean processes. In respect to the further development of the lean PDVSD display, suggestions are made which functions and features should be implemented prior to first testing in industrial environments.

# FOREWORD

This is the American edition of the diploma thesis in partial fulfillment of the requirements for the degree of 'Diplom-Ingenieur (Maschinenwesen)' at the Technical University of Munich (TUM).

The research which led to this thesis was conducted at the Massachusetts Institute of Technology (MIT), from June, 15th 2004 through December, 20th 2004. It was supervised by Prof. Warren Seering at the Department of Mechanical Engineering, MIT, as well as by Dipl.-Ing. Hans Stricker and Prof. Dr.-Ing. Udo Lindemann at the Department for Product Development, TUM.

The different requirements on format, printing and publishing led to the necessity of two different editions. This American edition fulfills the requirements of formatting and publishing present at MIT. The two editions do not differ in content, but in page count. Whenever this thesis is referred to in other literature, it should thus be stated whether the American or German edition was used.

Both editions, as well as additional material like presentations and working papers, are welcome to be requested from the author at the email address given below.

Munich, January 2005

Martin Graebsch

graebsch@mytum.de

# ACKNOWLEDGEMENTS

*In principio erat verbum.*
John 1,1

*One can not not communicate.*
Paul Watzlawick

I would like to thank the many people who have contributed to this thesis. Only with their effort and good will, as well as with certain fitting coincidences the life is apparently so full of, this thesis and my stay at MIT became possible.

Specifically, I would like to thank LAI and TUM for the opportunity to spend half a year as a visiting student at the Massachusetts Institute of Technology. I would especially like to thank Prof. Warren Seering for his excellent advice, support and a friendly welcome in Cambridge. I would further like to warmly thank Jin Kato, Ryan Whittaker, Vic Tang and Christoph Bauch for the friendly and valuable collaboration. In Germany, I would like to thank Prof. Udo Lindemann for opening the opportunity and establishing contacts with MIT. Furthermore, I would like to thank Dipl.-Ing Hans Stricker for helpful advice and friendly supervision.

Without many people’s support, it would not have been possible for me to meet the organizational requirements that nowadays make such endeavors a tough choice. I would like to thank the people at CareerConcept AG for uncomplicated and quick support. Furthermore, I would like to thank Dr. Wagner from the student office at TUM, as well as Mrs. Brennan from the international student office at MIT for helpful advice. Last not least, I would like to thank very much Mrs. Wagner at the Frankfurt consulate, as well as Mrs. Hesse for friendly and indeed valuable help.

On the personal side, I would like to thank very much my parents, grandparents, and my siblings for encouraging me, and for warm and always welcome news from Dortmund. I would further like to thank my friends in Dortmund, Munich and wherever they were during the time, who shared many interesting thoughts, good stories, experience and, well, life. I would very much like to thank my roommates for friendship, a warm welcome in Boston, and an interesting and very enjoyable time of my life. Above all, I would like to express my sincere gratitude to Tiina. Throughout this arduous time of separation, you have been a strong support, a best friend and a beloved partner. *Aitäh!*

# TABLE OF CONTENTS

# 1 Introduction

In this chapter, the thesis and its context are outlined. The why and what of the research is described bottom up. A certain familiarity with the concepts of Lean Thinking and Value Stream Analysis/Mapping is suggested prior to the reading of this chapter, as well as the rest of the thesis. Hence, reading of WOMACK & JONES [2003], BAUCH [2004] and MCMANUS [2004] is highly recommended.

## 1.1 General Context: Lean Product Development

In a modern, worldwide market, it has become vital to speed up time to market. As the development process causes much of the time it takes to proceed from a customer's demand to the delivery of the right product in the right quality [see also CLARK & FUJIMOTO 1991, pp. 67], shortening the development cycle times is a major concern of designing enterprises worldwide [ibid, p. 1].

In order to deliver the right product quality, *effective* product development has long been the focus of product development research; since engineers sought a way to demystify the art of creating successful products [see WÖGERBAUER, 1943]. From its beginnings in the middle of the last century, systematical product development has evolved to a complex and rich set of methods, tools, and best practices [see for example EPPINGER & ULRICH, 1995, and LINDEMANN, 2001]. However, designing the right products does not necessarily embrace making the products the right way. In contrast, *efficient* product development has not been paid much attention to in product development. Management approaches usually stop at defining resources, people and time, and sequencing the tasks within the process. Consequently, the overall task of designing a product is commonly controlled by stage gates or milestones, at which the product and spending of resources is approved, but not the product development process itself. How the tasks are subdivided, and their respective outputs connected, is left to a project manager with both limited responsibility and rights. He or she relies on experience and methodical approaches, and has to stand his or her ground against functional barriers [see MCMANUS 2004, p. 10].

In manufacturing, efficiency is a main issue, as inefficient production directly raises costs. For many years, the Toyota Production System was a landmark in efficiency, and many studies have sought to understand its underlying principles. These principles and their application have become widely know as lean production [WOMACK et. al. 1991].

The basic Lean Principle is the concept of value, and its counterpart, waste. According to that concept, all process activities can be classified as adding either value to the product or not. Waste can be further divided into non-value-adding activities (NVA) and required non-value-adding activities (RNVA). Ultimately, Lean Thinking seeks to identify and eliminate all waste from a process. The difficulty lies in the application of this theoretical concept to real processes. As

McManus [2004, p. 109] points out, activities can be difficult to classify. Processes that seem value-adding at first glance show considerable amounts of NVA and RNVA under further and more detailed examination.

The elimination of waste at any level of detail is very appealing for an apparent reason: Waste elimination can result in overall process improvements in all three major aspects – quality, cost and time – simultaneously, as waste can be understood as the consumption of resources yielding negative effects. Hence, eliminating waste frees these resources for other purposes. In other words, "the traditional linkage between high quality and low efficiency is broken by lean - the quality is free" [McManus 2004, p. 12].

Given the great success of enterprises which challenged and succeeded in the transition to lean production as Toyota [Womack & Jones 1991] and Porsche [Womack & Jones 2003, pp. 189-219] it is not surprising that current research seeks do adopt the ideas of lean to product development as well, in order to enhance process efficiency, to facilitate effective enterprise integration, and to create the right product [see *Lean Engineering* in McManus 2004, p. 9].

It is expected that the implementation of lean ideas can provide major advantages [Wheelwright & Clark 1992], and first results indicate the expectations can be met [Lean Aerospace Initiative].

## 1.2 Thesis Context: Value and Flow in Product Development Processes

Lean is often referred to as the synthesis of five basic principles: Value, Value Stream, Flow, Pull and Perfection [Womack & Jones 2003, pp. 29-98]. In product development, these principles can not be adopted directly from their origin in production, as the circumstances are different. For example, product development processes must deal with uncertainty about the product, act on a mix of professional backgrounds, and are not repeated [these issues are discussed in depth in McManus 2004, pp. 11-14 and Bauch 2004, p. 25]. The two principles of value and flow are of paramount importance in that respect, as follows.

*Value*, firstly, means in manufacturing the customer's perspective on quality and cost of the product. In product development, the "product" or output is not a material artifact, but a set of instructions, specification and models which altogether define the product and its creation through production. Thus, the value created by product developments is information, not an object.

*Flow*, secondly, is of great importance in manufacturing because an unsteady flow causes a big proportion of the cost. Adapted to product development, lean information flows seek a seamless and smooth transition of information from one place to another [McManus 2004, p. 29]. That encompasses information related to both product and process [Bauch 2004, p. 11; Womack &

JONES 2003, p. 15]. Of course, product information can also be retrieved without (direct) communication, e.g. through analysis of a competitors' product.

Efficient communication in product development processes with multiple participants, thus, means facilitating the seamless flow of valuable information. This is precisely the objective of the research this thesis is embedded into. Currently, the group around Prof. Seering at MIT's Department for Mechanical Engineering is developing a lean product development value stream display (PDVSD) that helps to plan, display and control product development processes, in order to identify and eliminate waste, and to enhance communication.

The following paragraphs will elaborate on the specific content of the thesis.

## 1.3 Scope of Thesis

As a stepping stone in an long term effort to facilitate seamless information flow on valuable information, this thesis (a) focuses on the concepts of information and communication, (b) gathers resulting requirements for a lean product development process tool that is currently under development at MIT's Department of Mechanical Engineering, and ultimately (c) conducts a field study to evaluate assumptions on the relations of value and actual information and communication.

The scope of the thesis is limited to the discussion of "information" and "communication" in product development research, under the lean perspective. Hence, the implications of social and computer sciences are mentioned, when appropriate, but elucidations thereupon are kept short.

In the following, this paragraph provides reasoning behind the decision to focus on information and communication.

- Paragraph *1.3.1 Systematical Approach to Research Importance*, p. 12, guides through a deduction based on the interdependencies of waste drivers, which shows that waste drivers related to information and communication need further examination.
- An approach more related to practice argues that a company facing a continuously changing environment needs means of effective and efficient information and communication to maximize flexibility within the product development process, as shown in *1.3.2 Practical Approach to Research Importance*, p. 15.
- Many lean techniques seek enhancing the transparency of manufacturing processes. Paragraph *1.3.3 Empirical Approach to Research Importance*, p. 15, explains why similar techniques in product development promise benefits.

For a quick introduction, the reading of these above mentioned paragraphs is not deemed necessary, and can be skipped and returned to later.

Towards the end of this chapter, paragraph *1.4 Research Questions*, p. 16, and *1.5 Thesis Outline*, p. 17 provide more information on the thesis.

### 1.3.1 Systematical Approach to Research Importance

It can be systematically deduced that the waste drivers related to information and communication have, despite not being a major concern of recent product development research, a great impact on overall product development process performance. This approach relies on a cause-effect analysis of altogether 35 waste drivers, conducted by BAUCH [2004].

Starting with the graphical representation of the cause-effect analysis of waste drivers [2004, p. 75], BAUCH recommends to focus first on active and critical waste drivers in order to achieve major improvements. In *Figure 1-1 Systematical Deduction of Research Importance* this is part of the first step. Only the right hand side of the matrix is displayed, as it contains all active and critical waste drivers. In addition, all waste drivers are omitted, which base upon topics not directly addressable by product development research. The specific reason to omit them is discussed as follows.

- Poor compatibility. Whenever two programs or computer systems are not interoperable, methodical product development cannot help but advise to buy other systems.
- Poor capability. Similar to the above stated point, methodical product development has no means to speed up computers.
- Remote locations. As locations are tied to many inflexible factors as buildings, infrastructure and cultural boundaries, changing locations is not easy and touches many organizational problems rather than product development. However, development of tools that facilitate virtual development is helping to overcome this particular problem.
- Insufficient readiness to cooperate. The motivational problem is of concern to psychologists, which have background and experience in the intricacies of emotions and thinking.
- Incompetence / poor training. Educational problems are not of direct concern to product development research.
- Unclear rules. Communicating and enforcing rules are important tasks, and pivotal to successful management. Product development research should adhere to management issues like this, but not overextend.

However, any methodical approach to an engineer's work can and should be judged by its ability to enhance any of the above mentioned factors. A method is of no use if its practicability is lessened by not taking into account the circumstances of product development.

The second step in the deduction, as shown in *Figure 1-1 Systematical Deduction of Research Importance*, is identifying the waste drivers that are already worked on. The current development of a lean product development enabling display embraces the counteracting of the following waste drivers:

- Poor synchronization as regards contents.
- Poor synchronization as regards time and capacity.
- Handoffs.
- Unnecessary testing equipment and prototypes.

Chapter *5 Development of a Lean PD* provides more information thereupon.

Integrated in the second step in *Figure 1-1 Systematical Deduction of Research Importance* is the identification of waste drivers that are in the main focus of other fields of research. Not taking into account all of the waste drivers that have been identified as belonging to any of the above mentioned criteria, this is solely:

- Poor knowledge re-use. Knowledge management offers approaches and solutions to this particular waste driver.

On the cause-effect chart of waste drivers, there are 3 waste drivers left which can not be assigned directly to the classification given above. They are:

- Deficient information quality.
- Ineffective communication.
- Unnecessary detail and accuracy.

As the last of these waste drivers - unnecessary detail and accuracy - can be viewed as a subcategory of the first, deficient info quality [see STRONG 1997, p. 39] and effective communication emerge as important steps in the understanding and pursue of a lean product development process. Understanding their impact, intricacies and possible excitation is what this thesis aims at.

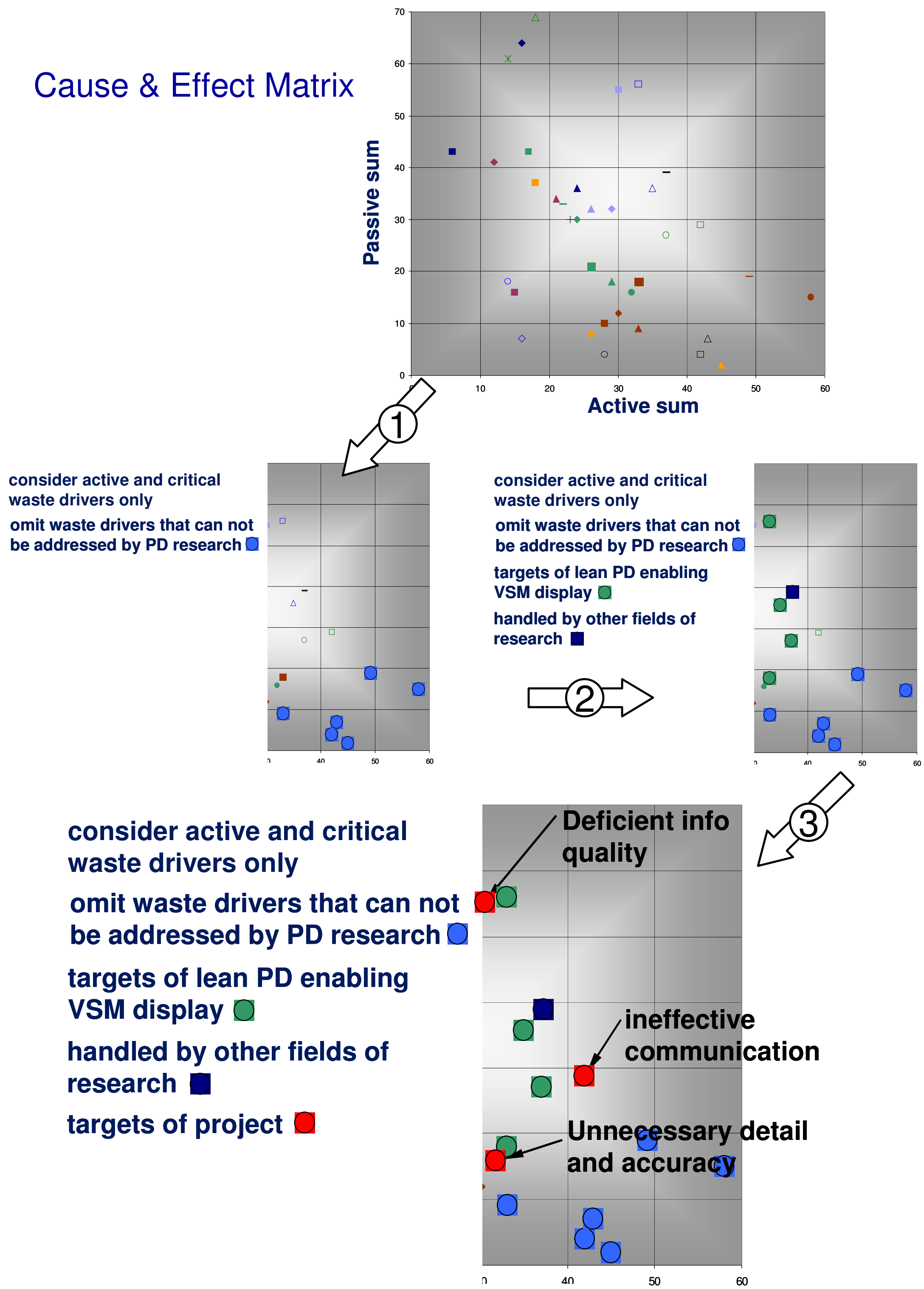


*Figure 1-1 Systematical Deduction of Research Importance (Initial Cause & Effect Matrix as in* BAUCH *2004)*

### 1.3.2 Practical Approach to Research Importance

The target of a lean enterprise is to provide value for customers and other stakeholders. In quickly changing markets, this means a constant refocusing on the customers' needs. The producing industry achieves this by innovative products and short product lifecycles. In order to cope with these, a demand for both efficient and effective product development arises. Efficiency can only be reached if all activities and resources match the specific circumstances of a design phase. Effectiveness requires the accomplishment of well-understood requirements expressed by the customer and other stakeholders.

As each of the phases has a different set of circumstances, and requirements are under constant surveillance, the product development effort has to be flexible to both the changing customer's definition of value – or the improving understanding thereof – and the transition through the product development phases.

True flexibility means flexibility of all resources, including human. Thus, the organizational structure of a given product development team is continuously changing. In order to provide valuable output, and to receive valuable input, a given entity within this continuously changing project relies heavily on up-to-date information about whom to communicate with, in what way, and about what. In this information producing environment, understanding both content and process type information is vital.

Thus, a lean enterprise should profit from a deep insight in the intricacies, dependencies and constraints of information and communication in product development, and hence this study.

### 1.3.3 Empirical Approach to Research Importance

In manufacturing, thoughtfully applied Lean Thinking has, according to WOMACK ET. AL. [1991, p. 48-69], started a revolution. Despite their sketchy outlook, some few principles haven proven to be powerful enough to change thinking about the way in which products are produced, throughout many industries.

Lean Thinking relies on the concept of value, and the elimination of its opposite, waste. Its success in manufacturing is partly a result of waste reducing efforts.

In a survey in the aerospace industry conducted by MCMANUS [2004], engineers assessed 40% of their activity as pure waste. In addition, 62% of their time on job was conceived as idle. In notional combination, that would assume that 77% of an engineer's time on the job is pure waste [see MCMANUS 2004, p. 12].

Connecting the large amount of waste in product development, and the success of waste reduction in manufacturing, it can be expected that the basic principles of Lean Thinking hold effective means to improve the product development process – once waste is identified clearly.

In manufacturing, the transparency is enhanced through value stream mapping. It is essential to detect waste [SHOOK & ROTHER 1999, p. 4]. Likewise, in product development, value stream mapping facilitates process improvements [MORGAN 2002, p. 22].

Concluding, as in product development the processed good is information flowing by means of communication, understanding these concepts thoroughly is necessary to enhance transparency. Thereby, identifying value and waste, and facilitating improvements through principles of Lean Thinking become possible. Regarding the large amount of waste in product development, and the effectiveness of Lean Thinking in manufacturing, the potential results are expected to be massive [see also MCMANUS 2004, p. 13]. First studies have found a strong correlation between the use of sophisticated process improvement tools in a lean context, and success [MCMANUS & MILLARD 2002].

## 1.4 Research Questions

The goal of the thesis can be refined to three research questions, which are given below.

In a product development context that is in search for opportunities to improve its performance, it is important to know where to start. BAUCH [2004] has proposed an order of waste drivers, based upon the interdependency of waste drivers, but it is unknown so far what the impact of each is – how likely they occur, and how grave the consequences are. This thesis takes the information perspective, and thus seeks to answer, *what waste types are the most frequent in information transfer? What are their effects?*

Yet, insight in the frequency and impact of information waste does not lead to improvements, unless it is understood how they occur. Furthermore, the potential value of information in product development can only be realized, when it is transferred to other tasks. Thus, an important question is *how do means of communication, communication behavior and waste correlate? Can recommendations be made, that suggest certain usage of means of communication under certain circumstances?*

The previous questions form a general and abstract approach. This thesis is, however, embedded in the development of a computer based value stream display for the use in product development. The envisioned lean Product Development Value Stream Display (lean PDVSD) aims at multiple process enhancements such as increased transparency. As an integrative part of this long-term project, this thesis has the goal to gather systematically all requirements for a value stream display which arise from the discussion of information and communication. Hence, the last question of this thesis is *what constraints and requirements arise for a product development value stream display?*

## 1.5 Thesis Outline

In order to address the problems of information transfer in lean product development processes, and to render possible the potential for improvements, the first step is to clarify the concept of information. In chapter *2 Information*, p. 18, this is addressed thoroughly. Parallel to that, the systematical gathering of requirements for the Lean Product Development Value Stream Display (Lean PDVSD) begins, and continues throughout the following chapters.

Information without a context which values it is waste. As the context of any process is build upon communication, to understand this latter concept is essential. Chapter *3 Communication*, p. 78 takes a look at the aspects of communication in product development.

Chapter *4 Value Stream Mapping*, p. 88, gives an overview about current research and use of different value stream mapping techniques. Most of those techniques are used in manufacturing, but recent examples show their spreading in product development. The chapter concludes with an assessment on accomplishments of the applications and modifications of VSM techniques for product development, and the emerging difficulties. Concluding the chapter, the systematical gathering of requirements for the Lean PD VSD will end.

Based upon the findings in previous chapters, and especially upon the established set of requirements, chapter *5 Development of a Lean PD Value Stream Display*, p. 94, guides briefly through the development and current state of the proposed display.

In order to address the research questions (see the previous paragraph), in chapter *6 Field Study*, p. 100, a field study conducted at MIT's course "Product Engineering Processes" is described. The intent, the setting and methodology, analysis, and of course results can be found there. Ultimately, conclusions for the further development of the envisioned Lean PD VSD are given.

Chapter *7 Outlook*, p. 141, finally gives an outlook on future research and development of the Lean PDVSD. The author's reflection on project and thesis is given as well.

Concluding this thesis, a *8 Summary* can be found on p. 145. The *9 Appendix* on p. 147 contains lists of supporting material, tables, and figures, as well as the references.

# 2 Information

This chapter establishes a comprehensive concept of information in the product development context. Based upon that, the requirements for a value stream display and its different possible representations are extracted. Within the text, these requirements are enumerated and indicated by a suffix in the format “(R###)”, in order to facilitate easy reference. Numeration starts with (R030), as (R001) to (R029) have already been identified by previous work. All requirements are collected in attachment 1.

The first paragraphs of this chapter discuss information itself and its properties. An approach to a comprehensive definition of the concept of information in product development (*2.1 Definition of Information*, p. 18) avoids misunderstandings and further explains the scope of the discussion. The next paragraphs take a look into the general purpose of information (*2.2 Types of Information*, p. 27). The focus of the following paragraph lies in the different physical aspects of information (*2.3 Information Carrier*, p. 33). The next paragraph about information quality is meant to show the properties and qualities of information (*2.4 Quality of Information,* p. 41).

The second set of paragraphs discusses information in the context of product development processes. Paragraph *2.5 Generation of Information* (p. 54) discusses how information is created, from a micro-level perspective. The perspective is broadened in the following paragraph (*2.6 Information Flow*, p. 57), wherein information is understood as a processed good flowing from task to task. Especially the obstacles that inhibit free flow are identified. The chapter is concluded with the intricacies of the most basic assumption of Lean Thinking – value – with information (*2.7 The Concept of Value in Information*, p. 62).

## 2.1 Definition of Information

There are two purposes for defining “information”, and hence for this paragraph. The first one is to avoid misunderstandings when the term “information” is referred to. The second one lies in the deduction of direct requirements for the overarching goal of the development of a product development value stream display. If the “nature” of information can be clearly identified, so can the advantages and disadvantages of certain procedures, tools and methods which produce, encode, transfer, analyze and interpret it.

In literature, many approaches to the definition of information can be found. The following two paragraphs introduce approaches that are relevant to product development, and discuss their influence on this thesis. The chapter ends with a model that combines the two approaches, and gives a summary of findings.

### 2.1.1 Views on Information

A promising hands-on approach to the definition of the term “information” is to look at other sciences. This is conducted in this paragraph.

Unfortunately, the term “information” is not defined universally. Across sciences the definitions differ, take different approaches and have different views. Some common examples:

- In information sciences, “information” is – not without dispute – seen as negative entropy, in other words the mathematical opposite of uncertainty. This definition is measurable; the lower the probability, the higher the information. It can be expressed in the equation $I := -\log_2(P)$, wherein P is the probability of a case, and I its informational content. This definition was introduced by SHANNON [1948]. It does not embrace context, interpretation and consciousness.
- In physics, “information” is seen as one of the three entities that together constitute existence, alongside matter and energy [*The unity of nature,* WEIZSÄCKER 1974]. Unsurprisingly, this definition can be found in engineering literature as well [see, for example, PAHL & BEITZ 1996, pp. 29]. The relations and possible conversions between the three entities are not understood thoroughly yet (e.g., in quantum mechanics).
- In social sciences, “information” is used in the context of syntax, semantics and pragmatism. In fact, there are many sciences that have different approaches. (Computer) linguistics seek to understand and develop mechanism of en- and decoding of information [HERKNER 1991, pp.131]; in cognitive sciences, the interpretation of information is studied [THOMAS 1991, pp. 163]; and the representation of information is of interest in media sciences [FISCHER & WISWEDE 1997, pp. 291].
- In philosophy, there have recently been attempts to establish an all-embracing definition of information, but it is safe to state that there is no such thing as a generally accepted, universal and all-embracing definition [WIKIPEDIA 2004a]. The term can rather be understood as a container of a multi-facetted field of concepts, which themselves can be classified into different definitions for specific needs [for an exhaustive classification, see DIN 44300-1].

To make matters worse, in product development, many views are used simultaneously.

- Designing computer-based tools that support the product development process requires the use of the terminology in information sciences. Speaking with ZUMPE & ESSWEIN (2002, p. 245), “in order to make pieces of information accessible to a user, they have to be analyzed and structured”.
- Electronics and data processing are integrated into complex mechatronical products. The method of function structure mentioned in PAHL & BEITZ (1996, pp.31-37) can be used to facilitate the development of such products; it is based on the definition of

information in physics (see above). Information, in this context, is defined to describe (physical) interactions in products.

- The management of processes, as well as certain creativity methods, embraces the interactions of humans, and thus information in the context of sign, language, communication and interpretation. The various approaches to information in social sciences are used for interactions of process participants (e.g., engineers).

Concluding, in product development research aiming at the design of computer-based tools which represent processes of development of mechatronical products, confusion about terminology arises and cannot be overcome by a simple definition. To avoid misunderstandings, it is thus seen as appropriate to differentiate between basic *views of information*, which will be deduced in the following.

Based upon the above elucidations, three *views on information* in product development can be defined:

- *Information in tools*, which is based on the terminology in information sciences. It embraces computer-based as well as paper-based (and other) tools.
- *Information in products*, which is based on the physical definition. It can be represented through function structure analysis.
- *Information in processes*, which is based on social sciences. It needs a context of persons and organizational circumstances.

It is important to understand that the views are non-exclusive, especially at the interfaces between two or more "realms". For example, an electronic excel-document sent by email can be viewed as information in a process (when sent from one engineer to another) and as information in a tool (since, in this case, an email-client is the tool). It may even contain data produced by a car's ESP system, thus being (transformed) information in a product. What differs is the focus. Viewed as information in a process, the focus is on the sender and receiver of the email, the title, the date and time it was sent, and so on. Viewed as information in a tool, the focus is on it's representation as bits and bytes, the programs that handle and store it, the file size and so on. Finally, viewed as information in a product, the focus is on the actual data generated by a machine.

### 2.1.2 Derivation of Information

Aside from the point of view on a given piece of information, it is of interest to know how it is formed in (product development) processes. Information is a multifaceted element of a complex context, embedded in transfers, time, and projects. Hence, many authors associated to product development research seek to classify information (in a broader sense) according to the criterion of progression, or derivation. In the following, some examples of the classifications will be discussed.

#### 2.1.2.1 Simple model of derivation

MILLARD (2001, p. 26) links the progression of information to its flow and maturing of information through processes. His model assumes that raw data has to be organized in order to become information, that accessed information becomes knowledge, and ultimately applied knowledge becomes wisdom. It can be easily illustrated, as shown in *Figure 2-1: Progression of Information (according to MILLARD, 2001)*, p. 21.

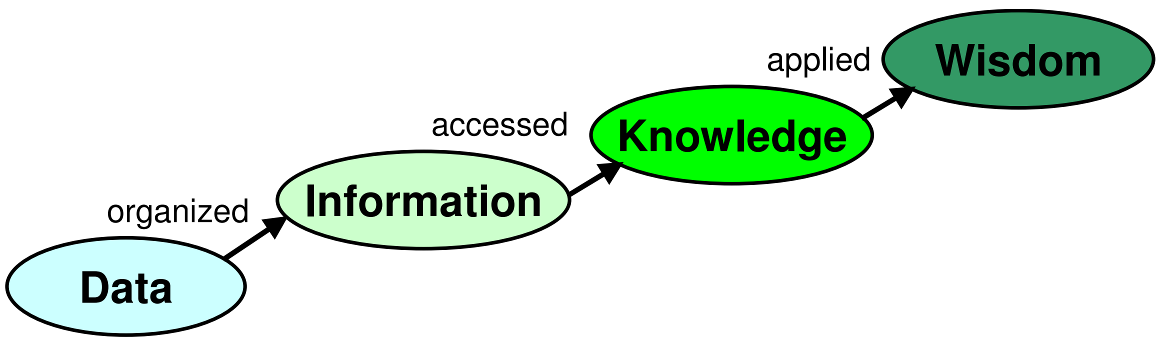


*Figure 2-1: Progression of Information (according to MILLARD, 2001)*

MILLARD states that not every amount of raw data results in wisdom, as problems in the transition from one state to another occur. He explains this by the existence of seven categories of PD Information Wastes (which will be explained in detail in paragraph *2.7 The Concept of Value in Information*, p. 62). This model can quickly explain why not every piece of information is valuable, and what the goal of processes dealing with information should be - to produce wisdom. It is, however, far too simple for the purpose of this thesis. It lacks, for example, an explanation for the generation of data, and does not take into account the user. Furthermore, the terms data, information, knowledge and wisdom are neither defined nor explained by examples.

However, it is important to remember that information is an element in a chain of interactions, and that its value can be decreased by certain actions and circumstances.

#### 2.1.2.2 Complex model of derivation

A similar, yet more complex model is presented by BAUCH [2004, pp. 26-28]. It is based upon models to be found in IRLINGER [1999, pp. 20] and SCHWANKL [2002, pp. 77-81]. *Figure 2-2* shows the model given by BAUCH [2004, p. 27].

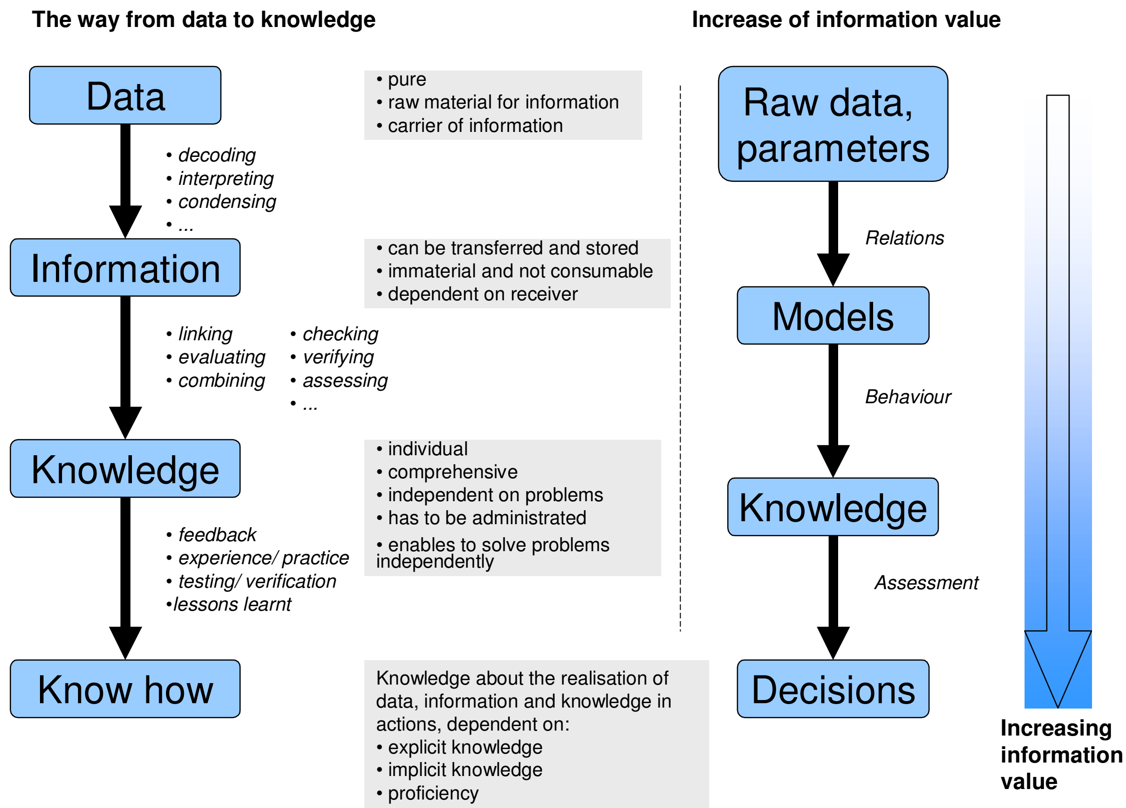


*Figure 2-2: Derivation and value-creation of information [BAUCH 2004]*

The characteristics of the model are:

- The states are defined much more carefully than in MILLARD [2001].
- There is a mutual dependency between the states.
- The transition from one state to the other is blurred, and can be facilitated in many different ways.
- Knowledge can not be transferred directly from one person to the other, but rather needs to be transformed into information first.
- The last state in the derivation is called know-how, the "realization of data, information and knowledge in actions". It can be interpreted as a kind of meta-knowledge.
- It is juxtaposed to a very similar chain of increase of information value, which is more process oriented, as opposed to the focus on individuals.

This comprehensive model hints at many difficulties that can occur in information generating processes. In contrast to the model presented by MILLARD [2001], it defines the terms data, information and knowledge, and describes in more detail what happens in the process of transition. But, inconsistencies remain:

- The figure states, that information is immaterial, but on the other hand can be transferred and stored. This is true for electronic information alone, but not for printed documents.
- If data is a "raw material" and a "carrier of information" at the same time, how can the structure of a document be defined? It is certainly not a raw material (though consisting of it), but it carries information.

Concluding, this model leaves open many questions about the nature of information. Nevertheless, some important features can be extracted. It is important to keep in mind that knowledge needs to be encoded in order to be transferred, and that there is a difference in the individual and the process-oriented derivation of information.

#### 2.1.2.3 Relative model of derivation

Using a very simple model as a basis, AHMED ET. AL. [1999, pp. 121] study engineers and their work, in order to develop a tool meant to bridge the experience gap between novice and experienced designers by supporting the user with appropriate knowledge. The authors state that traditional definitions (mentioned are NONAKA, COURT, WIGG and HUBKA) are (a) inconsistent relative to one another, (b) generally distinguish information from data through a context, and (c) not useful for their purpose, which is similar to the one this thesis is embedded in. They conclude that the concepts of data, information and knowledge are indeed relative, and cannot be defined in absolute terms. In the resulting model, the user plays a vital role in distinguishing data from information and knowledge, and consequently its usefulness. "For example, information can be data for some users and knowledge for others" [ibid, p. 126].

To explain the relative concepts, two *stages* are proposed:

- The awareness stage, in which awareness of context makes the difference between information (which implies meaning), and data.
- The interpretation stage, which separates knowledge and information.

Information is thus dependent on the contextual awareness about the data. Knowledge can be gained through interpretation of this information. The derivation of information in this concept is shown *in Figure 2-3: Relative concepts of data, information and knowledge [Ahmed et al, 1999]* on p. 14.

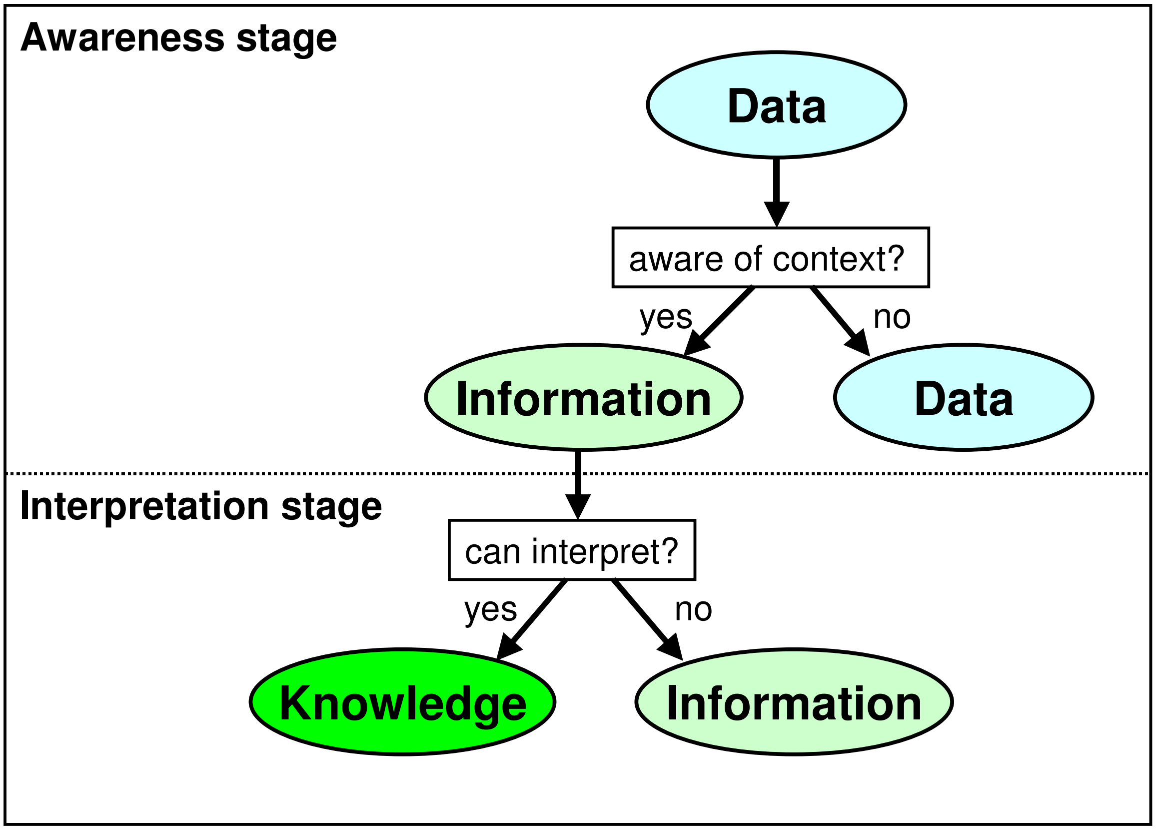


*Figure 2-3: Relative concepts of data, information and knowledge [AHMED et al, 1999]*

The model, though similar at a first glance, has some fundamental differences to the one presented by BAUCH (2004).

- In AHMED ET AL., interpretation makes the difference between information and knowledge, as opposed to BAUCH, were it characterizes the transition from data to information.
- In the latter model, information can not be transferred “as is”, but only data. Information does not exist without context and a conscious mind that is aware of it. Thus, a certain element (e.g., a file) of a (product development) process cannot be defined generally as information or knowledge.

The awareness stage is not always an actively undertaken activity. Furthermore, when information is transferred within a (product development) process, it can not be ruled out that the transfer is accompanied by meta-information. In this case, every station of the transfer is well aware of the context and thus does not see the transferred item as mere data, but information.

Hence, the terminology used in the model differs from the one generally used by process participants, and confusion arises.

#### 2.1.2.4 Conclusions on derivation

Lamentably, literature offers no comprehensive and consistent definition of information in the context of derivation. It is deemed inappropriate to develop a model of derivation without taking into account the different views of information, for the very reason that confusion will not be decreased thereby. Pragmatically, in the following chapters and paragraphs, whenever information is referred to as an element of a chain of progression/derivation, it will be stated which view is used. An attempt to overcome the inconsistence is presented in paragraph *2.1.3 Two-dimensional Definition of Information*, p. 26.

Nonetheless, some important aspects of information in (product development) processes can be extracted from the analysis of the discussed models.

- Information can be seen as an element in a chain of different states, which have blurred borders.
- Information is based on data.
- Information can be used to generate knowledge.
- In order to transfer knowledge, it has to be encoded.
- Encoded knowledge is called "data" by some authors and "information" by others. For this thesis, it is used neither definition exclusively, instead the circumstances as well as the applicable views are described.
- Not every type of knowledge can be encoded with the same easiness. As a result, information transfers usually depend on both explicit and implicit knowledge.
- Progressing through the stages, value can be created (A further look into the concept of value is provided in paragraph *2.7 The Concept of Value in Information*, p. 62).
- If the transformation from one stage to another is flawed, value can get lost.
- The usability of transferred information depends on the user, the process and many properties of information like information quality.
- The user of transferred information plays a vital role in the generation of value.
- The user has to be aware of the context of the transferred information, and must be able to interpret it, in order to gain knowledge.

Based on these aspects, the following general requirements for a lean PDVSD tool are deduced.

- (R030) The user of transferred information has to be taken into account. In order to create value (and to gain knowledge), he has to be aware of the context of the transferred information, and must be able to interpret it. That imposes upon the tool the requirement to transfer contextual information alongside content.

- (R031) As a certain representation of encoded knowledge, the PDVSM display cannot contain implicit knowledge, but it should help to encode knowledge that has not been represented in an explicit form before.
- (R032) In order to prevent losses of value through the transmission from one stage to another, the tool should seek to facilitate the transfer of information at the highest possible stage. Specifically, existing representations of encoded knowledge should not be encoded in a different structure. For example, if the tool is used to transfer a file that fits the need of the receiver, the sender should not be forced to decompose it.
- (R033) The perspectives of both individual and overall process have to be taken into account for any tool that has a long-term concept on value.

### 2.1.3 Two-dimensional Definition of Information

The main inconsistency in the use of the terms information and data can be boiled down to the following contradiction: In process view, information is data in the right context [as in AHMED ET. AL. 1999], and thus a mere file is considered to be data. However, according to the tool view, a file contains information (in contrast to data, like a couple of bytes). So, which definition is right in the context of the thesis?

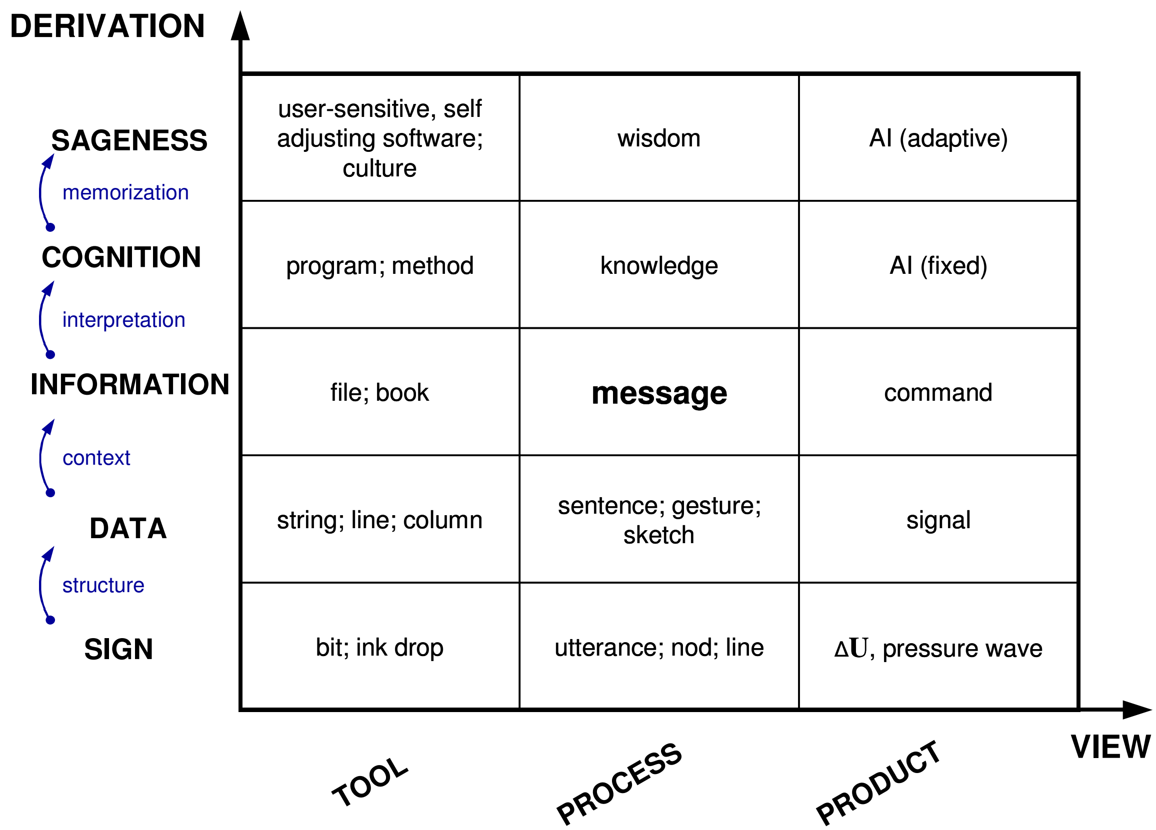


*Figure 2-4: Two-dimensional Definition of Information*

As the thesis needs to address both views (process view for the lean perspective, and tool view for the development of the lean PDVSD software), and is meant to enable discussion of professionals from different backgrounds, *both* definitions have to be followed, and neither is sufficient for the purpose of this thesis. Thus, *Figure 2-4: Two-dimensional Definition of Information*, p. 27 represents an attempt to merge the concepts of derivation and view into a wider, two-dimensional definition of information, and is presented hereby to be discussed.

In the above shown figure of the proposed two-dimensional definition, each of the cells provides examples of terms that are used in a product development context, for the sake of easy comprehension. In the following, the most commonly used terms are discussed shortly, in order to show the compliance with the above proposed definition, and to clarify the use of these terms for further use in this thesis.

- A *signal* is "the physical form by which information is conveyed", as PAHL & BEITZ state [1996, p. 29]. They are "received, prepared, compared or combined with others, transmitted, displayed, recorded, and so on". The definition takes the "typical" engineering perspective (product view), and in this case the stage of data. Of course, certain products, especially personal computers and telephones, can be used as tools in product development processes, and confusion is likely to occur.

- Again citing PAHL & BEITZ [1996, p. 29], a *message* is "information exchanged between people". Thus, it is an information stage, process view entity. This very definition of information is the one most used in the subsequent paragraphs and chapters. Note that the term "message" (process view) is not the same as the term "file" (tool view). A file can be part of a message and transferred thereby, but it does not, by itself, enable a person to interpret - unless it is communicated.

- *Knowledge* is a term used in the process view to describe the stage information leads to, if it can be interpreted. The term is very important in the field of Knowledge Management. TOMAS & HULT [2003, p. 189] define it as "credible information that is of potential value to an organization". They further elaborate on, "a critical part of the […] Knowledge Management process is the transformation of information into knowledge, a phenomenon that takes place at various places in the process […]." The definition is thus in compliance with the definition shown above in *Figure 2-4: Two-dimensional Definition of Information*. Knowledge, as well as experience, influences the success of the design process [AHMED ET. AL. 1999, p. 121].

In the following, whenever the term "information" is used and the specific view is not deducible from the context, it will be clarified. Furthermore, examples will be used extensively in order to provide a sense of practical correspondent to the abstract discussion.

## 2.2 Types of Information

An approach to clarify the extensive connotations of information in product development bases upon the categorization of its types. In this paragraph, different types will be introduced and discussed. The result will be a concept on types, as well as requirements for a lean PDVSD tool based thereupon.

A "type" of information can be understood as the result of its purpose. For example, if the intent is to let someone know a meeting has been cancelled, the resulting information will be of a different type than the one that is intended to let someone know that the car runs *x* miles on a gallon of gas.

### 2.2.1 Categories of Information

SLACK [1999, p. 30] has proposed a categorization into four types ("categories") of information:

- Product information, which is directly related to the developed product and the technical effort to do so.
- Project information, which is directly related to the management of the project. It includes resource planning and schedule management.
- Process information, which "defines bow the product development process is to be executed" (For example, ISO9000 requirements). The definition can be interpreted as the indisputable framework of a project to take place in.
- Business information, which is related to business processes like sales and marketing.

The categorization by SLACK is used to identify four different information flows that altogether constitute the value stream in product development processes (for a detailed discussion of information flows, see paragraph *2.6*, p. 57). Regardless many considered interactions between the different types of information flows, SLACK focuses his further elucidations on project and product information flows alone, omitting his definitions of process and business information.

Whatsoever, what makes SLACKS categorization problematic to handle is the difficulty in separating the definitions. Some examples:

- Project information has a heavy influence on product information. The timeline, funds and tools (accounted for in costs) influence the value of a product. When project information becomes product information, and how product information shapes project information (e.g., when results of a test require a change in schedule), is left unclear.
- Marketing information is, or at least should, be tied directly to a product. In a lean product development effort, customer needs are of utmost importance for the creation of value, and find (or at least should find) their direct translation into specifications. In the opposite direction, new products have to be aggressively promoted to the right customers. Thus, tracking this flow and its multiple interactions with the product is very important.
- The differentiation in project and process information is sometimes difficult to establish, especially if there is no clear border in management. This circumstances can usually be found in small projects, where there is no, or only loose, connection to an organization with strict rules.

Concluding, Slacks categorization is a good attempt at organizing the great variety of information, but lacks an appropriate application to product development. The main flaw is that

Slack's definitions are meant to have sharp borders, but in reality, these borders are not easily detected, and may sometimes not even exist.

By acknowledging that information often serves many purposes at the same time, and that in fact numerous interactions between the types are very important (as waste is believed to occur especially at these interfaces), it does not seem appropriate to enforce a categorization of exclusive types.

For the purpose of this thesis, a non-exclusive, high-level categorization is established in the following paragraph.

### 2.2.2 Non-exclusive Types of Information

In product development processes, a very basic differentiation, is the one between content type, process type and noise type information. It is based on the purpose of the piece of information under consideration, and can be easily illustrated in a comprehensive way, as shown in *Figure 2-5: Types of Information*, p. 31.

- *Content type information* is intended to provide someone information *about the product to be developed*. Common examples are specifications, drawings, product contracts, simulations, CAD-models and the like.
- *Process type information* is intended to inform someone *about the context of the development*. Examples are schedules, telephone numbers, expenses for product development resources, organizational charts, among many more.
- *Noise type information* has no developmental purpose. Examples are spam and personal mail.

A single piece of information (for example, a paper-based document) can be produced with the intent to serve either one or both developmental purposes. Much alike, any piece of information can be used for either purpose. It seems likely that if information is used for a purpose that does not match its initial intent, the reduction of value and/or the occurrence of waste is probable. This hypothesis will be a focus in chapter *6 Field Study*, p. 100.

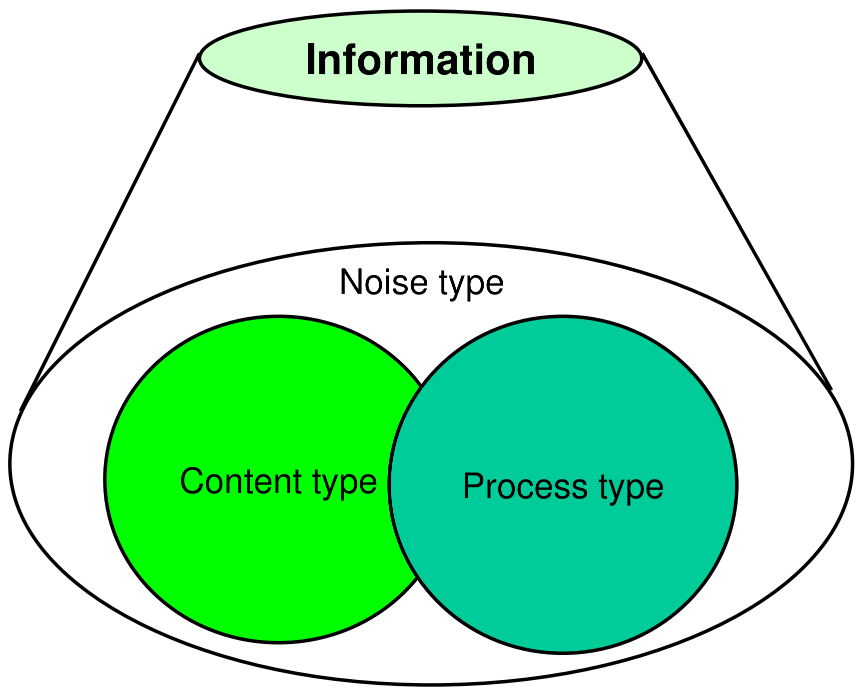


*Figure 2-5: Types of Information*

Note, that the concept "process type information" is **not** the same as "information in processes". The former is based on the intent, the latter on the view (see paragraph *2.1.1 Views on Information*, p. 19). Both concepts can overlap for the same piece of information, but are independent from each other. For example, a CAD-file is content type information, but in its transfer from one person to another it can be viewed as information in a process. In contrast, a schedule is process type information, but when transferred, can be viewed as a piece of information in tools.

Despite being almost always waste, it is acknowledged, that noise type information can never be eliminated totally. After all, product development processes are conducted by humans, who have legitimate interests aside the product and its development. An interesting question which unfortunately cannot be answered yet without straying into the field of beliefs is: If noise type information is fostered, rather than eliminated, will this help content and process type information to spread? Personal networks certainly help to distribute and gather information [see, for example, ALLEN 1984]. In contrast, if distributed and gathered information tends to be noise type information alone, less value is produced, since producing, sending and receiving of *any* type of information requires resources (=cost). To the author's knowledge, there has so far not been an attempt to establish a relation between the three types of information (or similar categorizations), that can describe, yet alone predict, under what proportions the efficiency of product development processes is best. It is further believed, that this relation would depend on circumstances like business culture, size, duration and complexity of the project, and diversity of professional backgrounds.

It is rather easy to develop definitions that sub-categorize each of the types of information. For example, content type information can be subdivided into technical, presentational and customer type information. Process type information can be subdivided in project and function type information. However, there are two aspects to be taken into consideration. On the one hand, an excluding sub-categorization (if a single piece of information is unerringly assigned to one subtype only) does not make much sense at all, since information is commonly produced in order to merge different backgrounds into a new piece of information. A non-excluding typology of information, on the other hand, cannot be all-encompassing and manageable at the same time. For the purpose of this thesis, the pragmatic approach is that process and content type information will not be sub-categorized further, but both can have technical, presentational, customer-related and/or other qualities, in the case further differentiation is needed. An analogy can be found in products, which can have a multitude of "-illities".

It can be tried to define the term "information" based upon this considerations. Thus, information would be everything that is sent with a purpose. The definition has flaws, though, since even the non-existence of a transfer can be of informational value to someone. This dilemma is very similar, if not the same, as the one circumscribed by WATZLAWICK [for a quick reference on WATZLAWICK, see WIKIPEDIA 2004b]: "One can not *not* communicate".

Chapter *6 Field Study*, p. 100, will analyze whether there are measurable differences between types of information under the perspective of waste.

### 2.2.3 Conclusion on Types

The following aspects can be extracted from the discussed categorizations of information:

- A differentiation of information in types can be useful whenever interactions of different information flows are analyzed. It is assumed that whenever information is used for a purpose other than its intent, or serves more than one clearly defined purpose, waste is likely to occur. In chapter *6 Field Study*, p. 100, this question will be looked upon.
- The quality of a piece of information is linked to the fulfillment of its purpose, thus, if it serves more than one purpose, the quality can be different for each.
- A basic, non-exclusive differentiation of information in content, process and noise type information is believed to suffice for most purposes. Chapter *6 Field Study*, p. 100, will test that hypothesis.
- There cannot be deduced a useable definition of information from considerations on its purpose.

For the development of a (PDVSM) tool, however, the basic differentiation into two categories is useful to systematically structure requirements. Furthermore, some other aspects have to be kept in mind:

As the tool is meant to enhance process transparency, it needs to

- (R034) encode any relevant process type information in a way that is easy to use for the sender.
- (R035) convey the sender's intent without adding noise to the purpose.
- (R036) be easy to understand for the receiver, in a way that the purpose is clear.

As far as the exchange of content type information in considered, the tool should

- (R037) not alter content type information.
- (R038) link the container (e.g., file) of the content type information to the purpose of its transfer by means the tool.

Ultimately, considering noise type information, the tool is required to

- (R039) Facilitate the exchange of personal noise type information
- (R040) Clearly marking noise type information as such
- (R041) Provide privacy that is necessary to encourage personal (noise type) information.
- (R042) Exclude non-personal noise type information, like spam.

The requirements (R039) through (R041) are given for the sake of completeness, and open to debate. It is believed that personal communication within product development processes can help to facilitate the flow of content and process type information, but, given other circumstances, can as well inhibit it. Furthermore, and quite important in the context of this thesis, a tool that can provide channels for personal noise type information is believed to have much better acceptance, which can help introducing it.

## 2.3 Information Carrier

Information itself can not be displayed, transferred and stored, but only by the means of a carrier. It influences the handling of information, can affect its quality, and thus its value to a process. Hence, the most important question of this paragraph is, *in what way do information carrier and information value correlate?*

The concept "carrier", as presented in this paragraph, contains the aspects of the actual physical structure of information, its technical function in (product development) processes, and the representation of information.

Note that the views on information in tools and in processes are blurred when talking about the carrier of information. Most aspects affect both realms, and therefore, this paragraph does not use one or the other view exclusively.

### 2.3.1 Physical Structure of Information

Basically, any physical structure can be used to carry information, and many different physical effects are actually used: Electromagnetic waves (radio waves, lasers, infrared light), electric effects (Voltage or current variation), pressure waves (sound, hydraulic controllers), and a great variety of solid objects with certain qualities like magnetism (in hard disk drives) or optical structures (CDs, ink). All the previous mentioned types have in common, that they are used to carry encoded information. Of course, non-encoded information in the form of a model also has a physical, solid structure, but generally of a much larger shape.

Two technical categories of physical structures emerge:

- *Durable information*, which basically encompasses all solid structures.
- *Non-durable information*, with all forms of waves and electric effects.

Obviously, durable information has the great advantage to enable documentation, but can potentially be a problem if the information is in any way dangerous to overall process performance (e.g., classified information).

During information transfer in product development, the physical effect and hence the two categories are typically changed often. Speech (pressure waves, non-durable) is received, manually transformed into a drawing (optical structure, durable), automatically transformed into a file by a scanner (electronic, durable only if saved), automatically transformed into wireless signals (radio waves, non-durable), received and again transformed automatically into a file (electronic, durable only if saved), and ultimately printed out (optical structure, durable). The more interfaces there are, the higher is the potential risk for errors. Despite some often-quoted problems like computer crashes, machines tend to transform information more reliably than humans.

The actual cost for transformation is dependent on many different factors like the amount of data, the required number and complexity of receivers, distance of transport, et cetera. Despite of being of great interest in the context of value (remember the basic interpretation of value equaling quality divided by cost), it will not be discussed herein, for reason of scope of the thesis.

Any transformation of the physical structure of information other than the one into the product is by itself not of any value. They are non-value adding activities, and whether they are required or not depends on the context.

For any product development tool, it can be concluded:

- (R043) Information must be transformed in a durable structure, since sending and receiving can not always occur at the same time (different time zones, organizational circumstances), and information may be referred to over a long period of time.
- (R044) The physical structure of the input and output of the tool should be of a great variety and match the infrastructure of a typical product development environment, in order to reduce introduction cost and potentially erroneous transformations.

The categorization into durable and non-durable physical structure of information will be illustrated, among other properties of information carriers, in paragraph *2.3.4 Conclusion on Information Carrier*, p. 40.

## 2.3.2 Technical Functions of Information

The physical structure of information is meant to fulfill certain technical *functions*, and its ability to do so is discussed in the following.

- *Storage*. Lots of information needs to be stored for reference, documentation and the like. In this case, it has to be of a durable physical structure, or transformed into it. The transformation can occur automatically by the means of a tool (a tape recorder, a PC writing information onto a hard disk drive, a printer, …) or manually (writing, drawing, modeling). To facilitate storage, a durable structure is necessary but not sufficient, since it must be organized and archived in order to be recovered.
- *Transportation*. In order to communicate, two people or devices need to transport information. Non-durable information, on the one hand, has the advantage of being able to be transported very fast and cheap (at the speed of sound or light), and does not always need an infrastructure for the transport itself. The range, however, can be limited (a few meters in the case of speech). Durable information, on the other hand, needs an infrastructure in order to be transported, and the transport is, as a result, generally much slower. At the beginning and in the end of a transport, there has to be a sort of infrastructure to send and receive the information, which varies greatly in its complexity, availability and price. For instance, eyes and ears can be understood as humans build-in and quite reliable infrastructure for sending and receiving; on the other range of the spectrum, an antenna to receive radio waves is a costly and complex technical device for the same basic technical function.

- *Display*. The designated end user for process view information (see paragraph *2.1.1 Views on Information*, p. 19) is a human being, whose consciousness enables value-creation. Thus, the varied physical structures have to be displayed, because there is no direct interface to a human's mind. Common examples are sheets of paper, computer screens, sound, but also object like rapid prototyping models or clay models. Not every physical structure can be displayed in a way that it can be perceived by a human. In that case, it has to be transformed. Note that the display function is independent to the information's durability. Sheets of paper are durable, and the function of display is integrated into the carrier, yet durable magnetic particles on a hard disk drive are not an appropriate display. In the case of non-durable information, some can be perceived directly (speech, gestures), while others cannot (radio waves).

As with the physical structure, technical functions are generally not value adding activities. Whether required or not depends on the context. Only the display of information can (e.g., if the customer pays for it) be of value. Companies that do not produce products rely entirely on this type of value, for example consulting firms and engineering services. For this companies, it is thus of utmost importance to fulfill any thinkable requirement of the display of information.

Several basic requirements for the fulfillment of functions can be deduced:

- (R045) The tool should store information carriers reliably. This encompasses a usable way to archive and recover information.
- (R046) As product development processes in big companies tend to involve many locations, the carrier of information must be able to be transferred fast and cheaply.
- (R047) Any (process view) information must be displayed to the end user in a way that enables good perception, under any environmental circumstances it may be useful for.

The technical functions of information will be illustrated, among other properties of information carriers, in paragraph *2.3.4 Conclusion on Information Carrier*, p. 40.

### 2.3.3 Representation of Information

Depending on its way to display it, information can have a variety of different representations. This paragraph will discuss the most common representations of information in product development, relate them to the concept of value, and ultimately conclude on requirements for a lean PDVSM tool.

Note, that in this paragraph, representation refers only to the view on information in processes (see *2.1.1 Views on Information*, p. 19), since the value of information can only be assessed by a (human) user of process view information. The – internal – representation of information in tools and products has very different constraints and is discussed, for example, in computer sciences [for an extensive and interdisciplinary discussion on multimedia objects, see SCHULMEISTER 1997, pp. 19-71].

#### 2.3.3.1 Encoding and Decoding

In order be represented in a physical structure, information needs to be *encoded*. During this process, a mental image ("internal representation", as called in psychology) of the information is mentally and manually transformed into a physical representation. Further transformations can succeed automatically (e.g., transforming numeric data into a chart by the means of a program). The receiver of information decodes the representation back into an internal representation.

Encoding and decoding are very complex processes. For instance, in order to understand the encoding and decoding of verbal representations of information (e.g., language), linguistic sciences, psychology and neuropsychology have elaborated a great variety of theories that seek to explain that very process [see, for example, HERKNER 1991, *chapter 3: Sprache und Wissen*, pp. 129 – 177]. Encoding and decoding of internal representations of non-linguistic quality (e.g., spatial structures, graphical abstractions, physical ideas) is, to the authors knowledge, even lesser understood [theories on internal representation of visual ideas have been proposed by PAIVIO as outlined in KLUWE 2002, p. 150. In English literature, more information can be found in *Elements of Graph Design*, KOSSLYN 1994].

As a side note, the content of information is altered (subconsciously) during the processes of encoding and decoding. This question is discussed in psychology; interested readers can find more on that topic in HERKNER [1991] and FISCHER & WISWEDE [1997].

#### 2.3.3.2 Categories of Representations in Product Development

The most common *representations of information* in product development (and some examples for each) are:

- *Non-verbal* (mimic, gesture). Most non-verbal communication occurs unintentionally and is subject to individual perceptions. In social science, the focus on non-verbal communication lies in the context of personal relations [for a short introduction into non-verbal communication in social psychology, see FISCHER & WISWEDE 1997, pp. 295-297]. Personal relations *are* important in the process context, but will not be discussed herein, according to paragraph *1.3 Scope of Thesis*, p. 11. However, there is one manifestation that is of special interest in the technical context: Gestures can be helpful when (spatial and/or chronological) relations in technical structures are described. Across cultures, non-verbal representation of information can lead to serious misunderstandings.
- *Verbal* (utterance, expression, comment, statement, speak). Verbal information is widely spread in product development, because its use is fast, simple, and comes at no cost. However, there are several restrictions on the usefulness. If verbal information is not

transformed (e.g., by a tape recorder or phone), it is tied to the physical presence of the speaker, has a very limited range, and is non-durable (physical and technical restrictions). The fact, that encoding mental representations of spatial and chronologically relations into verbal information can be difficult and inefficient, limits its usefulness further (representational restrictions). For instance, it is very difficult (not to say, impossible) to verbally represent an assembly drawing completely, precisely, and without redundancy. The same representational restrictions hold true for decoding (e.g., translating the perceived words into a mental image of a technical structure). The possibly biggest advantage of verbally represented information, however, is that it enables very quick feedback cycles by means of a conversation. Another important aspect of verbal and non-verbal information is that it can transfer implicit meta-information (e.g., certainty, trueness) by the means of cadence, pitch and other characteristics. Chapter *4 Communication* (p. 78) returns to that aspect, but due to the thesis' scope, a detailed discussion of the phenomenon is not provided. The interested reader can find exhaustive elucidations in the social sciences [for example, start with WIKIPEDIA 2004b].

- *Alpha-numerical* (plain text, structured text, tables, calculation). Alpha-numerical representation of information can be understood as a durable transformation of (explicit) verbal information. Hence, the same representational restrictions apply, but the physical restrictions are less severe. In a typical product development environment, alpha-numerical information can easily be distributed (mail, email), copied (photocopier) and stored. Compared to verbal information, encoding takes more time, but greatly simplifies the task in the case of complex information; decoding can be faster, and gives the reader a degree of freedom by letting him or her choose when to decode what part. A disadvantage of alpha-numerical information is the inherent delay between sending and receiving in feedback loops (conversations, or rather correspondence). Depending on the used tool, the delay can be very short (chat), intermediate (email) or large (traditional, international letter). In chapter *3 Communication*, p. 78, the aspect of communication feedback will be discussed further. Automatic transformation from verbal to alpha-numeric representation of information is possible (voice typing), yet not used widespread. It is believed that the reason for the limited use lies in a) the coexistence of verbal and graphical information in product development, and b) possibly in the limited reliability of such systems.

- *Graphical* (sketch, illustration, drawing). A graphical representation of information is very useful to convey information that shows spatial structures, which is often the cause in product development. The representation can vary greatly in detail, accuracy, ease of use and cost. From rough and fast sketches to elaborate, complex animations of CAD-models, many nuances can be found in product development. Graphical representations play an important role and influence efficiency and quality of the design process positively [RÖMER ET. AL. 2001, p. 189]. For graphical representation of information, similar physical restrictions as with alpha-numeric representation apply. In the case of

CAD tools, the infrastructure in the form of CAD programs can vary between environments, so that graphical information can not be displayed correctly or get lost altogether. Graphical represented information can easily be combined with alpha-numeric representation, since they commonly rely on the same physical structure (paper or computer file).

- *Artifact* (sketch model, clay model, mock-up, prototype, product itself). Being a physical object, artifacts can transport any representation of information that can be transformed into a physical structure. They are most commonly used to represent spatial relations of objects, but can contain much more information. In the case of a prototype, and depending on the resolution, almost any (content type) information can be represented. Artifacts are solid and face severe restrictions for transfer, or rather transport, as weight, space and maximum applicable acceleration result in high cost and time required to transport them. However, the information itself can be transformed into a non-solid representation and thus transferred much more easily. For example, information can be represented by a rapid prototyping model, and the necessary data to build it can be sent by email. Encoding information in an artifact is time-consuming, and decoding can take even more time (e.g., when a piece of information needs to be retrieved by measuring). Artifacts, however, can prove technical functionalities tied to physics, which sometimes is hard to facilitate through verbal or alpha-numeric representations.

For a given information transfer, representations in more than one of the above mentioned categories and/or sub-categories can be used simultaneously.

Representing information in one way or the other can influence the quality of information, and the performance and efficiency of an information transfer. In chapter *3 Communication*, p. 78, some further theoretical discussion can be found thereupon, and in chapter *6 Field Study*, p. 100, a correlation of representation and information transfer waste is sought.

The envisioned lean PDVSM tool aims at enhancing process transparency and facilitating efficient information transfers. In order not to establish requirements based on assumptions, this is delayed until after the field study. However, some can be established right away.

- (R048) Information should be represented in a way that facilitates easy, errorless en- and decoding. Therefore, the representation through the tool should match the internal (mental) representation.
- (R049) As the lean PDVSM seeks to display process type information usually represented both graphical and alpha-numerical (for example, a Gantt-Charts), it should facilitate these categories of representation. That way, traditional ways of representation can be used in parallel, thus simplifying the transition.
- (R050) The representation of information by an artifact is not appropriate, since the time-consuming process of encoding prevents flexibility. The difficulty of transport is prohibitive as well, and is already mentioned in (R046).

The following paragraph merges the previous elucidations on physical structure, function and representation into a comprehensive model.

### 2.3.4 Conclusion on Information Carrier

Any carrier is basically a combination of physical structure, function and representation of information. It can thus be spoken of a multi-dimensional concept, which can be illustrated, as shown in *Figure 2-6: Information Carrier*, p. 40.

This concept of information carriers in product development is hereby proposed as a model that can facilitate understanding of aspects, and enable discussion. To the author's knowledge, there is no similar graphical representation of the technical aspects of information in product development.

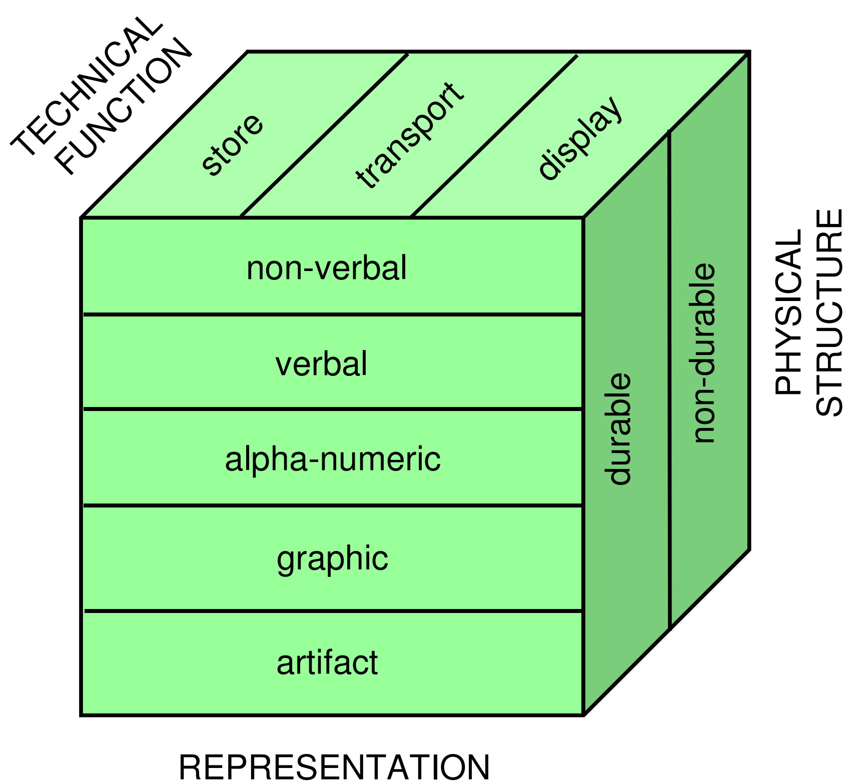


*Figure 2-6: Information Carrier*

Note that this thesis uses the concept "carrier" not synonymous to the term "medium". A carrier can be described without any reference to the activity of communication; it is a static, theoretical description of the information's structure. Many theoretically possible carriers may not make sense at all, and carriers can generally be communicated by more than one medium. Media, on the other hand, are certain types (or combinations) of carriers used for communication in a certain way. Basically, they are "tools of communication". To give an example, video is a medium that can communicate any carriers like body-language, graphics and alpha-numeric information. However, the same carriers can be communicated by means of a meeting. Since media can not be discussed without the context of communication, they can be found in chapter *3.3 Media in Communication*, p. 84.

## 2.4 Quality of Information

If information is understood as the product of a process, a multitude of aspects can be used to describe its quality, quite the same as with "real" products. Many approaches exist; in the following, the most important are discussed.

The first subchapter *2.4.1 Definition of Information Quality* (p. 41) defines information quality, and the following two subchapters discuss a variety of aspects of information quality (*2.4.2 Product Quality of Information*, p. 42, and *2.4.3 Specific Information Quality*, p. 43). Ultimately, subchapter *2.4.4 Information Quality in Product Development* (p. 52) deduces further conclusions.

### 2.4.1 Definition of Information Quality

A definition of information quality has two purposes. Firstly, it helps to avoid misunderstandings when discussing in an environment of quite blurred concepts. Secondly, with a good and comprehensive definition, any given piece of information can be compared to the definition of high-quality, and thus be checked and/or measured. Thereby, improvements in task-based and overall process performance can be tracked.

According to ISO standards, (general) quality is defined as "the totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs" [ROTHERY 1993, p. 13]. It is left unclear, what these needs are, and who should formulate them. The definition thus leads to misunderstandings, as different perspectives can lead to conflicting needs.

Specific definitions related to information have defined high-quality information as "fit for use by information consumers" [STRONG ET. AL. 1997, p. 39]. It is a catching, easy to memorize definition, but it disregards the perspectives of the provider of information as well as the one of the overall process performance.

From a lean product development perspective, MILLARD [2001, p. 25] renders that concept more precisely by characterizing information quality in terms of Form, Fit, Function and Timeliness (FFFT).

- *Form*: information must be in concrete form, explicitly stored.
- *Fit*: information must be in a form that is useful to downstream processes and provided seamlessly
- *Function*: information (in the form of a design) must satisfy end-user and downstream process needs, and communicate an acceptable amount of risk
- *Timeliness*: the right info at the right time.

The terms “form” and “fit” demand a useful information carrier, as proposed in paragraph *2.3 Information Carrier* (p. 33). Note, that what makes a carrier useful, and what not, depends on the information itself, and can thus not be stated generally. “Form” describes a good representation of the information; “fit” brings in the information customer’s perspective on the carrier. Chapter *6 Field Study* (p. 100) studies correlations of a carriers’ usefulness and the information types. Another important aspect contained in MILLARD’S definition of “fit” is seamless flow. Seamless flow means uninterrupted, fast forwarded information, and thus requires the carrier, the medium and the communication process to intertwine well. Paragraph *2.6 Information Flow* (p. 57) discusses that idea in more detail. “Function” and “timeliness” refer to the usefulness of the information itself for downstream processes. They are high-level requirements on the information’s content (function) and process performance (timeliness). The questions is, what exactly are the “end-user and downstream process needs”? And, are the provider’s requirements on information important at all? As information does not always flow downstream, does the same characterization apply for upstream or cross-stream flowing information? Concluding, MILLARD’s characterization provides some important insight into the requirements of lean processes, as it embraces the process and end-user perspective, but it is not comprehensive enough to check and/or measure the quality of a given piece on information. It is thus not a useful definition of information quality.

Before a definition is given in paragraph *2.4.4 Information Quality in Product Development* (p. 52), the next two paragraphs discuss in more detail aspects of (information) quality.

### 2.4.2 Product Quality of Information

As shown in paragraph *2.5 Generation of Information* (p. 54), in companies, information can be seen as a product. Following that view, this paragraph seeks to define information quality trough product quality.

However, severe difficulties exist in establishing a comprehensive yet measurable representation of product quality, and thus concluding from that to quality of the “product” information. One example of recent efforts to boil down the great variety of aspects, and ultimately visualize product quality can be found in ELLIOT et. al. [2003]. A vast set of attributes, each of relative importance to customers, is proposed. Through surveys, the customers’ perceptions are gathered, and then analyzed, evaluated and finally represented in a graphical format (perceptual bubble-mapping). The maps can be used to make decisions about resource planning decisions [ibid., p. 1239]. It would be very useful for product development, if the decision on internal resource allocation could be based on such a representation. The lean PDVSD display could in this way relate the actual planning to perceptions dictated by the customer. The "customer", in this case, would be manufacturing. Unfortunately, the perceptual bubble maps as proposed by ELLIOT ET. AL. combine quality attributes with market data, and rely on a definition of quality relative to competitors. Since in most product developing companies, there is no open market for development, and thus no direct competitor, this concept is not useful for the adoption to product development processes.

Within product development, information quality is an absolute measure, and only through benchmarking a perspective of relativity can be introduced. Unfortunately, companies seldom can compare their procedures and information to the ones in another company, because it is, unlike a product, not available on the open market.

### 2.4.3 Specific Information Quality

In STRONG ET. AL. [1997, p. 38], altogether fifteen aspects in four categories of information quality are proposed. BAUCH [2004, p. 29] has illustrated them in a comprehensive way, which is – slightly modified – shown in *Figure 2-7* (p. 44).

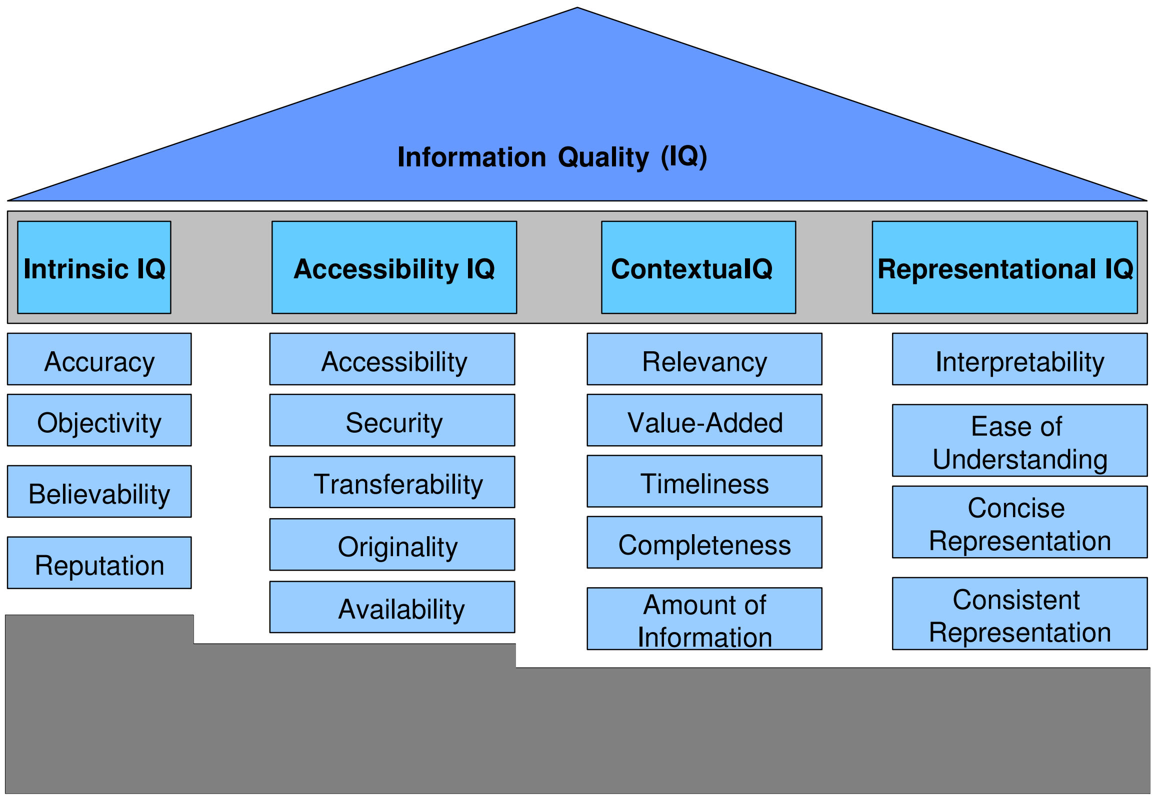


*Figure 2-7: Information Quality (illustration as in* BAUCH *2004, layout slightly modified; terms as in* STRONG ET. AL. *1997, transferability, originality and availability added)*

A similar approach is presented in PAHL & BEITZ [1996, p. 53]. They name criteria for characterizing information ("*Klassifizierungskriterien*"). In order to be processed, information has to meet a user's requirements in any of these characteristics [ibid.].

In the following, each of the terms is discussed under the perspectives of lean product development. The discussion follows the categorization proposed by STRONG ET. AL., adding the terms used by PAHL & BEITZ, and completing the discussion with some aspects not mentioned by neither of the authors.

#### 2.4.3.1 Intrinsic Information Quality

Intrinsic information qualities are qualities inherent to the information itself. They are, however, not independent to a context. *Believability* and *Reputation* have connotations that can only be ascertained when the provider of information is taken into account, and rely on the judgment of others, what makes them particularly difficult to measure.

- *Accuracy* means precision and correctness. In the English translation of PAHL & BEITZ, the term *sharpness* is given, but the author believes that accuracy matches the meaning better. *Correctness* can be corrupted by a great variety of actions. Some are induced by the person who generates information (e.g., typographic errors, miscalculations, inappropriate use of definitions); others are induced during the transfer or transformation of information (e.g., data and signal errors, translation errors). Correctness is, of course, vital to ensure the safe and flawless function of technical systems. However, proof-reading over and over does not add value to the "product" information, and should be limited to a reasonable practice, depending on the criticality of potential errors. For example, it is of paramount importance in technical specifications in space and aerospace systems, as errors can lead to fatal accidents, and much less important in meeting minutes meant to document. *Precision* describes the level of detail, or "degree of refinement", as dubbed in PAHL & BEITZ [1996, p. 53]. A higher level of detail generally leads to higher time-consumption, and should thus be pulled by the subsequent task dependent on actual needs. Precision embraces as well the use of a well defined terminology that is understood by both sender and receiver. For the lean PDVSD tool, the following requirements can be deduced.
    - (R051) The information contained in the PDVSD should be correct. Without imposing a burden to the actual user, this can be achieved, for example, by routines that check text for typographic errors and avoid the familiar mismatch of day and date.
    - (R052) The process type information displayed, and the content type information delivered by the means of the PDVSD, should have the precision requested by the tasks that depend on it.
- *Objectivity* means that information should be given in a non-biased way, specifications of agreed-on measures. This is easy to ascertain for technical information. However, information about feelings, opinion and emotion is sometimes necessary (when commenting on a design, for example). In that case, objectivity can be interpreted as the call for a balanced account on someone's beliefs, rather than brusque statements.
- *Believability* can only be ascertained through experience. If information is not believable, but true, the sender needs to add meta-information like references and explanations that supports his information. The problem is that believability is critical only to the receiver of information. If the sender does not know well the receiver's experience and openness, this may cause feedback loops or even rejection.
    - (R053) The lean PDVSD tool should hold means that facilitate quick and convenient adding of meta-information to any content information it transfers.

  - (R054) The lean PDVSD tool should display the name of the receiver of information, because it enables the sender to generate information according the receivers background.

- *Reputation* is an important aspect of information quality, especially when the information flows across seldom used interfaces. *Reliability*, as given in PAHL & BEITZ, focuses more on process perspective rather than the content, but basically circumscribes the same problem. Information can be rejected regardless of its relevance, for example if the sender or the approach taken to generate the information itself suffers from bad reputation. One of the best known occurrence in product development is the “not invented here syndrome”, in which case information needs to be “sold”. There are many strategies that seek to raise reputation, but essentially, all of them do not add value to the information itself. The root cause is distrust and prejudice, and can only be overcome by long-during, well working relations. As this needs time, and does not add value to the information itself directly neither, it may not make sense at all under the perspective of overall process performance. However, in product development processes a receiver can commonly choose neither the receiver nor his methodology. In this case, it may be advisable for the sender to choose an indirect way to transfer the information, even though this contradicts to the principle of seamless flow, because any flow is better than none at all.
  - (R055) The lean PDVSD tool should work reliably, e.g. stable and in generally appropriate quality, so that information offered through this channel is not rejected a priori.

#### 2.4.3.2 Accessibility Information Quality

Accessibility information quality is directly linked to the transfer of information itself, and thus to the flow of information. It could be dubbed transferability information quality, thus conveying the technical function of transport, but as “accessing” is notional closer to the lean principle “pull” this thesis follows the terminology used in STRONG ET. AL.

- *Accessibility* describes the ease of access to information by a receiver. There are many obstacles that prevent access to information: (1) unawareness about the existence of information, (2) ignorance about where to find the information, (3) lack of resources and/or tools to pinpoint the location of information, (4) insufficient training in tools designed to pinpoint at information, (5) denied access to information, (6) lack of tools to retrieve information, (7) lack of resources and/or tools to handle and process information. Based upon these obstacles, requirements for the lean PDVSD tool can be deduced:
  - (R056) The lean PDVSD tool should signalize the availability of information.

  - (R057) The lean PDVSD tool should indicate the place where information can actually be accessed.
  - (R058) The use of the lean PDVSD tool should not require (a lot of) training effort.
  - (R059) The lean PDVSD tool should clearly state which information is granted to whom, and the designation of receivers should be easy.
- *Security* embraces two perspectives. First, intentional as well as unintentional corruption, attack, deletion and sabotage can render information useless or even deleterious. Second, security of information means the need for classification, e.g. in the case of new inventions that have been submitted for a patent, design studies, and the like.
  - (R060) Information contained in the lean PDVSD tool should be secured against corruption, attack, deletion and sabotage.
  - (R061) The lean PDVSD tool should provide means to restrict access to classified information.
- *Transferability* is mentioned by neither STRONG ET. AL. nor PAHL & BEITZ, but it is important under lean exigencies. The transferability of information is dependent on whether the physical structure (see *2.3 Information Carrier*, p. 33) matches an appropriate medium and an available infrastructure, and whether these are operational.
  - (R062) The lean PDVSD tool should rely on an infrastructure that is available and reliably working in any environments that it is sought to be used in.
- *Originality*, proposed by PAHL & BEITZ, indicates whether or not the original character of a given piece of information must be preserved. That is often the case if the person who generated the information can be held responsible for it. Originality is then often enforced by assigning a required level of security to the information, and restricting legal and/or financial availability (see below).
  - (R063) If organizational circumstances demand a direct responsibility for the information contained within the lean PDVSD tool, the (legal) person held responsible for the information should have means to assure its originality.
- *Availability*, neither mentioned by PAHL & BEITZ nor STRONG, encompasses legal and financial restrictions that apply to information. For instance, patents and registered designs can severely inhibit the use of information. There are many stages of availability, notably free, licensed, and unalienable information. Normally, availability is not an issue *within* companies. However, if companies collaborate with subsidiaries, availability can quickly become an obstacle to the lean information flow.

- (R064) If the lean PDVSD tool is used to display legally and/or financially restricted information, it provide means to clearly mark the information's status.

#### 2.4.3.3 Contextual Information Quality

Contextual information quality concerns the process the information is generated for. Thus, contextual information quality cannot be ascertained only by analyzing the information itself, which makes it particularly difficult to measure. Some of the following aspects of contextual information quality, especially "Value-added" are closely tied to concepts of Lean Thinking, and will be discussed in greater detail later (see *2.7 The Concept of Value in Information*, p. 62). Anticipating, there are many facets to value, and herein the receiver's perspective is taken, rather than the overall process and/or customer perspective.

- *Relevancy* is arguably the most important information quality. If information is not relevant, it is useless, or rather waste. Additionally, the generation of it is a non-value adding activity as well, consuming resources that could have otherwise benefited parallel processes. As one of the few information qualities, it is a digital (true or false) quality. However, an information transfer usually does not convey only one piece of information, so that parts can be useful whereas others aren't. Being a digital quality, it is relatively easy for the user of information to evaluate it in retrospect. Retroactive evaluation does not lead to lean processes, so the real problem is faced by the provider of information. For him or her, it is of utmost importance to know the needs of the information receiver in order not to generate irrelevant information.
    - (R065) The lean PDVSD tool, when used not only to display information but as a communication tool, should provide reasonable means to discuss and indicate the information content needs of downstream processes.
- *Value-Added*, dubbed simply *value* by PAHL & BEITZ, is seen by them as the importance of a given piece of information to the recipient. The concept is of paramount importance in lean product development, and will thus be discussed in a separate paragraph (see *2.7 The Concept of Value in Information*, p. 62)
- *Timeliness* encompasses two closely related qualities: (1) *timeliness* in the narrower sense (e.g. in-time delivery), and (2) *actuality* [PAHL & BEITZ] in regard to the points in time when the information is useful or outdated. There are difficulties in ascertaining actuality, as information can be referred to and/or used even after the initial purpose has (or has not been) fulfilled. For example, a hypothetical program that automatically deletes electronic information when a pre-defined point in time has been reached (thus reducing inventory, which is a lean strategy), hinders the re-use of knowledge, and gravely affects documentation enforced by legal backgrounds. However, timeliness in the narrower sense is certainly important, and can quite easily be measured.

  - (R066) Any information contained in the lean PDVSD tool should include the date and time of its generation.
  - (R067) The lean PDVSD tool should facilitate the indication of the existence of new versions of information.
- *Completeness* denominates the quality assigned to information that provides its user with all needed information. Information can be incomplete if parts have not been generated altogether, or if parts are missing (e.g., have been lost during the transfer). Complete information can however convey too much information. In this case, it (or parts thereof) are irrelevant or have a level of detail that is too high.
  - (R068) In case a transfer consists of multiple parts (e.g., several files), the lean PDVSD tool should hold means to indicate their affiliation to a specific information transfer.
- *Amount*, which is described by PAHL & BEITZ more precisely as *volume* and *density*, in regard to the number of words and pictures needed for the description of a system or process. This quality can also mean the electronic "volume" or rather file size, which is of importance when assuming the view on information in tools. From the user's perspective, it is sometimes difficult to set a precise goal to the volume of a piece of information. Dependent on the circumstances, the sender's abilities and capabilities, and the format, information can be more or less (electronically) compressed, and more or less (semantically) concise. It is thus seen as appropriate to provide default rules for maximum volume (e.g., an email client cannot handle files larger than a certain size), and to specify the default only if needed (e.g. if a supervisory function demands a short summary of not more than one page). This is used in some methods and tools, enhancing other information qualities. For example, in Toyota's *A3 problem solving tool* as described by MORGAN [2002, p. 206], utmost accuracy and refinement is enforced by physically limiting the available space to an A3 shaped piece of paper.

#### 2.4.3.4 Representational Information Quality

Representational information quality denominates the actual representation of a given piece of information (see *2.3.3 Representation of Information*, p. 36) matching the user's requirements. Thus, for all aspects of representational information quality, the same basic challenge to the sender exists: What representation fits best the respective user? The question is rather difficult to answer precisely, because representation is tied closely to apperception, an internal process that occurs subconsciously and thus eludes direct observation. Apperception is discussed in paragraph *3.1.2 Sender and Receiver*, p. 80. Furthermore, in chapter *6 Field Study* (p. 100), it is sought to analyze the correlation of representation of information and communication in product development.

As ZUMPE & ESSWEIN [2002, p. 246] state comprehensively, "presentation aims to illustrate each informational unit, its features and relations towards each other units as a whole. It is complete, all-embracing, correct, conclusive in itself and consistent"

- *Interpretability* describes the user's ability to deduce the correct knowledge from the received information, based upon the representation of the information (see paragraph *2.1.2.3 Relative model of derivation* (p. 23) and AHMED ET. AL. 1999). The interpretability of a given piece of information is tied to it's physical properties, and can have a variety of inhibiting factors: (1) illegible alpha-numeric information (e.g., too small characters), (2) blurred graphics (e.g., bad quality scan of a drawing), (3) inaudible verbal information (e.g., voice too low or distance to speaker too great), (4) impeded line of sight to speaker (thus preventing from interpretation of non-verbal information), and finally (5) impediments in the use of an artifact (e.g., when procedures of measuring cannot be undertaken due to the object's fragility). In the case of poor interpretability, short communication feedback loops are favorable to the overall process performance. Since the sender of information usually does not have to process the information anew (thus consuming time), he or she is able to merely adjust the representation, and can thus provide almost instantly information with a higher interpretability – provided, the problems do not stem from a defect of the infrastructure and/or medium used for the transfer.
    - (R069) The interpretability of information displayed by the lean PDVSD display should be assured by appropriate ergonomics.

- *Ease of Understanding* is, in contrast to interpretability, not related to the physical properties of the representation, but instead to the user's abilities. It can be spoken of two subcategories: *Complexity* [PAHL & BEITZ] and *straightforwardness*. *Complexity*, defined by PAHL & BEITZ as the structure and variety of symbols as well as "elements, units or complexes" of information. Measuring the variety is rather easy, attempts to measure the complexity of a structure of a text (*Readability*); however, is a field of science in psychology. Current tools take into account as much as 250 measures and are thus deemed as inappropriate to denote a requirement on information [for readability, refer to MCNAMARA, 2004]. Howsoever, in product development, guidelines and recommendations can be given, such as a standard to use a specific modeling language (e.g., unified modeling language, UML). In any case, complexity can not be established as an absolute measure applied to all information. Dependent on the user's ability, the required level complexity is relative, what leads to the term "straightforwardness". Every single user has, dependent on education, experience, mental capability and circumstantial factors (e.g., stress, available timeframe), a different esteem of what is straightforward, and what not. For the sender of information, that imposes the need to know the receiver and his or her capabilities. Information can thus not be designed on the basis of theoretical conclusions. However, ease of understanding can be obtained, much alike interpretability, more easily by media with short feedback loops (e.g., meetings, phone calls), and in a culture of honesty and forthright communication.

  - (070) The lean PDVSD tool should facilitate means for communication with short feedback loops.

- *Concise Representation* refers to the syntactical structure of information, not to its precision (which is an intrinsic information quality, see *accuracy* in paragraph *2.4.3.1 Intrinsic Information Quality*, p. 44). There are several ways to enhance the syntactical structure of text, for example with tables or paragraphs. For information that is not represented alpha-numerically, similar strategies apply. Verbal information can easily be structured similarly to alpha-numerical information. Concise representation of graphical information encompasses the use of (distinguishable) colors and avoidance of misperceptions.
  - (R071) The lean PDVSD tool should display informational units in a structured, concise manner that grants the user quick access to relevant parts.
  - (R072) The lean PDVSD tool should hold means to structure information within an informational unit.
- *Consistent Representation* means that the representation of information should not change for the same type of information neither within a given informational unit, nor in between transfers. Many companies actually seek to enforce consistent representation by forms or specimen copies, and especially in engineering there are numerous norms that have to be met by documents (e.g., technical drawings). Formatting information does not increase the customer's value of a product directly, but does generally increase overall process performance by avoiding misunderstandings, or information waste. Howsoever, in the case of preliminary information meant to be used as a boundary object for discussion within short cycle, quick feedback medium, total consistency needs not be assured, and is often considered as to hinder creativity.
  - (R073) The lean PDVSD tool should display information in a consistent manner throughout the tool.
  - (R074) For the use in different environments (e.g., companies), the lean PDVSD tool should facilitate adoptability of its layout.
- *Form* is seen by PAHL & BEITZ as the difference between graphic and alpha-numeric data. The term is deemed not appropriate, as it could be misleadingly interpreted as describing the physical structure of information as well. Furthermore, information is not limited to graphical and alpha-numerical representation. The term "form", thus, conveys no hitherto unmentioned aspects.

### 2.4.4 Information Quality in Product Development

This paragraph basically seeks to conclude from the definition of information quality for actual processes; the problems that arise, and how they can be prevented.

STRONG ET. AL. [1997, pp. 40-45] show ten "potholes" that cause information quality issues, give examples, link each pothole to the affected types of the proposed information qualities, state the organizational effect, indicate warning signs, describe commonly used patches and problems therewith, and ultimately propose "real solutions" based on root-cause analysis. For the sake of brevity, this thesis will not restate the elucidations found therein.

Although showing a variety of approaches and possible solutions, their strategies have a limited usefulness for the purpose of this thesis, and lean product development in general.

First of all, STRONG ET. AL. do not consider product development specifically. Most of the potholes are related to situations that involve the use of a database with multiple entry and retrieval points. In product development, however, the typical information transfer occurs in a 1-to-1 or task-to-task situation, with the exception of meetings used to delegate and reconnect. Seldom information is stored and collected over a long time (as with the often cited example in STRONG ET. AL. of medical information of a patient). Secondly, Strong et. al. do not analyze information quality under the perspective of overall process value and Lean Thinking. Resulting, their solutions lack a trade-off between effort and effect. Thirdly, their proposed real solutions are too general in order to be put to immediate use. For example, the pothole of "lost information" (seen as affecting completeness, correctness and relevancy) is proposed to be counteracted with "statistical process control, process improvement, behavioral control and proper incentives", but it is left unclear, how this can be facilitated. Fourthly, they do not take into account the interdependency of deficient information quality aspects.

BAUCH [2004], from a lean perspective, proposes a comprehensive set of waste drivers that occur in product development. The waste drivers encompass several common problems and circumstances that can lead to obstacles that prevent the seamless flow of valuable information, and more or less directly stem from information quality issues.

The waste drivers related to information quality (and their respective corresponding aspect), are:

- People waiting for data, information (timeliness)
- Information waiting for people (timeliness)
- Lack of direct access (accessibility)
- Information hunting (accessibility)
- Unnecessary detail and accuracy (accuracy)
- Critical path related queues (timeliness)
- Large batch size (amount, specifically: volume)

- Over-dissemination of information (relevancy)
- Deficiencies in IQ attributes (catch-all term, used by BAUCH especially for intrinsic information quality and any other information quality issues as proposed by STRONG ET. AL.)
- Erroneous data and information (correctness)
- Poor knowledge re-use (accessibility)
- Unclear goals and objectives (deficiency in contextual information quality, leading to poor relevancy)
- Insufficient readiness to cooperate (availability, accessibility)
- Poor compatibility of IT resources (accessibility)

The waste drivers related to information quality can be understood as causes, whereas the information quality aspects are indicators. It stands clear, that the comprehensive list of information quality presented in *2.4.3 Specific Information Quality* (p. 43) is not matched by the waste drivers as indicators of poor process performance in a comprehensive way. The waste driver "deficiencies in IQ attributes" can lead to severe misunderstandings, as double assignments of problems to this and other categories are likely to occur.

BAUCH furthermore seeks to determine the interdependency of waste drivers by the means of a cause & effect matrix, ultimately concluding on a prioritized order. However, the order proposed by BAUCH does not take into account neither *likeliness* to occur nor *severity* of impact. Thus, their interdependency is a somewhat theoretical model.

With the set of waste drivers presented by BAUCH as indicators, and the definition of information quality, it is only known what *can* happen in product development, and what plausible causes are. But in order to assign resources efficiently to improvements, the questions persist, what *does* happen? Under what circumstances is the information quality too low? What are the effects in terms of waste (of resources, opportunities, time, …)? How can they be prevented? What does the effort of prevention cost in terms of value? Can a level of quality be claimed, that represents the optimal tradeoff between effort and effect, thus practicably maximizing value?

Simply, this is unknown. Thus, chapter *6 Field Study* (p. 100) seeks to shed light on these questions.

Before this thesis leaves the discussion of information, however, its' understanding as an element in dynamic processes needs to be further fostered. Hence, the following paragraphs discuss generation, flow, and ultimately value of information.

## 2.5 Generation of Information

In product development, content type information can not be mined like resources. It has to be created by the right person (or people) with the right tools, by applying knowledge (see *2.1.2.4 Conclusions on derivation*, p. 25). The generation of information in product development is a diverse, interdependent process that involves many participants, objectives, tools and constraints.

This paragraph takes a short look at how information is generated, and what requirements arise for the lean PDVSD tool. It is restricted in scope to a single, identifiable task in a larger process. The interdependencies of tasks, and hence the flow of information in between, is discussed in *0 However, it* is important to keep in mind that meeting the requirements is not a question of yes or no. To what extend they are met influences, along with the operational requirements, the performance of the process, and subsequently the quality of the generated information.

Information Flow, p. 57.

The first subchapter discusses the prerequisites that have to be met for the generation of information in general (*2.5.1 Prerequisites for Generation of Information*, p. 54). If the prerequisites are fulfilled, certain operational requirements influence the task itself (*2.5.2 Operational Requirements for Generation of Information*, p. 55)

### 2.5.1 Prerequisites for Generation of Information

In contrast to manufacturing, there is no "machine" that generates value; instead it is accomplished by humans, or rather employees. In order to do so, they require, among other things:

- *Knowledge*. The capability of an employee to accomplish a task, and thus generate information, relies on his knowledge (see *2.1.2 Derivation of Information*, p. 20). He or she either already has know-how about a specific task, or needs knowledge about how to achieve the required know-how (meta-knowledge). The latter is of great importance in rapidly changing environments, where tasks alter at a higher pace than traditional learning (university career, company sponsored further education). Knowledge can be gained through education and experience, and provided it can be expressed explicitly, imparted. Imparting explicit knowledge is what Knowledge Management aims at.
    - (R075) The lean PDVSD tool should be accompanied by explicit knowledge (e.g., manual or events) about how to use it and what to use it for.
- *Proficiency.* Aside knowledge, information processing relies on human properties that can not be imparted. Intelligence, skill, creativity, the capability to withstand stress and other properties are very important, as they influence both efficiency and effectiveness of generation of information itself, as well as the ability to gain and impart knowledge. These properties and how they can be improved, are subject to discussion in psychology and social sciences.

- *Conducive ambient conditions*. Employees need an ambient that helps to generate information. Depending on the task, which ambiance is conducive and which not differs. For example, in order to gain knowledge from a book, most employees prefer a silent ambiance which enables concentration; on the other hand, co-location and animate ambiances can lead to conducive tension. Alternating between ambient conditions by changing location is not quite common in companies that assign a work space to employees, but is practiced in others.
    - (R076) The lean PDVSD tool should be portable and ubiquitous, so that it can be worked with in any location.
- *Motivation* is regarded by psychology to be the driving force behind all actions of a human, but it is a field far to complex to be discussed herein in detail. However, for the lean PDVSD tool, some requirements arise:
    - (R077) The lean PDVSD tool should be introduced in a way that its benefits are clear.
    - (R078) The lean PDVSD tool should be designed in a way that its use avoids frustration.
- *Tools and Methods*. Human properties like memory span and proficiency in mental arithmetic can be enhanced greatly by tools and methods. Tools have varying qualities, cost (ownership and application) and versatility, ranging from basic tools like pens and paper to testing apparatus, workstations and the like. Methods lack a physical structure, but range in complexity as well. The use of tools and methods needs to be learned. From the process perspective, the acquisition and use must be justified economically.
    - (R079) The lean PDVSD tool should impose no greater expense than their use can justify through reduced cost.
    - (R080) The lean PDVSD tool should facilitate integration and interchangeability with other tools and methods that are present in product development.

### 2.5.2 Operational Requirements for Generation of Information

If the prerequisites are met sufficiently, the generation itself depends further on operational requirements.

- *Objectives*. Without objectives and overarching goals, all information generation fails short to be fruitful for the process. Objectives are process type information, and all information qualities (see *2.4.3 Specific Information Quality*, p. 43) apply.

- (R081) The lean PDVSD tool must convey objectives along content type information, so that the purpose of both the input information and the information to be processed is clear.

- *Resources*. The generation of information requires, above all, time. Determining the required time beforehand is, in contrast to manufacturing, not an easy task since tasks are commonly non-repetitive. Indirect resources are energy (e.g., electricity) and raw materials (e.g., paper). All resources can be expressed in cost, with the intricacy of time having indirect effects on cost and customer value.
    - (R082) The lean PDVSD tool should hold means to display the time a task is expected to require, and for control reasons the time that is actually consumed.
- *Constraints*. In product development, the overall process requires the generation of information to meet certain rules. The information itself has to be documented, stored, needs to fit quality regulations and similar constraints. The generation is embedded in rules, responsibilities and rights.
    - (R083) The lean PDVSD tool must meet organizational and project requirements for the generation and handling of information.
- *Input and Output*. In product development, the generation of information relies largely on input data of up-stream and concurrent processes. In order to become information instead of remaining data, the incoming data has to meet the user's requirements on information quality. As multiple sources are common, the input has to be complete. Likewise, the outgoing information requires a clearly identified receiver, with clearly stated needs.
    - (R084) The lean PDVSD tool should hold means for the receiver to specify his needs on input information.
    - (R085) The lean PDVSD tool should hold means for sender and receiver to discuss the information quality of a piece of information to be transferred.

### 2.5.3 Conclusions on Generation of Information

The elucidation of the two previous subchapters on prerequisites and operational requirements can be merged and illustrated in a logical flow-chart, as shown below in *Figure 2-8: Generation of Information* (p. 57).

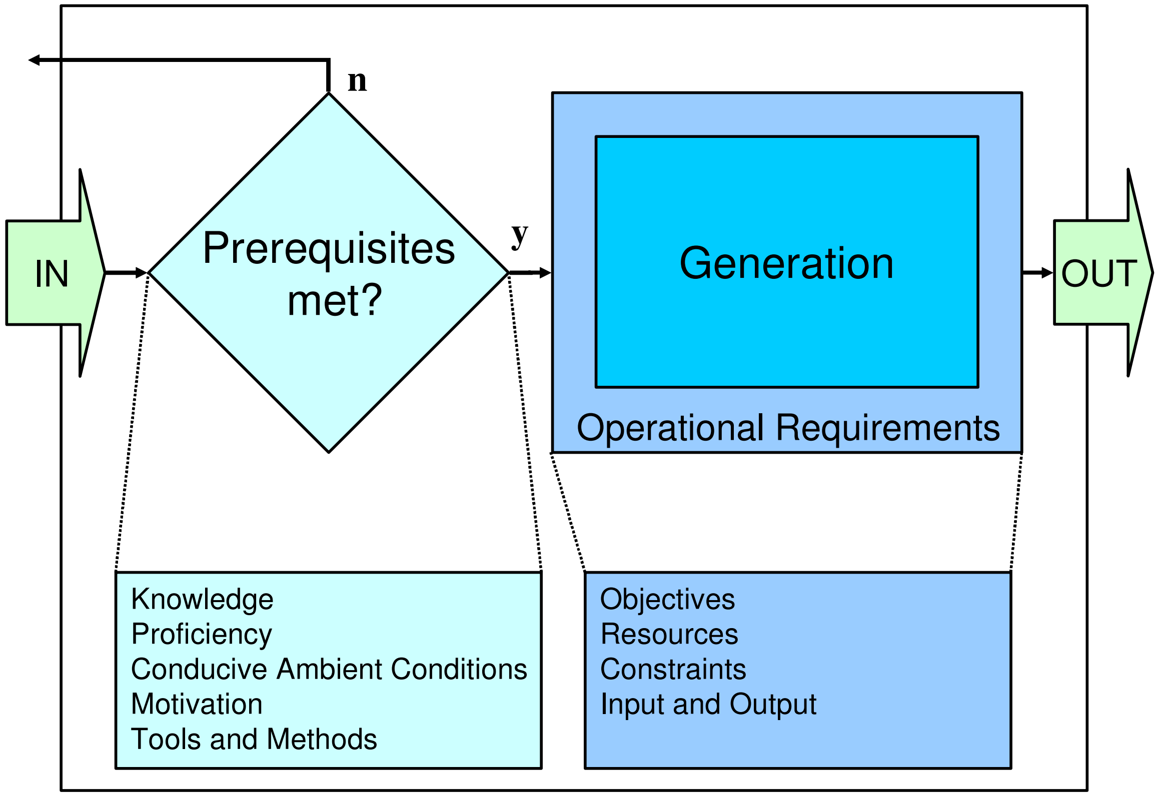


*Figure 2-8: Generation of Information*

However, it is important to keep in mind that meeting the requirements is not a question of yes or no. To what extend they are met influences, along with the operational requirements, the performance of the process, and subsequently the quality of the generated information.

## 2.6 Information Flow

The previous paragraph shows the generation of information within a task, but leaves open the question where input information comes form, and where the output goes to. This paragraph discusses the interconnectivity of several tasks, problems that can occur when information flows, and ultimately how information flows can be made visible. As well, requirements for the lean PDVSD tool are gathered.

TOMAS & HULT [2003, p. 192] state, that "the transferability of information (and knowledge) is a critical determinant of an organization's capacity to create a sustainable competitive advantage. The issue of transferability is paramount in both intra- (such as between functional units and management levels) and inter-organizational settings (such as supply chains, strategic alliances, and joint venture development)." In lean terms, transferability of information translates to seamless information flows, but the statements hold true.

In this paragraph, information flow is understood as the transfer of information, without considering its content at all. Thus, physical and functional dimensions are discussed, but not the problems that arise through misinterpretation and alike. These issues arise in the context of communication, and are discussed in the following chapter (*3 Communication*, p. 78).

### 2.6.1 Dimensions of Information Flows

Information must flow, because it is not possible for a single person to operate competitive product development processes – most products are far too complex. As it can not be prevented, what is the best way for information to flow? Lean Product Development proposes a "seamless information flow" [McManus 2004, p. 29], in order to realize the benefits of lean processes. Thus, the questions are, what is a seam, and how can they be circumvented? In the following, it is discussed in what dimensions information can flow, and for each, examples of seams.

The most obvious dimensions of information flows are spatial distances. Information is passed from a person to another, and thus information has to be transported. The actual distance information covers is not the same as the one between two persons; mail for example is not transported in a direct line, and a piece of electronic information may take even several itineraries at once. Distance can affect the quality and cost of information (e.g., voice becomes low with even short distances, costs for a phone call rise). To make information flows seamless in spatial dimensions, it is thus recommendable to reduce the distance of sender and receiver, or to choose information carriers which ensure constant quality and cost with increasing distance.

Another physical dimension information flows in is time. As with spatial dimensions, the time-consumption for information transfers depends on its carrier. Solid carriers like mail or clay models must be accelerated, which, generally spoken, requires more energy with increasing velocity, and a (technical) infrastructure to accomplish. This results in increasing cost with increasing speed (e.g., airmail vs. normal). Electronic carriers, on the other hand, advance at such a high speed that time-consumption is negligible. Voice is not as fast, but as it covers only short distances, the problem is negligible as well. Concluding, a seamless information flow in time is accomplished with carriers that do not require acceleration.

A non-physical dimension of information flows is the variety of functional steps that are necessary to facilitate the transfer. Functional steps are specific tasks that altogether enable the transfer. In the simplest case, sender and receiver connect directly, without any intermediate steps. Phone calls and face-to-face conversations are good examples for step-less information transfers. However, a lot of information transfers do require functional steps: Large files have to be printed out, letters are carried by few (intra-organizational mail) or many (inter-continental shipping) steps, and if reports have to be signed, they may be sent electronically to a secretary, printed out, transported, signed, and sent back by mail. Note that only the second of signing itself adds value, the rest is waste (see *2.7.2 Information Waste*, p. 72). The problem are not the steps itself, but the resources they require (waste!), and the possible quality reduction that can result (e.g., when information gets lost). As well, prior to each step, information usually is waiting. Reducing or eliminating these functional seams in the information flow is not quite easy, but generally spoken, sender and receiver should connect as directly as possible.

- (R086) The lean PDVSD should be available with full functionality to every person involved in the process, in order to prevent steps in its use.

Concluding, seamless information flows travel short distance fast, and directly from sender to receiver.

Thus, an important disadvantage of the proposed lean PDVSD tool arises. If information is transferred by it, it is not transferred directly from sender to receiver. Yet, the advantage is that information is transferred to multiple potential receivers at a time. This unique property of information, that it can be multiplied at virtually no cost, is discussed in the following sub-chapter.

### 2.6.2 Divergent and Convergent Information Flows

In concurrent product development, multiple tasks work simultaneously towards the definition of a single architecture or even components. Thus stems the need for information to flow sideways, instead of purely downstream, and to send it to multiple receivers. As a result, information flows diverge and converge frequently.

Several organizational problems arise. First of all, if starting a task depends on multiple pieces of information, poor synchronization can lead to waiting. Second, if multiple sources use different means and carriers of communication, conversion of the different pieces of information may be difficult. Third, if the flows end at physically dispersed locations, movement is necessary. Waiting, conversion and movement do not add value, they are waste (see *2.7.2 Information Waste*, p. 72). Hence, seamless information flows impose the necessity for synchronization in time and means, as well as co-located final destinations of information flows. The best solution is to reduce convergent and divergent information flows to a minimum, but without compromising the benefits of concurrency.

The Lean Product Development Flow method proposed by OPPENHEIM [2004] makes use of synchronized converging information flows by installing frequent meetings.

- (R087) The lean PDVSD tool should hold means to synchronize time, location and format of convergent information flows.

### 2.6.3 Iteration in Information Flows

Product development requires iteration in order to design technical functions. PAHL & BEITZ [1996, p. 53] point out that information converses with iteration, as a solution to a technical problem is approached step-by-step, and each loop is based on the results of the previous loop. Iterations occur frequently at all stages of the problem solving process. This is not problematic by itself, but as problem solving is usually undertaken by multiple persons and tasks, information transfers and thus flows are necessary.

Iteration in product development is different than in manufacturing. When iteration occurs in production of assembly, it can generally be said that the previous task was imperfect. The resulting iteration is basically a repetition. In contrast, in product development, implicit knowledge about the task is not lost (completely), and explicit knowledge is usually worked with. Thus, it is difficult to ascertain when iteration adds value, and when not.

However, several conditions can lead to inefficient iterations and waste. First, if the iteration cycle is performed by different persons, implicit knowledge is lost. Second, if the iteration cycle does not make use of previously elaborated information, concurrency would have been the faster solution (which decreases time to market). Third, as iteration can be seen as a feedback loop, faster feedback (smaller cycles) generally lead to better control, but increase information transfer.

- (R088) The lean PDVSD tool should hold means to display and plan necessary iteration cycles.
- (R089) The lean PDVSD tool should hold means to provide iterating tasks with previously generated information.

### 2.6.4 Quantity in Information Flows

Depending on the quantity of information, tasks can encounter difficulties. Too much or too less information can affect the performance of tasks.

SCHWANKL [2002, p. 82] states that information shortage can cause (unwanted) iterations which can lead to an increase in overall development time. This is particularly true if not all requirements, results and especially decisions are disseminated, so that development efforts are fruitless. Hence, accurate planning of information flows, and good overall process transparency are necessary.

However, information can have unexpected value to the receiver. Ideas can be adapted to other fields, transparent decision making processes enhance the understanding of constraints and thus for decisions made, and so on. SÖDERLUND [2002, p. 427] thus mentions, that redundancy is an important issue in knowledge processes. Contrary to manufacturing, "redundancy is often seen as beneficial, as it creates opportunities for individuals to invade one another's functional boundaries, which helps in the process of transferring information".

In contrast, over-dissemination can result in "information flooding" [SCHWANKL 2002, p. 83]. If process participants are struggling with sending and receiving pieces of information and don't have time to produce value, productivity is critically low. The ability to filter the right information fast and reliably is limited, and depends on an individual's proficiency. Too much information results in longer "lead times" as well, since pieces of information have to be analyzed one at a time.

Hence, a tradeoff situation is the result. As the quantity of information an individual actually receives beyond required content type information can not be planned accurately, and as the ability to filter reliably depends on the receiver, this tradeoff can not be resolved satisfactorily during the planning phase. The responsibility to decide which information to send whom (aside required content type, of course), thus lies with the sender. He or she should take into consideration the information itself, its potential value, the receiver, and circumstantial factors before deciding what to send whom.

### 2.6.5 Visualizing Information Flows

In order to improve process performance by enabling information to flow seamlessly, the problems need to be seen. Thus stems the necessity to somehow perceive the actual information flows. Unfortunately, information itself is generally not directly visible. What can be perceived, are visible representations (such as computer screens), physical carriers (paper documents), and the actions that produce, transport or transform it (going to a meeting, drawing, etcetera). The biggest advantage of electronic information for transport - the lack of a physical structure that has to be transported - is at the same time its biggest disadvantage when it comes to visibility. Only sender and receiver are aware of a transfer, and have to produce additional, not value adding information if they want others to know.

In Lean Product Development, some ideas have been proposed to enhance the visibility of information flows. They are discussed in the following.

SLACK [1999, p. 31] proposes to use a Quality Function Deployment Information Flow Framework. Therein, customer needs are translated by the means of several QFD matrices from customer needs to ultimately production requirements. SLACK further assigns each step a product development phase. He states, "This framework assists in visualizing the core product development information flow", but it represents idealized segments of the product development process rather than to reveal the underlying value stream activities. It is the representation of a logical, somewhat theoretical information flow, and thus does not help to identify opportunities for process improvement at all. Task, senders and receivers are not identified at all.

MCMANUS [2004, p. 55] proposes "war rooms" to make information visible. In these, key information is kept on the walls for all to see, as "a time-honored method for high-priority projects". The same strategy is proposed by OPPENHEIM [2004] for the Lean Product Development Flow (LPDF) framework. The obvious problem of information displayed in a room is, that in order to see it, one has to move there, as rooms have a limited size. Thus, this approach can only make sense for small projects, where all participants work closely together. Otherwise, the display of information is limited to those who have access to the war room (In the case of LPDF, management), and still has to be transformed and transported to other participants. For simpler processes, MCMANUS [2004, p. 55] proposes “a progress board or a simple web page”. A web page has the great advantage of virtual omnipresence, but can increase the effort to represent information. MCMANUS thus assumes it should be maintained without major effort.

- (R090) Maintaining the lean PDVSD tool should not cause more effort than its benefits can justify, especially from the direct users.

MILLARD [2002, p. 90] proposes communication systems that can aid in establishing pull systems for information and enable more efficient flow within the process. He envisions them to be electronic, for the sake of efficiency. The idea to merge communication and process display is worth pursuing, as switching between tools can be reduced. Process and content type information can coexist in the same framework.

- (R091) The lean PDVSD tool should be integrated in existing communication systems.

PETERS [1997 p. 190] proposes the tracking of information flows through bar codes and automatic identification. In this way, technical data can be captured, but only if information has a physical carrier. This is not feasible at all in product development environments.

Concluding, several approaches on how information flows can be visualized exist, but none is comprehensive, easy to use and without cost. In chapter *5 Development of a Lean PD Value Stream Display*, p. 94, the ideas herein are discussed and weighted against all other requirements.

## 2.7 The Concept of Value in Information

The previous paragraphs of this chapter discuss several facets of information which hold true for conceptual environments outside Lean Product Development, but scarcely mention that context directly. Hence, this paragraph seeks to establish a conceptual relation between “information” and “value”, and discusses the insight and conclusions that can be gained thereof.

The position of Lean Product Development is that identification of and concentration on value, reduction of waste, and continuously improvement of processes based thereupon, enables “business viability in a globally competitive and informed environment” [MILLARD 2001, p. 13].

As stated previously and by many authors from a Lean Product Development perspective [e.g., in MILLARD 2001, p. 25], it is information that flows through a product development process. The lean strategy can thus be only effective, if information value and waste can be identified. Speaking with ROTHER & SHOOK [1999], in order to facilitate process improvement, it is necessary to “learn to see”.

The first subchapter establishes a conceptual connection between information and value. In the following, the second subchapter approaches the lean idea from the other side, by identifying information waste. Ultimately, at the end of the chapter, a model of information value is concluded, and insights are discussed.

### 2.7.1 Information Value

Value itself is "a product (…) which meets the customer's needs at a specific price at a specific time" [WOMACK & JONES 2002, p. 16]. And the product development contribution to that is, accordingly, "a capability delivered at the right time, for the right price, as defined by the end user" [MILLARD 2001, p. 24].

SLACK [1999, p. 15] formulates this basic thought in an equation. Slightly altered, the equation is:

$$V = \frac{Q \times f(t)}{C}$$

*Where: V = Customer Value*

*Q = Quality (in the customer's perception)*

*f (t) = Function of time (the shorter time to market, the better)*

*C = Cost of the product or service*

Three main strategies emerge as integrative to Lean Thinking: Assure quality, shorten time to market, and reduce cost. Of course, there are many business strategies that have one or the other of these strategies as objective, but in Lean Thinking, all three of them are equally important – and all of three of them have the customer's perspective.

In the following, three subchapters discuss each of the strategies (quality, time, and cost), and in what way information value can be identified within them. Later, subchapter *2.7.1.4 Task Dependent Information Value* (p. 68) introduces a different approach to identify information value, based on the characterization of tasks. Following that, subchapter *2.7.1.5 Micro-level Information Value* (p. 71) discusses ascertaining information value on a task-to-task level. Ultimately, subchapter *2.7.1.6 Conclusion on Information Value* (p. 71) evaluates each of the approaches.

#### 2.7.1.1 Product Quality Information Value

The first apparent strategy is hence, to assure that the product meets exactly the customer's need for quality, which encompasses "the totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs" [ROTHERY 1993, p. 13]. In SLACK [1999, p. 25], the product development perspective on product quality is further specified in the equation:

$$V = \frac{\sum[N \times (1 - R)] \times f(t)}{C}$$

*Where: N = Customer need*

*R = Risk (as perceived by the customer)*

*V = Customer Value*

*f (t) = Function of time (the shorter time to market, the better)*

*C = Cost of the product or service*

For industrial products, N is dependent only on the customer; however, for consumer goods, marketing induced product innovation can be leverage.

Product development, thus, has the tasks to assure the customer needs are expressed by the product specifications, and that the risk (of failure to meet the requirements) is reduced. A task aside the main information stream is research and development, in order to facilitate product innovation which can help to strategically foster consumer need.

It can be concluded directly, that activities in the main product development value stream produce valuable information, if either (1) costumer needs are applied to product specifications, or (2) product risk is reduced.

**Customer Needs**

For the customer needs (1), that means in the end that "external customer-based measures of value must be translated into internal measures" [SLACK 1999, p. 17]. There is an effective and feasible tool that facilitates this – the product contract, which contains all information about the customer's needs, and their translation into technical specifications. The difficulties lie in the development of the product contract itself, and the strict enforcement of the postulation. This thesis will not further elaborate on product contracts, but one requirement for the lean PDVSD tool can be deduced:

- (R092) The lean PDVSD tool should hold means to mark all transferred content type information with all applicable customer requirements. Thus, the flow of product quality information value tied to the development of technical functions can be tracked. Tracking requirements that apply to all technical functions, like safety regulations, does not provide insight in the processes and is thus not advisable.

**Reduce Risk**

For the reduction of risk (2), that means that information that reduces customer risk is valuable. Customer risk, an unusual term in product development, can be translated into uncertainty about product performance. Concluding, information that reduces the uncertainty is valuable. The reduction of risk over time can be illustrated by a monotonically increasing curve, as shown in CHASE [pp. 97-99]. However, *when* to enhance certainty about product features is an important aspect.

In a classical, open market situation, the customer is not interested in certainty until he or she buys the product. Thus, information that increases certainty before the product development effort ends, is, from the customer's perspective, not directly appraisable. Two types of uncertainty exist: Unpredictability, and incertitude. Uncertainty can thus be reduced in two ways: (1) Analysis, prototyping and testing provide insight into possible solutions, reducing unpredictability. They cost time and other resources, and can result in conclusions that invalidate a technical solution previously thought to be promising. In this case they are (from the customer's perspective) waste. (2) Making decisions on specifications and thus determining the product, reduces incertitude and the complexity of the task. To the customer, such a decision is valuable, but if based on false conclusions, can likewise reduce quality. Hence, the risk of product failure has to be weighted against the understanding and possible scope of solutions, as well as the complexity of the overall task.

- (R093) The lean PDVSD tool should contain and display all made decisions that define the product completely, intelligibly and with good accessibility. This encompasses decisions for as well as against solutions.

In some situations, the customer *does* have insight and interest into the risk of failure during the development process. Development of military aircraft (a primary focus of the LEAN AEROSPACE INITIATIVE) is a good example for situations in which the customer (in this case, the U.S. government) is a direct stakeholder to the risk during the development. This interest can be translated into requirements for the different stages of a development. Or, expressed in another way, the customer is being "sold" the product several times - each time he makes a decision whether to support further development or not. In that case, information that reduces the risk according to the requirements on certainty of the next stage is valuable. Again, the decision *when* to produce that information is a tradeoff decision, and will not be discussed herein. As a side note, it is probable that LAI will intensify the study of this question in future.

#### 2.7.1.2 Time Reducing Information Value

The second strategy emerging of the basic equation of value is to shorten time to market. It is thus a question concerning process improvement. Taking into account the lean principle of perfection, process improvement is not a singular achievement, but continuous.

In Lean Manufacturing, massive reductions in production time can be achieved through concentrating on value adding activities, and assuring that the object flows seamlessly in between. In the never-to-achieve perfect state, there would not be a single second in which the material is not transformed towards the final product. Ideally, the (spatial) flow would even stop, since movement is not valuable itself. In this (hypothetical) perfect state, the product would be produced in one huge step, from raw materials to delivery, right where the customer wants it to be. There is a variety of tools and methods that enable the transformation of manufacturing processes towards that perfect state, and in the following, some of them are discussed for possible transferability to product development.

**Pull**

Kanban cards improve information flows through introduction of the pull principle [BICHENO 2000, p. 136]. Kanban cards work as a signaling device, so that a task is not started unless demand is signaled. Signaling information is to manufacturing, what valuable process information is to product development. There are many scenarios in which not-content-type information can enable value creation, and in the following, some examples are given.

Whilst tasks in product development are generally of a much longer duration than the ones conducted on a shop machine, Kanban-like systems can be introduced to product development. For example, a specific task, say task A, demands information of a certain type, which might be available in another concurrent task (say, B, C and/or D). Furthermore, it may be difficult (and wasteful, e.g. “information hunting”) for A to gain knowledge about which other task can, and when, provide that information. Furthermore, sending requests to all three of them would interrupt their procedures. Now, if A simply signalized the demand on a “Kanban”-board, one other task (say, B) could then pick up the task and provide information to A, while all other tasks would remain undisturbed. In order to introduce this system, the need for a certain infrastructure arises (see below), and the rule that during idle times, and once every Takt interval, every task should look for this sort of requests. One aspect is important: Kanban cards are physical, thus, removing them from a board reliably prevents other tasks from picking up the request, which is pure waste. Hence:

- (R094) The lean PDVSD tool should hold means for units (e.g., task forces, persons) to request specific information from other, unspecified users of the system. When a pick-up occurs, the request must be removed from the display so that other units cannot see it anymore. Ultimately, a note should be sent to the requesting unit about who picked the task up, and when it is planned to be delivered.

**Transparency**

However, most product development tasks do not arise spontaneously. Careful planning assumed, it should be clear who receives what information from whom. But even meticulous planning can not always predict the exact duration of a task, since in product development, each task should have never been done before (if that's not the case, the problem, or rather waste, is "poor knowledge re-use", see *2.7.2 Information Waste*, p. 72). Resulting, the point in time when information is ready for a transfer can not be determined precisely, and idle times can arise on both ends, which results in waste. Again, signals could be sent, so that A and B are aware of the other side's status. If then A has not finished, B could schedule accordingly, avoiding idle time. The other way round, if B is not ready, A can avoid rushing through the last stage of its task to hit the deadline, or can do other urgent tasks. But, most important, if both are ready, the transfer can occur earlier, and without producing handoffs in other tasks.

- (R095) The lean PDVSD tool should hold means for units to signalize readiness for planned information transfers.

In manufacturing, a given work piece is only at one machine at a given point in time. In contrast, concurrent engineering seeks to facilitate simultaneous work on one "work piece", e.g. a function. Especially during the time when up- and downstream task overlap, the need for communication is high. Preliminary data is used by the downstream task, preliminary results based upon that are needed by the upstream task. So, a system that signalizes the availability of preliminary information and the need therefore can help to facilitate concurrent engineering.

- (R096) The lean PDVSD tool should hold means to signalize the availability as well as the need for preliminary information.

In each of the above discussed three cases, process type information is sent in order to facilitate a faster flow of content information. The term "value" is a little bit misleading in this context, since the signal itself is of course not valuable. But, the platform on which the signalizing information is sent can be streamlined for least effort to send and receive it.

**Reduce Changeover Times**

In Lean Manufacturing, substantial reductions in production time can be achieved when die change times are reduced, seen as "the time from the last piece of the previous batch to the first good piece of the next batch" [BICHENO 2000, p. 148]. In product development, the basic tool for the generation of information is knowledge, and it cannot be "changed" easily [see paragraph *2.5 Generation of Information* (p. 54). There are however two aspects that can be seen as analogue to quick die change times in manufacturing: (1) experts (or expert systems) that provide specific knowledge to any process participant that is in need of it, as soon as possible; (2) multi-skilled employees that can do the work of others that are currently not available, e.g. in the case of illness or other forms of absenteeism.

Both ideas rely on high-quality information; in the first case, the expert has to provide information that can quickly be put to use by the receiver, in the second case, if progress has been made so far from the currently absent person, the second employee is in need of good, problem-focused documentation. Both types of information enable value creation.

Of course, whether these theoretically deduced "tools" actually work in a busy product development environment is not known, and has to be tested. In chapter *5 Development of a Lean PD Value Stream Display* (p. 94), a plausible way to enable a system of signalizing information is introduced, and put to test in chapter *6 Field Study* (p. 100).

#### 2.7.1.3 Cost Reducing Information Value

The third strategy to increase customer's value is to reduce cost. A very similar equation can be found in REINERTSEN [1998, p. 65], wherein value equals utility divided by cost.

Product development contributes to cost in manifold ways: (1) development program cost, (2) acquisition cost, and (3) operating, support and retirement cost [from SLACK 1999, p. 25].

The cost for acquisition and operation of the product are largely set during product development. Here, technical functions are chosen, materials selected, and manufacturability determined, which can sum up to nearly all of the actual product cost [SLACK, p. 23]. Put as a question, *in what way can product development reduce the technical cost of the product*? This particular question is basically what integrated product development aims to answer [*Integrierte Produktentwicklung*, see chapter 4 *Kostengüstig Konstruieren*, EHRLENSPIEL 2002]. Provided that there is a strong connection between manufacturing and product development, design for manufacturing can reduce the production cost greatly. However, the question is discussed in classical product development and thus not scope of the thesis.

Development program cost is the cost that is directly caused by the development, e.g. cost for engineers' wages, for patents, infrastructure (which includes rent, telecommunication cost, electricity and so on), movement (for example, postal services and flight tickets), and materials for prototypes. Any information that helps to reduce these costs enables value creation for the customer.

The bulk of the development program costs are linearly dependent on time: wages and rent for infrastructure. The strategy would thus be to reduce development time (see paragraph *2.7.1.3 Cost Reducing Information Value*, p. 68). Costs related to transport (either information or persons) can be reduced by co-location and virtual development environments.

- (R097) The lean PDVSD tool should be ubiquitously available.

#### 2.7.1.4 Task Dependent Information Value

McManus [2004, pp. 28-29] provides a table which characterizes different tasks according to their value – light green is "closest to value-added", medium blue embraces activities where the circumstances make the difference between "necessary non-value-added", value and waste, and dark gray is seen as "necessary non-value-added at best".

The table is shown below in *Table 2-1*, p. 70. As information is the result of a task (see *2.5 Generation of Information*, p. 54), the items of the table could thus be translated into aspects of information value in product development.

| Task Contributes to… |
|---|
| **V1. Definition of End Product with desired Functional Performance** |
| The task affects the definition and/or functionality of the end product delivered to the customer. It contributes directly to either the function or the form that affects the function. For example, requirements specification, design decisions, material/part/subsystem specification, geometry specification, etc. |
| **V2. Definition of Processes to Deliver Product** |
| The task directly affects the processes necessary to deliver the end product to the customer. It includes the design or procurement of the tools and processes necessary for manufacturing, testing, certification and/or other downstream processes, such as the creation of manufacturing and assembly procedures. |
| **V3. Reduction of Risks and Uncertainties** |
| The task contributes to eliminating uncertainties in performance, cost, and/or schedule. Typically, tasks include the analysis, prototyping, and testing of the product; the testing of tools/production processes, risk analysis, and cost/schedule management. |
| **V4. Forming Final Output** |
| The task directly contributes to the final documentation given to the customer or manufacturer. This typically includes the documentation of the materials, parts, subsystems, and systems, and documentation to meet legal and contractual constraints. |
| **V5. Facilitating Communication** |
| The task aids necessary communication. Typically includes reviews, meetings, and discussions with other company or industry personnel. |
| **V6. Enabling Other Tasks** |
| The task is necessary for other tasks to proceed, although it does not directly contribute to the design, production, or testing of the product. |
| **V7. Meeting or Reducing Cost and/or Schedule** |
| The task emphasizes maintaining or improving cost and/or schedule. For example, many management and process improvement tasks. |
| **V8. Learning or Resource Improvement** |
| The task contributes to the skill base necessary to do future work. This definition includes developing greater knowledge, improving tools or processes, creating new technologies, and communicating this knowledge throughout the team. |
| **V9. Enhancing Employee Job Satisfaction** |
| The task is a positive experience that increases the desire of the employee to do similar tasks; it enhances the professional development or skill bases of the employee. |
| **V10. Other** |
| The task performs a necessary or valuable function not covered in the above categories. Examples might include contributions to work environment, environmental impact reduction, satisfying of regulatory or contractual requirements, the following of mandated processes, or the satisfaction other constraints. |

*Color code:*

*Light green – tasks "closest to value-added"*

*Medium blue – tasks' value depending on circumstances, most "necessary non-value adding"*

*Dark Gray – tasks "necessary non-value adding at best"*

*Table 2-1: Aspects of Value in Product Development Tasks [McManus, 2004]*

However, ascertaining value according to the nature of a task, and likewise information value, is not deemed as appropriate to understand the concept of value in product development. First and most important, the customer's perspective is lost. He or she does not evaluate the way a product is defined, but just the result. Second, the characterization does not take into account the constraints of a product development process. For example, a task may determine specifications (thus being "closest to value-added", according to McManus), but determining specifications too early can comminute the solution space, thus eventually reduce the product's ability to meet the user's needs. Third, if a task is only seen "as is", the process context is lost. A task can be fruitless if it does not yield results. For example, defining a schedule (V2, "closest to value-added") is waste, if the schedule is not used at all. The same holds true for information quality that is too high from the user's perspective, which is a waste of resources.

As a result, which task is valuable in the product development context, and thus which task produces valuable information, can not be deduced serviceably by categorizing different types of tasks. Process context and customer have always to be taken into account.

#### 2.7.1.5 Micro-level Information Value

If the information flow is focused up to a task-to-task level, a value can be ascertained to the information flowing within. McManus [2004, p. 43] encourages that point of view, and states: "Value assessments can also be made of the information flows between the processes. These assessments are best done by those on the receiving end of the data flow." This micro-level perspective is closely tied to information quality (which is perceived by the receiver of information, see *2.4 Quality of Information*, p. 41), and can help to improve micro-level processes. Any information can thus have a micro level value.

However, as the perspective is very narrow, so are the expected results. First of all, the micro-level perspective only makes sense if information of a certain, similar type takes the same route repeatedly. Second, the customer's point of view is lost entirely. The customer is not interested in the process layout, and thus this important degree of freedom (altering the process layout) should not be left out. An omitted information flow through better process layout is infinitely better than an information flow streamlined for 100% perfect information quality.

It is tempting for any process participant to identify his or her task as value-adding; in order to be able to say (or think) that what he or she does actually matters. This phenomenon is expected to be very prevalent in organizations where people identify themselves with their task or function. However, it should be kept in mind that there is no "mine" or "your" task. From the customer's perspective, the only thing that matters is the result. He will reward a good result by purchasing the product, and this reward should be the one identification is based upon.

#### 2.7.1.6 Conclusion on Information Value

If a product development process is to truly "go lean", all strategies have to be employed at the same time. Assuring quality enhancement, time reduction and cost reduction at the same time is, however, an enormous task. Numerous possible incentives exist, and it may indeed be difficult to employ all of them simultaneously. However, in the end, all efforts can be traced back at the basic principle – provide customer value, as show above.

Regarding information, it is valuable if it increases the customer's value directly by enforced decisions. Likewise, information enables value creation, if it is used to assure quality (e.g., testing), speeds up the process, or reduces cost. In any case, *information is only valuable if it is needed*. Any activity in product development that leads to unused information is waste.

Note that the German term "Wert", which translates into value, is sometimes mentioned in German engineering literature [SCHWANKL 2002, p. 78; BAUCH 2004, p. 27]. However, "Wert" and value are different concepts, as "Wert" is increasing with the transformation of information, from raw data through (conceptual) models to knowledge and ultimately decisions (similar to the derivation of information, see paragraph *2.1.2.2 Complex model of derivation*, p. 21). In contrast, Lean Thinking ascertains the value of information in regard to the contribution to product definition, regardless of its stage. For example, a decision has the highest information "Wert" in the above mentioned model, but may not increase customer's value, and thus be waste.

The next paragraph will clarify the concept of information value further by discussing everything which is not value.

### 2.7.2 Information Waste

The success of Lean Thinking is based upon the reduction of waste. Lean Thinking does not aim at speeding up machines, does not require employees to work faster and harder, and does not aim at innovation. Likewise, no single tool for these "classical" objectives can be found in collections of lean tools [see, for example, BICHENO 2000]. The potential for improvement simply stems from the inefficiencies present in the execution of a process, which, as a side note, renders it applicable to *any* process.

The first important step for lean improvements is thus the identification of waste, and the second its removal. In order to identify information waste in product development, this paragraph will analyze product development waste types identified in multiple sources [MILLARD 2002, p. 26; MCMANUS 2004, pp. 50-51; BAUCH 2004, pp. 46-69], and link them to the generation of information. It is furthermore sought to understand, how a given piece of information can indicate waste in activities. Ultimately, requirements for the lean PDVSD tool are deduced where applicable.

Howsoever, for a comprehensive understanding of waste, it is necessary to keep in mind that waste can be identified at any level – enterprise level, product level, development process level, project level, task-to-task level, and even in every single action. In the following, the discussion is conducted on an abstract level, but most of the examples relate to project and task-to-task levels.

In literature, waste is sometimes called *muda*, which is the Japanese translation.

#### 2.7.2.1 Waiting

Waiting occurs, when something can't happen because a prerequisite is missing. BAUCH [2004, p. 48] has identified three different types of waiting – people waiting for information, information waiting for people, and people waiting for capacities. Information itself can not *be* waiting type waste, but it can be *caused* by information, e.g. when its inappropriate quality causes processes to be adjusted imperfectly. The other way round, imperfect activities can cause inappropriate information quality, or the sheer lack of it. SLACK [1999, p. 32] points out that "Waiting" is a catchall term for problems in product development processes.

Requests for postponement, information laying physically on a desk, and a filled mailbox are examples that can serve as an indicator of waiting type waste. When analyzing processes, a good measure for waiting is the delta of times between requesting (available) information and receiving it. This is rather easy with emails.

- (R098) The lean PDVSD tool should hold means to track the duration a contained piece of information is not accessed.
- (R099) The lean PDVSD tool should hold means to indicate that a person (or capacity) is idle, or waiting for information.

#### 2.7.2.2 Transport

In order to get from one to another task, information has to be transported. Transport clearly does not add value to the information itself. In BAUCH [2004, p. 48], the subcategories Excessive Data Traffic, Handoffs, Stop and Go Tasks/Task Switching, and Ineffective Communication can be found. The actual impact of transport, which means it's cost and time-consumption, is influenced by (1) the information carrier (e.g., it's whether it is physical or not), (2) the information quality (e.g., amount, or security) and (3) the circumstances (e.g., distance, or available means of transport).

Electronic information transferred in environments equipped with appropriate infrastructure can lead to less transport waste, as distance does not matter and time-consumption is negligible. However, preparing to send information still requires time. When many information transfers between the same senders and receivers occur in a given period of time (e.g., during a discussion), co-location is a strategy worth to consider, but it causes movement waste if temporarily. Another aspect of transport waste is that physical transport can require planning, which does not add value either. The "leanest" way to speed up information transfer is to omit it. Two subsequent tasks can be merged into one, thus eliminating a handoff which does not only produce transport waste, but can cause the reduction of content type information, and increase the need for process type information. This approach is similar to the one in manufacturing, when Lean Thinking reversed the traditional, evermore precise subdivision of tasks into specialized subtasks [see Womack e. al., 1991]. The limit to that approach is, that engineers can not have unlimited knowledge, and that the need for increased speed demands concurrency. Avoiding handoffs should, because its potential is so great in terms of waste reduction, take place during planning. However, the possibility may arise during the design phases.

Physically represented information is always a direct indicator of transport waste. Unfortunately, measuring the actual cost of transport waste is not easy, and so is thus the tradeoff between movement and transport for (temporarily) co-location.

- (R100) The lean PDVSD tool should facilitate the altering of the displayed process layout, in order to merge two tasks into one.
- (R101) The lean PDVSD tool should be represented electronically, to reduce transport waste.

#### 2.7.2.3 Movement

Whereas transport is passive (information being transported), movement is the active. In BAUCH [2004, p. 50], the sub-categories Lack of Direct Access, Information Hunting, and Remote Locations thus describe the movement towards or with information. MCMANUS [2004, p. 51] adds small scale operations like keyboard and mouse handling.

For all cases wherein movement is the active counterpart to transport (described above), the same strategies can reduce it; with the exception of temporarily co-location which requires a tradeoff decision.

Basically, any movement other is waste if it is not defining valuable content type information. It is thus easy to detect visually. Information itself can indicate movement waste only indirectly, e.g. if it is proceeding an actual movement, or asking for the place where to find it.

- (R102) The lean PDVSD tool should hold means to show the place where information is stored.
- (R103) The handling of the lean PDVSD tool should be efficient.

#### 2.7.2.4 Over-Processing

This category contains typical types of waste – activities that are not required at all. In product development, this means overshooting on quality requirements, and fragmenting tasks. The different authors find many examples and sub-categories. Over-processed information uses more resources than necessary for its generation.

Despite being a very important type of waste, it is not feasible to detect over-processing by analyzing information itself. The process context has to be considered, as well as the needs of the receiver on information qualities (i.e., level of detail).

#### 2.7.2.5 Inventory

In product development, inventories are basically quantities of information that await a user, and could thus be seen as waiting waste. However, as for some information the need to use it arises long after its initial use (e.g., as in documentation), not every information actively awaits a user, and then the perspective shifts to the tool view (see *2.1.1 Views on Information*, p. 19). Thus, the problems concerning information inventory are related to the storage and accessibility.

Information itself reveals inventory waste, if it is generated to search in either electronic or physical archives, or to manage them.

- (R104) The lean PDVSD tool should hold means to easily search for, store, and manage information contained therein.

#### 2.7.2.6 Over-Production

Whereas over-processing encompasses inefficient generation of activities within tasks, over-production describes unnecessary generation and handling of the tasks itself.

In contrast to most other waste types, information itself is tightly dependent to over-production, as most processes result in information. If the overall process is known, it is fairly easy to detect over-processing by analyzing pieces of information. However, measuring it in this way is not feasible, since the information does not tell about the resources that its generation and handling consumed. In the case of over-dissemination [BAUCH 2004, p. 61], it can be argued whether this type of waste is detrimental at all. On the one hand, over-disseminated information does increase the time needed to pick out relevant information. On the other hand, it increases process transparency, and can lead to unexpected but valuable input from stakeholders not thought of previously.

The application of the Pull principle helps to reduce over-production waste, and requirements for the lean PDVSD tool can be deduced thereof. They are, however, discussed in the context of value creation; see “Pull” in *2.7.1.2 Time Reducing Information Value*, p. 66.

- (R105) The lean PDVSD tool should display tasks and information flows represented therein in such a way that easy perception of over-production is facilitated.

#### 2.7.2.7 Defects

Defects are basically deficiencies in intrinsic information qualities (for a detailed discussion, see *2.4.3.1 Intrinsic Information Quality*, p. 44). The most common type is erroneous data and information; they can result from poor testing and verification [see BAUCH 2004, p. 62].

Defects can affect both process and content type information. In the latter case, consequences can be devastating, for example if safety issues are concerned.

It is very difficult to detect defects by just analyzing a piece of information. However, defects can become apparent when subsequent information transfers refer to them. Finding root causes for a defect is even more difficult, since the possibilities are almost infinite – any single operation could have potentially caused it.

- (R106) The lean PDVSD tool should hold means to trace back the itinerary of a given piece of information.

#### 2.7.2.8 Re-invention

Re-invention occurs, when information is generated despite the fact that it is already available. BAUCH [2004, p. 65] speaks of poor design and knowledge re-use, which can be interpreted as referring to content- and process type information, respectively.

It is hard to systematically detect re-invention by analyzing transferred information, since this would require time-consuming enquiries. Moreover, there is commonly no information indicating indirectly to re-invention, since that would require someone else to conduct the enquiry.

- (R107) The lean PDVSD tool should hold means to structure and present the content type information contained therein in a way that facilitates the awareness and usability of it for tasks not initially aimed at.

#### 2.7.2.9 Disabilities

The waste drivers identified by BAUCH [2004, p. 66] that pertain to the category "lack of system discipline" share the commonality of referring to process participants (e.g., engineers) and their inaptitude to generate information adequately. Failure to meet prerequisites (motivation, proficiency, knowledge) and deficient operational requirements (unclear goals, responsibilities, rules) are discussed in paragraph *2.5 Generation of Information*, p. 54.

Some disabilities become apparent if transferred information is analyzed (e.g., use of inappropriate tools and methods), but most can, if at all, only be detected indirectly in this way (spent resources, insufficient readiness to cooperate). If initial plans and actual transfers are compared, timeliness as a result of poor schedule discipline can be detected and measured.

The resulting requirements for the lean PDVSD tool are presented in paragraph *2.5 Generation of Information*, p. 54.

Note: The term "lack of system discipline" is deemed inappropriate, since some prerequisites and operational requirements are not a question of discipline at all. Instead, the term "disabilities" is used, because it conveys a broader meaning. Moreover, the tenth category found in BAUCH [2004, p. 68], limited IT resources, can be subsumed into operational requirements. It should as well be spoken of general limited resources, as any unavailable tool or method can reduce the efficiency of generation of information.

### 2.7.3 Limitations of the Concept of Value

In the previous paragraphs, several difficulties concerning the identification of waste and value in product development are identified, but the concept itself is not discussed critically. In this paragraph, issues are pointed out that constitute limitations to the concept itself, in the product development context and under the perspective of information.

First, in the context of evaluating activities, MCMANUS [2004, p. 43] points out that “traditional categories of ‘value-added’, ‘necessary non-value added’ and ‘pure waste’ are not always useful when taking a first look at the value of the current state tasks”. Some activities may add value, but do this inefficiently. Others can add some value by defining a component, but at the same time limit the potential for value of other components. Resulting, there is no sharp line in between value and waste; instead and unfortunately, it can often be spoken of shades of gray.

Second, product development is, despite all planning and methods, a process with uncertain outcome. Many different ideas are developed in the beginning, and later fewer are pursued, until ultimately one exactly defined solution exists. Now, are the discarded approaches, ideas and solutions waste? They certainly are not important to the customer, and thus do not have customer value, but it is safe to state that without a broad solution space any development is determined to fail.

Third, a company does not only exist to satisfy customers. Employees, shareholders, and society have legitimate interests aside cheap and appealing products. Furthermore, strategic considerations like research, brand value and market position influence all activities within a company, including product development.

Concluding, whenever activities and resulting information in product development are analyzed under the lean perspective, it has to be kept in mind that the concept of value and waste alone fails short to explain and justify every action.

# 3 Communication

This chapter explores the concept communication under the perspective of lean product development, in order to show the importance of high quality communication for efficient product development. Alongside the discussion, potential waste is identified, and requirements for the lean PDVSD tool gathered.

Product development processes rely heavily on communication. A comprehensive explanation is offered by MILLARD [2001, p. 88]: "In an ideal world, a single person, with all required knowledge, would complete the process from beginning to end and require no handoffs until product delivery to the customer. The problem comes in the amount of knowledge a single person can account for, and the time required for completing a large task. Thus emerges the need for a work breakdown structure, but while keeping the goal to create as few handoffs as feasible." In order to facilitate a handoff and information transfer, people have to communicate.

A definition of communication in product development is provided in the first paragraph (*3.1 Definition of Communication*, p. 78), along the basic concepts of sender and receiver. Paragraph *3.2 Circumstantial Factors of Communication*, p. 83, sets the previously obtained definition in a context, focusing on the product development background. Media as containers of information carriers are introduced and discussed, (*3.3 Media in Communication*, p. 84). Ultimately, in paragraph *3.4 Means of Communication*, p. 86, tools which actually transfer media are discussed.

## 3.1 Definition of Communication

The concept "communication" has, much alike "information", a multitude of aspects and connotations. In field of studies like psychology, linguistics and telecommunication sciences different definitions are used. As with the definitions, the fields of study are varied.

In the context of this thesis, communication is defined as an *interpersonal connection across tasks, with a limited time frame, for the purpose to define, conduct and control the transfer of information generated in one task to another*. The technical concept of input and output of black-box tasks is very similar, though it fails to convey the sense of a limited time frame. This definition leaves out communication within task, so that communication as understood herein can not generate information, but only transfer. Interpersonal interaction as reciprocal interdependency [THOMAS 1991, pp. 54-70] is omitted as well. The reason behind this restriction is that communication as value-adding activity within a task is already captured and discussed in the context of generation of information; see paragraph *2.5*, p. 54, and that interpersonal interaction is considered not to be improvable by the envisioned lean PDVSD.

The most important aspects stemming from the above given definition are discussed in the following paragraphs. It is not deemed necessary to mention other definitions, as no results can be deduced for the lean PDVSD tool thereof, which is envisioned to represent only transfers and no other form of communication.

### 3.1.1 Communication as Connection

In SPEAR AND BOWEN [1999, pp. 99-100], the Four Rules of Toyota's Production System (TPS) are identified. It is argued that the rules constitute the tacit knowledge underlying every activity, and "guide the design, operation, and improvement of every activity, connection, and pathway for every product and service". One of the rules is circumscribed as "how people connect". The rule explains how people who perform individual work activities connect with one another. It can be expressed as follows: Every connection must be (1) standardized and (2) direct, unambiguously specifying (3) the people involved, (4) the form and quantity of the goods and services to be provided, (5) the way requests are made by each customer, and (6) the expected time in which the request will be met [ibid, p. 100]. The six aspects are briefly discussed in the following.

(1) - Standardization is only feasible wherein transferred information can be categorized in re-occurring patterns. In the highly dynamic, unpredictable early phases of product development, these patterns are not always detectable for the content of information (e.g., a raw idea). However, the carrier and process type information of the very same information (e.g., a sheet of paper, name and date) can well be categorized and thus standardized. Standardization assures that the technical functions of the carrier of information (storage, transport and display; see *2.3.2 Technical Functions of Information*, p. 35) are facilitated, as the receiver thus knows the format of the incoming information and can foresee whether he or she can handle its reception. As well, the sender can rely on proven methods of sending.

- (R108) The lean PDVSD tool should hold means to categorize and standardize information transfers.

In Lean Thinking, standards are not abided as law, but rather constitute "best practice" and are up to be challenged whenever problems or opportunities for improvements arise. SPEAR & BOWEN [1999] speak of "experiments".

(2) - The directness of transfers is discussed in paragraph *2.6 Information Flow*, p. 57.

(3) - Specifying people involved in an information transfer is of paramount importance, as without responsibilities, control and tracking are impossible. Thus, the application of the lean tenets of pull and perfection, and thus improvements, are impossible.

- (R109) The lean PDVSD tool must hold means to state the involved and responsible persons of every information transfer.

(4) - Specifying form and quantity of the goods and services to be provided beforehand is difficult in dynamic product development, especially in early phases. The form can be specified, as discussed in the context of standardization, see above. Quantity, in contrast, is a concept that

has not much value to information. For example, it is not deemed appropriate to define a number of ideas to be transferred from a brainstorming exercise unless it is (roughly) evaluated how many valuable ideas are actually generated. The same holds true for determining a number of pages, sentences or byte to a given piece of information. However, setting a range can help to guide the providing task without restricting the output too much.

(5) - Specifying the way requests are made by each customer (4) is only feasible in the cases when the customer is known beforehand – in static, repeating processes. It is thus applicable to product development only for repeatedly occurring and planned transfers.

Nonetheless, it is possible to assign responsibility to a process participant to bundle external requests and subsequently distribute them within the process. However, this approach contradicts the goal of direct transfers, and has a major flaw: The participant can not know the answer to every request, and in this case has to redirect, which consumes time and is waste. In Lean Thinking, a function responsible to manage external, unplanned information requests is thus to be avoided.

- (R110) The lean PDVSD tool should hold means to state the (field of) information a given task is responsible to provide upon request.

(6) – Specifying the expected time in which the request will be met is necessary for both previously planned transfers and spontaneously arising requests, in order to prevent idle times and waiting of the requesting task. In both cases, it is suggested for both sides to negotiate a time of transfer while taking the overall process into consideration.

- (R111) The lean PDVSD tool must hold means to state a planned time of transfer, as well as track actual times of transfer for review.

### 3.1.2 Sender and Receiver

In social sciences, the model of sender and receiver is the basis for theories on communication and interpersonal interaction. Based upon the one presented in THOMAS [1991, p. 60], *Figure 3-1*, p. 81 illustrated the model of communication. It uses terms discussed herein (Knowledge, information carrier, means of communication), and integrates the concept of information carrier as discussed in *2.3*, p. 33. Social sciences emphasize the interdependency of communication, which is understood as simultaneous, reciprocal influence on the interacting partners [ibid, p. 54].

Of interest in the product development context is not the *social* interdependency, but rather the *process* interdependency - problems that potentially inhibit smooth information flow or that deteriorate information quality. The lean approach to these problems is to be found in the activities involved in the process of information transfer, as Lean Thinking allows evaluating activities according to their contribution to customer value.

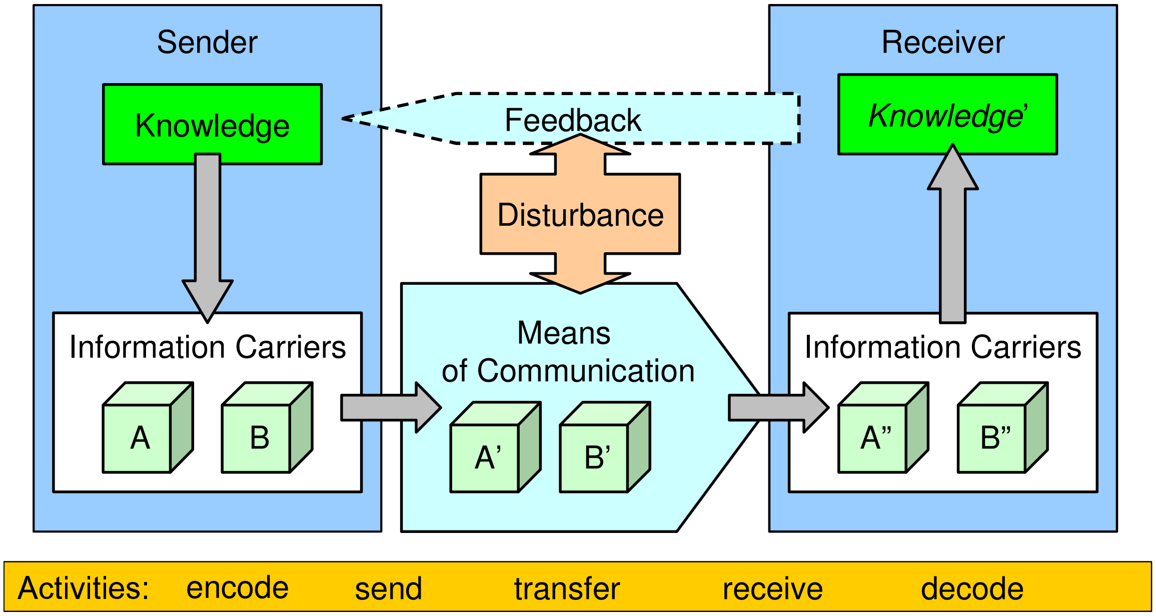


*Figure 3-1: Model of Communication*

The first step of interpersonal information transfers across tasks is the encoding of knowledge into suitable information carriers. This process is discussed in *2.3.3.1 Encoding and Decoding*, p. 37.

The second step is the actual sending of information carriers. Sending itself does generally not take a lot of time nor resources: It is a mouse click, an utterance, or giving a letter to internal mail. However, there are two aspects of importance.

First, the timing of sending is the sender's only way to influence the point in time when the information arrives at the receiver. Ideas from Lean Manufacturing propose to send information the instant it is pulled. This way it is assured that (a) receiving and actual perception are timely close together, as the receiver is expecting the information, and (b) in the case of short duration of transfer, feedback and control are easily possible, as an "communication channel" [Thomas 1991, p. 60] is already opened. Sending information the instant it is requested does not make sense at all neither for information that is not requested (but which is to be omitted anyhow, according to the Pull principle), nor for long or unpredictable transfer durations.

- (R112) The lean PDVSD tool should hold means to state the expected duration of transfer in case it is long or unpredictable (e.g., sending of models via international mail in multi-located product development), so that the sender can time the sending accordingly.

Second, sending of information decides upon the means of communication, which should match the carrier. It is thus the sender's responsibility that the actually used means of communication match best the overall process performance. Means of communication influence greatly the time, cost and several qualities of transfer, as discussed in paragraph *3.4 Means of Communication*, p. 86.

The third step in the model of communication is the actual transfer of information. Disturbances can influence the time and cost of transfer, as well as the informational content. They can have a great variety of reasons; from equipment over persons to environment. Examples of disturbances are background noise in phone lines, bright sunlight on presentation screens, computer viruses and personal dislike. For smooth transfers, disturbances have to be minimized; Lean Thinking suggests tracking the underlying problems by both sender and receiver whenever they occur [compare to manufacturing, *Rule 4: How to Improve* in SPEAR & BOWEN 1999, p. 102]. However, schedule might demand to transfer the information as best as possible, and approach the problem later in team learning efforts.

- (R113) The lean PDVSD tool should hold means to document disturbances of information transfers, so that they can be resolved during process review, or taken into consideration for future transfers.

The forth step in the model of communication is receiving. It actually consists of two steps: Receiving the carrier of information (e.g., email in mailbox), and becoming aware of it. The great advantage of means of communication wherein the receiver actually receives information by perception (e.g., a conversation) is that receiving and awareness thereof happen at the same time; the disadvantage is that it requires the receivers attendance, which can be difficult for communication across time zones or for very busy receivers.

- (R114) The lean PDVSD tool should hold means to indicate awareness of receiving by the receiver to the sender, if the information and its transfer are of great importance to a process.

The fifth step is decoding, which has basically the same potential errors and problems as encoding, and is discussed in *2.3.3.1 Encoding and Decoding*, p. 37.

Ultimately, *Figure 3-1: Model of Communication* on p. 81 shows a feedback arrow which takes commonly, but not always the same carriers, means and itinerary as the initial transfer. Feedback is of paramount importance in lean product development processes. It is a quick and direct way to control, improve and adjust content and quality of information and transfer, and thus the correspondent to the principle of perfection.

- (R115) The lean PDVSD tool should hold means to give and document feedback on the received information and its transfer to the sender, in case it can not be expressed directly (e.g. by means of conversation).

## 3.2 Circumstantial Factors of Communication

Communication takes place in a context which influences it. The circumstances can disturb the transfer and influence encoding and decoding, among other things. Influences can be categorized into processional, environmental and individual influences, which will be discussed briefly in the following.

### 3.2.1 Processional Influences

As the main resources for a product development process are time, money and knowledge, the lack of each can influence an information transfer and its performance. Hence, communication is subject to tradeoff decisions: How to communication efficiently with least waste of resources? How to communicate in reasonable time without leaving questions open? How to communicate with reasonable costs for flight tickets, accommodation or catering? How to communicate with reasonable dependency on supportive functions like facility management or administrators?

These tradeoff decisions have to be answered for each information transfer. Whatever function is responsible for the decision, it should keep in mind that communication does consume resources, and is thus of interest to lean improvements in that respect.

- (R116) The lean PDVSD tool should hold means to state expense of resources for communication, in order to plan, track and control them.

### 3.2.2 Environmental Influences

Environmental influences for communication are understood herein as aspects that stem from the setting of communication. Some aspects are persistent throughout several processes of a given company, like culture and language. They can not be addressed by a product development value stream display, and will thus not be discussed further. Others are manageable, like rooms and conditions (e.g., self established team rules like “no eating in meetings”).

- (R117) The lean PDVSD tool should hold means to state manageable environmental influences for communication, e.g. the room of a meeting.
- (R118) The lean PDVSD tool should be integrated into room management systems, so that planning within the tool does not contradict other facility planning tools.
- (R119) The lean PDVSD tool should hold means to include any form of agreements or rules that potentially influence communication.

### 3.2.3 Individual Influences

Being socialized persons, sender and receiver both have interests, motives and queries aside the process performance. Much like with the generation of information (see paragraph *2.5*, p. 54), certain prerequisites and requirements influence sender and receiver in en- and decoding, as well as sending and receiving.

PETERS [1997, p.187] states, "poor communication could result in alleged 'defects' in an otherwise excellent product, system or service. Therefore, appropriate and sufficient communication has become a necessary and vital personal attribute for the modern technical specialist". Communication proficiency of process participants is thus necessary, but it can neither be planned nor easily improved between one project and another.

Presented herein as an example, one of many aspects of individual communication proficiency is the confidence in data. A higher level of experience tends to lower confidence in data [AHMED ET. AL. 1999, p. 124]. Now, experience can not be "given", it has to be earned. Other factors may lie in personality and circumstances.

For lean product development and the development of the lean PDVSD tool, it can be deduced that "designing" information transfers and communication is only possible to a certain level. Theory can guide planning and help facilitating communication, but the (communicative) behavior of process participants is unpredictable.

## 3.3 Media in Communication

Media are understood herein as the container for one or more information carriers. For example, speech contains only verbal information carriers; in contrast, a document as this thesis contains alpha-numeric and graphical carriers at the same time. Thus, differentiation between carrier and medium is necessary. In order to discuss the usefulness and accordance with lean principles, it stands to reason that media may have an influence on the efficiency of communication.

This paragraph has not the intent to discuss in great depth the pros and cons of each medium used in a product development context. Instead, only the most important aspects for the development of the lean PDVSD tool are extracted, and some thoughts on lean processes given. In the following, common types of media in product development are briefly introduced.

**Documents**

Documents are a container for alpha-numeric and graphical carriers (see *2.3.3.2 Categories of Representations in Product Development*, p. 37). They can be either physical or electronic; the latter form facilitates distribution to multiple recipients. Encoding information in documents does take some time; on the other hand, the time required to decode it is very little and dependent on the receiver (instead of the sender, as in speech). Common examples for documents are Word™

documents, Gantt charts, CAD-drawings, and Power-Point™ presentations. Under lean perspective, the advantage of documents is that a certain structure and standard can be demanded and controlled.

- (R120) The lean PDVSD tool must hold means to store, transport and display documents of any used format (e.g., by starting other applications).
- (R121) It should be possible to automatically extract information contained in the lean PDVSD tool in form of a document, in order to use it in other means of communication (e.g., print, copy electronically, automatically generate .PDF file, …)

**Speech and Other Acoustic Media**

The only acoustic medium widely used in product development is speech, which contains all forms of verbal information carriers (sentences, but pitch and cadence as well). Speech can transport much more tacit information than text, but the interpretation depends on the receivers social skills. Skilled speakers can convince receivers without relying on the informational content. This potential richness, among the easiness to use, makes speech indispensable in product development. [These basic aspects, among many others, are discussed in much greater depth in HERKNER 1996, chapter 3: *Sprache und Wissen*, pp. 129-178]. Speech can be transported by any means, though only phone calls and meetings are common in product development. It can be deduced that the lean PDVSD tool as it is envisioned (containing mainly alpha-numerical and graphical information carriers) can not be the exclusive medium of communication for any type of information. For example, plans contained therein will most likely still be explained or discussed verbally. Furthermore, the quick and universal usability of speech is favorable to immediate problem solving in lean processes.

Aside speech, other acoustic media are warning signals, music etcetera. Warning signals use a singularity of acoustic media – the perception is passive; unless eyes, ears can not be shut.

- (R122) If warnings are to be implemented in the lean PDVSD tool, it should be considered to represent them acoustically.

**Other Media**

In product development, many other media exist. Especially in early phases, quick and easy to use media like whiteboards and chalk boards potentially enhance technical communication by big and easy to alter sketches. The aspect of quickness, combined with versatility, is of interest to lean development, as the resulting short feedback loops in teams facilitate short iteration cycles. Aside generation of information, they can as well be used for spontaneously enhancing communication across tasks, e.g. in a meeting. The problem is that durable documentation of information contained in a whiteboard or chalk board needs further technical equipment.

## 3.4 Means of Communication

Means of communication are understood herein as tools that transfer media of communication. In social sciences, it is spoken of a “communication channel” [THOMAS 1991, p. 54], but this definition has connotations of social interdependency that will not be discussed in this thesis.

Whether means of communication perform better or worse in respect to indicators of process performance (like timeliness) as well as waste drivers, is analyzed in paragraph *6.4 Analysis*, p. 110.

### 3.4.1 Types of Means of Communication

Herein, the most commonly used means of communication in product development are briefly discussed under the perspective of lean principles and the development of the lean PDVSD tool.

**Emails**

The use of emails in product development is widespread, and certain characteristics support this. First, emails are cheap – the infrastructure is already in place, and sending an email does not cost anything. Indirect costs, for example for mailing programs and anti-virus software, are low. Second, emails are versatile, as almost any electronic document can be transferred. Third, they are easy to use, as email software contains process information needed for sending as well (addresses, mailing lists). Forth, emails transfer information very quickly to the receiver. Fifth, sending and receiving an email are independent activities, thus it is not required for the receiver to participate in the communication.

However, emails have distinctive flaws. First, the sender does not certainly know whether an email reached the recipient(s). Second, the sender does not know if and when the email was read. Third, emails are inadequate to transfer large amounts of data like extensive CAD files. Forth and most important, emails are unidirectional, and thus prevent small feedback loops (and iteration cycles). The duration for feedback loops depends on many factors (overall number of emails, individual communicating behavior, and accessibility to network PCs, among others). In paragraph *6.4.3.2 Duration of Feedback Loops in Email Communication*, p. 131, the average duration of feedback loops in two student teams is analyzed.

Under lean perspective, emails can be characterized as follows: Very low movement and transport waste, but potentially high rework waste. Thus, theory suggests, that the use of emails to transfer set information within professional boundaries is fast and convenient, but that the use for information generation (e.g., in discussions) is wasteful and not adequate.

**Meetings**

Meetings are the most versatile means of communication, as they (1) allow the transfer of any media of communication, and (2) are multi-directional, and thus suitable for generation of information. Meetings, however, require movement waste, which can be reduced greatly by co-location.

In meetings, face-to-face conversation is possible, which transfers verbal and non-verbal representations of information, and thus allows a very rich and dense transfer and interdependency. As MILLARD states [2001, p. 88] "less than half of the information transferred in a face-to-face conversation come from the actual words spoken". For the highly interactive character, they are strongly preferred during coordination tasks [OPPENHEIM 2004, p. 367].

Whatsoever, meetings are no guarantee for interactive, rich communication. Social skills and behavior, and of course the actually transferred content of information, can reduce the potential value of meetings greatly. Whether a meeting is the appropriate means of communication is, under lean perspective, dependent on the tradeoff decision between movement and transport waste, likeliness of feedback, and potential value creation during the meeting.

**Phone Calls**

Phone calls are quick and relatively cheap, bi- or multi-directional (in the case of telephone conferences), and allow for transfer of acoustic media. Under lean perspective, they have the advantage to reduce movement waste, and being bi-directional, to allow for generation of information, reduction of re-work, and instant improvement. However, their restriction to acoustic media renders the transfer of technical information like spatial relations difficult (see *3.3 Media in Communication*, p. 84). For technical and especially judicial reasons, it is very difficult to observe and record phone calls, so that information flows within phone calls are hard to detect. In other words, phone calls lack transparency. Hence, it was not possible to include phone calls in the field study conducted for this thesis.

**Other means of communication**

Examples for other means of communication used in product development are websites, instant messaging (chat), groupware, message boards, and mail. As the field study does not cover these means of communication (due to the lack of use by the students), they are not discussed herein.

# 4 Value Stream Mapping

This chapter explores value stream mapping in product development, in order to serve as a theoretical background for the following chapter *5 Development of a Lean PD Value Stream Display*, p. 94. The chapter is kept short in scope, as most of the aspects are already stated in MORGAN [2002], MILLARD [2001] and MCMANUS [2004]. Additionally, general requirements for the lean PDVSD tool are deduced as far as they can not be found already in BAUCH [2004, p. 127]. This chapter is the last of this thesis to do so; the complete list of all requirements can be found in the attachments.

The first paragraph is a short introduction into value stream mapping, offers a definition, and points to recommended literature (*4.1 Background*, p. 88). In the second paragraph, the methodical framework and tools of value stream mapping are introduced (*4.2 Tools and ical Framework*, p. 89). In the third paragraph, PDVSM tools and approaches are juxtaposed with the conclusions from the previous two chapters about information and communication, in order to explain the need for the development of a lean PDVSD tool (*4.3 Conclusions on Product Development Value* Stream Mapping, p. 92).

## 4.1 Background

"Value Stream" as discussed in WOMACK & JONES [2003, p. 37-49] is one of the five basic lean principles. The concept conveys the understanding of sequential value adding activities along the chronological and spatial itinerary of a product, from raw materials to the finished product in hands of the customer.

Analyzing and mapping this stream with appropriate tools helps to identify many forms of waste: waiting, batches, movement and inventory, among others [see ROTHER & SHOOK, 1999. An example for a value stream map can be found on p. 32-33]. Facilitated by the resulting waste transparency, a future state map with less waste can be developed, and ultimately implemented.

Value stream maps have proven to be a useful tool for lean improvements. As Lean Thinking is sought to be applied to every process in companies [see, for example, LEAN AEROSPACE INITIATIVE on Lean Enterprise Transition], current research is developing value stream mapping tools appropriate for product development [MILLARD 2001, MORGAN 2002, MCMANUS 2004].

Product development value stream analysis and mapping can be defined as a method that seeks to understand and illustrate the succession of product development activities along which there is continuous addition of product attributes, in order to improve such efforts [compare to MILLARD 2001, p. 4, and SLACK 1999, p. 26].

## 4.2 Tools and Method

It can not be spoken of a consistent value stream mapping tool, but rather a variety of tools which are used to characterize different process attributes [see VSM tool characterization matrix in MILLARD 2001, p. 45]. They constitute integrative parts of a general PDVSM method [ibid. pp. 61-100, and MCMANUS 2004].

### 4.2.1 The PDVSM Method

According to MCMANUS & MILLARD [2002, pp. 693.1], the PDVSM method has the unique ability to support Lean ideology by (1) creating value for the customer, (2) illustrating flows of information and material, (3) facilitating the adaptability of processes to continually improve value and eliminate waste, (4) rendering time an independent variable, (5) embracing risk and variation in a creative and iterative design process, and ultimately (6) constitutes the foundation of an overall systems perspective, Value Stream Thinking.

Discussing point (4), although lean improvements lead to reductions in cycle times of development processes, time can never be truly free. What value stream mapping and lean considerations can facilitate, however, is to free resources that are bound to non-value-adding activities, and employ them beneficially either in the same process or another.

In reference to Value Stream Thinking as the overall system perspective and therefore and point (6), another framework is worth mentioning – the Lean Product Development Flow (LPDF) proposed by OPPENHEIM [2004, pp. 352]. It is based on lean principles and emphasizes product development value-pulling workflow pulsed by Takt periods. LPDF merges several ideas on lean process layout into a holistic framework, with the following characteristics:

- Detailed preparation in two steps (current and future state).
- Elimination of waste at process layout.
- Disciplined execution of product development processes.
- Dynamic allocation of resources.
- Driven by Takt periods of equal and short duration (e.g., one week each) in order to provide a constant, common and frequent rhythm to the entire team.
- Concurrent execution of multiple tasks, each described by a task sheet that states number, responsibility, in- and outputs, effort, resources and notes.
- Illustration of process by a flow map.
- Integrative events at the end of each Takt period.
- Frequent and both structured and unstructured communication based on pull principles.
- Reliance on a manager called Chief Engineer with vast responsibility and rights.

- Suitable for development processes that last less than two years, involve up to several hundred participants, and are relatively predictable and stable.
- Proper training in the framework, communication and coordination required.
- Currently field tested on an industrial pilot program, with results expected to be available in 2006.

In a study conducted by SÖDERLUND [2002. pp. 420], examples of projects which embraced very similar characteristics were analyzed and found to yield positive results. Approaching from a project management perspective, SÖDERLUND especially pointed out the importance of:

- Tough time constraints, as they create increased and necessary tension (global time).
- Communal, frequent, regular problem solving activities (global knowledge).
- Establishing and opening areas and creating channels for information and knowledge sharing (global arenas).

Concluding, the theoretical framework for value stream mapping is a complex systematical approach that aims at a multitude process improvements. It needs to be understood as a method that is still in development, and that several of its propositions and assumptions are not verified yet. For example, a question that is not yet answered in literature is how the PDVSM effort and process performance correlate in respect to efficiency. In other words, it is unknown whether there is a linear dependency of effort and efficiency or rather a curve of general shape, and if the latter is true, where a maximum efficiency can be found.

### 4.2.2 PDVSM Tools

The tools used for PDVSM efforts are Gantt charts, Ward/LEI maps, Process flow maps, Learning to See, System dynamics and the Design Structure Matrix. The tools are discussed in detail in MILLARD [2001, pp. 45-60]; a shorter overview can be found in MCMANUS [2004] and BAUCH [2004, pp. 128-132].

- (R123) The lean PDVSD tool should be integrated into other tools for value stream mapping. Ideally, it should be able to use it similarly and without much introduction; the platform should be the same.

It is suggested to evaluate the possibility to automatically generate output of other tools, e.g. Gantt charts, from the information contained in the PDVSD.

In the following, the Learning to See tool and the Process Design Tool are briefly discussed. All other tools are unable to show actual information transfers; hence, they are not considered important to the context of this thesis.

#### 4.2.2.1 Learning to See

The most important of the PDVSM tools, and the only one that can identify waste quantifiably (e.g., waiting), is dubbed the "Learning to See" value stream map. It is an adoption of the manufacturing VSM tool presented in the book of the same title [ROTHER & SHOOK 1999]. A lot of examples for Learning to See maps can be found in MORGAN [2002]. The Learning to See map features the following characteristic, which are important for identification and subsequently elimination of waste [a detailed list and discussion of elements and characteristics can be found in Morgan 2002, pp. 46].

- Chronological order of process steps represented in "process boxes", with length corresponding to the amount of time required for completion. It stems the difficulty to represent very short and very large tasks at the same time.
- Illustration of "product / design flow" by arrows between process boxes, with different notation for pushed and pulled information.
- Process type information represented in "data boxes" which are attached to the process boxes. The information contained therein is task time, time in system, changeover time, and value ratio.
- Process icons for indication of different types of delay.
- Event icons for releases, milestones, meetings and reports.
- Different types of information flow arrows for feedback, reciprocal dialogue, notification and program control. The distinction between these arrows and the product/design flow arrows is not made clear, as reciprocal dialogue can lead to generation of information, which would then require a product/design flow arrow.
- Different levels according to the timely resolution.
- No supporting software, thus drawn by hand on paper. This can potentially lead to poor readability and inconsistent representation if drawn by multiple persons, and reduces transferability greatly.

The tool is used to analyze and illustrate the current state, identify waste, and plan a new, lean state accordingly. Due to the complexity of product development processes, the map shows a lot of divergent and convergent information flows [for example, see MORGAN 2002, p. 85]. Hence, the process representation is not easy to interpret. Accordingly, McManus [2004, pp. 46] states "this can lead to excessive complexity, to the point where its usefulness as a tool for visualizing the process is lost".

Concluding, the Learning to See tool is useful for analysis and improvements for a single person or a small team, which needs proficiency in its use. It is not adequate to facilitate general process transparency to every process participant. Furthermore, stemming from its background in manufacturing, it is a tool designed for retroactive analysis. Hence, its usability for direct process improvement (in contrast to other than as a learning exercise) is limited to subsequent, very similar product development processes.

#### 4.2.2.2 Process Design Tool

In BICHLMAIER [1999], a computer-based tool for process design is proposed. Its goal is to facilitate planning of efficient processes under the perspective of integrated product development. Since the goal is similar to the one of the lean approach, and since it can be used to map processes, it will be discussed briefly herein.

The Process Design Tool (PDT) represents processes with process design elements ("Entwicklungsprozessbausteine") and interconnects them in a process net ("Prozessnetz"). The elements specify incoming information required for their beginning, as well as outgoing information; thus, the connection between the elements can be seen as an information flow. Furthermore, each element has black box properties and can be detailed into the process net contained therein. It results a logical structure of the product development effort, similar to the process flow maps introduced in MILLARD [2001, p. 29], but which states information needs and capacities.

Due to the software implementation, it is easy to use, distribute and alter. It is furthermore useful to understand, plan and control at which stage of the process which (product type) information is needed. The possibility to choose whether detailed sub-processes are shown reduces the perceptual complexity.

- (R124) The lean PDVSD tool should hold means to conveniently choose which sub-processes are to be shown.

Lean goals can, however, not be facilitated by the PDT. First of all, the lack of chronological relations hinders the identification and quantification of waiting and delay waste. The pure logical order furthermore fails short to depict information flows between overlapping tasks. The PDT can further not be used as an exclusive tool for planning, as responsibilities can not be assigned.

## 4.3 Conclusions on Product Development Value Stream Mapping

The currently used tools for PDVSM show limitations in their usability for illustrating, planning, enabling and controlling information flows in product development. The Learning to See tool can be used to reveal waste, but it is inadequate for accompanying daily work. Especially complex representation and the fact that it requires a physical information carrier, limit its usability to additional, retroactive lean improvements efforts. The PDT offers almost the opposite of features: Good, electronic representation, but very poor waste transparency.

In order to enhance information flows and communication on a constant, daily, non-retroactively basis, a new tool to be used by every process participant is necessary. The following chapter introduces the development of such a tool currently undertaken at MIT.

# 5 Development of a Lean PD Value Stream Display

The following chapter describes briefly the development of a lean product development value stream display (PDVSD) that is currently undertaken at MIT's Department of Mechanical Engineering by Prof. Seering, his group of students, and in collaboration with the Lean Aerospace Initiative. The chapter provides insight and understanding of a preliminary, paper-based version of the lean PDVSD, which is used for the field study described in the following chapter.

The first paragraph provides a sketch of the envisioned tool. The most important goals are described and an ideal state is drawn. The second paragraph sums up all the requirements which can be deduced from the previous chapters *2 Information*, *3 Communication* and *4 Value Stream Mapping*. In the third paragraph of this chapter, the initial version is presented. It is a paper-based planning tool that incorporates only the major aspects of the envisioned Lean PDVSD. The last paragraph of this chapter describes shortly the development of the computer-based Lean PDVSD. A pre-alpha version was shortly tested in 2.009, and some feedback gathered, which will be discussed herein. Further detail, especially on the development, related to this topic is expected to be published soon by Ryan Whittaker, MIT.

## 5.1 A Lean Product Development Value Stream Display

The previous chapter (*4.3 Conclusions on Product Development Value Stream Mapping*, p. 92) has shown the need for a lean PDVSM tool without the flaws of limited usability and poor waste transparency. In literature, some authors have expressed similar needs, as follows.

Based upon a short survey on waste in product development, SLACK [1999, p. 34] concluded that the product development process would benefit from better process tools, as *wait time* and *over-processing* emerged as the most prevailing types of waste.

MCMANUS [2004. p.65] states that "communication systems can aid in establishing pull systems for information and enable more efficient flow within the process. Web-based environments, common directories for information storage, and electronic transfer of data, can enable efficiencies not possible under many paper-based, push systems".

The two aspects can be combined, and hence constitute the basic requirements on the envisioned tool: Process representation and facilitating of communication. However, a third requirement of utmost importance is that the tool has to be accepted and used, which is only possible with reasonable effort for usage and through justifying results.

The tool to be developed is called lean Product Development Value Stream Display (lean PDVSD), since the basic idea is to create a representation of the value stream which is displayed continuously to every participant. The following paragraph explains the goals in greater detail.

### 5.1.1 Goals of a Lean PDVSD

The general goals of a lean PDVSD can be categorized and justified as follows.

**Increase Process Transparency**

As BAUCH [2004, p. 2] states, “transparency may be considered as one of the most important tools within the lean philosophy”. If the process is transparent to every participant, shared goals become possible and thus cooperative improvements. A similar concept is “Visual Control”, which is considered by SLACK [1999, p. 41] as a manufacturing flow technique which “has been found to be an effective approach to aligning teams and whole organizations towards meeting shared goals.”

The envisioned lean PDVSD tool aims at enhancing process transparency for every involved person.

**Identify Waste and Value**

Lean improvements rely on identification of waste. Thus, the PDVSD tool is envisioned to indicate all steps of the process which neither add customer value nor facilitate it. Hence, they can be identified and ultimately eliminated.

Naturally, identification of value and waste is difficult in product development, as discussed in *2.7 The Concept of Value in Information*, p. 62. Not despite, but because of this difficulty, a tool that helps in that respect is needed.

**Facilitate Efficient Communication**

SÖDERLUND [2002, p. 421], from a project managing perspective, stresses the “need for setting up arenas where […] formal and informal interaction may take place”, for the sake of responsiveness and error detection. With interactions, he means “frequent or continuous communication between the various sub-projects”, which is basically the same as OPPENHEIM [2004] demands for the LPDF framework. Inherent to efficient communication is the call for seamless information flow. MCMANUS [2004, p.64] expresses the goal, assure seamless information flow means to provide processes for seamless and timely transfer of and access to pertinent information.

The proposed lean PDVSD tool is intended to be such an arena for seamless communication to take place.

**Synchronize Tasks and Flows**

An important reason behind long development cycle times is waiting type waste, which occurs because of unsynchronized processes. Upon a detailed discussion of waste drivers, BAUCH [2004] has concluded the need to “provide a new tool to product development for the planning, execution, control and review of processes, […] in order to […] reduce product development cycle times”.

Hence, the lean PDVSD is envisioned to serve as a universally used managing tool for layout and synchronization of tasks and information flows in between.

**Introducing the Pull Principle**

ZUMPE & ESSWEIN [2002, pp. 145] understand information in a context similar to a market place, where the customer of information needs to have knowledge regarding the market structure (process information), as well as about the internal structure of the information he or she is looking for (meta-knowledge). Both requirements fit well with the proposed display, which highlights both process structure and the representation of content information. Thus, customers (here: process participants) become knowledgeable about available information and can request it accordingly.

## 5.2 Summarized Requirements for a Lean PDVSD

This thesis and previous work of Prof. Seering's group have resulted in an extended list of requirements for the lean PDVSD which is based upon basic goals, considerations on existing PDVSM tools (see paragraph *4.2.2*, p. 90), and the discussion of information and communication. It is provided in attachment 1.

To be considered an introduction, the most important are given below.

- Represent a PD Value Stream (R011, R014 and others) in a way that the process and its value is identifiable (R015) and easy to understand (R004 and others).
- Facilitate planning and control of the process (R012).
- Show interdependencies and information flow between tasks (R006, R007, and R008).
- Incorporate temporal aspect (e.g., timeline, R010).
- Display information that is available to every process participant (R019, R026, others)

It is important to understand that the list of requirements as attached to this thesis is not yet complete. Above all, requirements for the identification and categorization for waste types and value are missing. As well, it is not yet specified for what scope of project the PDVSD is aimed for, and what requirements for specific circumstances and industries are. These sets of requirements are currently under development.

## 5.3 Paper Based Version

The preliminary, most basic PDVSD tool described in this paragraph was designed for two goals. First, it is used as a tool to facilitate the field study described in the next chapter. The study requires a representation of a product development process to clearly identify tasks and information flows; the same representation is further offered as a help to the participating students. Second, it constitutes a pre-alpha prototype which is tested in the study. It is very important to develop the PDVSD in close feedback loops with potential users and customers, as it aims to be accepted and employed by every process participant. Thus, the basic layout was employed to gather feedback thereupon.

In attachment 3, an example for a PDVSD for one week of development time is given. It is taken from the many weeks actually observed and represented during the field study, and slightly modified (names de-personified, key added). The following explanations refer to the numbers of the steps displayed therein, easily identifiable by the labels of a "[###]" format.

## 5.3.1 General Layout

The paper-based version has a layout similar to other PDVSM tools. Process steps line up logically and chronologically from left to right. There is a border to the process within a team, so that external influences can easily be marked as such, if necessary (for example, task [057] in the upper right corner). Simultaneity is easily and perceivable as tasks can be aligned on top of each other.

At the beginning of a week, during the meetings, the schedule is discussed and planned, subsequently drawn in the PDVSD, and then provided to each team member. As the key in attachment 3 states (upper left corner), changes in plan, slippage and unplanned steps are, represented in red ink. Not realized specifications and items are marked with [braces], as in task [044], where the planned deadline (Friday, 11-19, night) was not met.

### 5.3.1.1 Format

The maps are drawn in Excel™, in order to (1) guarantee readability, and (2) facilitate simple, electronic distribution. The drawing in this tool, however, takes a lot of time and is not appropriate for deployment in companies. For the purpose of this version, it is suitable, because (1) maps are drawn exclusively by the author, and (2) negligible time is required to learn the drawing technique.

### 5.3.1.2 Timeline

The layout lacks a quantified timeline. Despite their chronological order and adjustment of width according to duration, tasks can not be tied to the point in time of their beginning or conclusion. The reason is that the drawing tool does not facilitate automatic adjustment and arranging of tasks. Moreover, a linear timeline is not deemed appropriate, as some tasks are very short in duration, and hence their representation within a week's schedule would be difficult to perceive. Exact manual adjustment to a scalable timeline, however, is considered to cause too much effort for too less result.

### 5.3.2 Tasks

All tasks within the process are represented in boxes. As with task [044] (upper middle), task have a unique number and a title that describes the work done within a task (in the case of [044], “Build Accumulator, Bellows”). Additionally, the tasks contain process type information as far as it was specified during planning. First, the responsible person is stated, whenever specified during planning (in this case, “D”). Second, the persons who are assigned to the task are specified, or a number of persons if, as in this case, only this is planned. Third and quite important, the start and end times for the specific task are stated (in this case, they are specified only by days). If no start time is specified, it is understood as “start as soon as possible”. Forth, if further explanations seem necessary, a description is provided. If necessary, a place for the task is specified as well.

### 5.3.3 Information States

The PDVSD features so-called information states that are represented by a circle. These information states constitute points in time where deliverables have to be met, and introduce a Takt time to the product development effort. In the actual process, each information state refers to a team meeting, where progress so far is discussed, and further efforts planned. Coincidentally, the same concept and notation is used by OPPENHEIM [2004] for the Lean Product Development Flow (LPDF) framework.

As with tasks, information states contain process type information on the title, location, time and attendants. Moreover, they express explicitly deliverables for that point in time, and specify tasks which are planned to be undertaken during the team meeting.

All information states of a complete product development effort are represented in another value stream map of much higher level. This additional, top-level value stream map is planned at the beginning of the development process, and can be displayed in the “war room” [OPPENHEIM 2004] of the development team.

### 5.3.4 Information Flows

Between tasks and information states, information flows are drawn as arrows to indicate logical and informational dependence of tasks. They are represented in the PDVSD only if planned, and are to be understood as a reminder to the responsible persons of the connected tasks to plan and facilitate an information transfer in between. At the sending task, the information flow is indicated by a small circle (to indicate a small information state at the end of a task); at the receiving task, the information flow is represented by a triangle. Additional process type information can be added to an arrow by a text tag.

Information flows can overlap, diverge and converge, just as discussed in paragraph *2.6 Information Flow*, p. 57. The layout requires sometimes to cross information flows with tasks. In that case, the flows are drawn behind the tasks (for example, behind task [060]).

Information flows between yet not completed tasks can be represented in the same manner, just by adding a sending circle (and receiving triangle) to the respective task, at the corresponded point in time where the information transfer is facilitated. To indicate mutual exchange of information, a special symbol is used which is a triangle merged into a circle.

### 5.3.5 Other Items

Milestones of the project are included into the PDVSD, and represented by a special symbol that resembles a milestone (see Technical Review, between task [092] and information state [055] to the right).

## 5.4 Computer Based Version

A pre-alpha version of the computer-based version of the lean PDVSD is continuously developed by WHITAKER at MIT. Due to the preliminary status and pending future publications, it can not be discussed herein. For more information, contact Prof. Seering, seering@mit.edu.

# 6 Field Study

This chapter gives record of a field study of information flows in MIT's 2.009 Product Engineering Processes course.

The chapter starts with a paragraph explaining the intents of the study (*6.1*, p. 100)

## 6.1 Intent

This paragraph describes the multifold intends of the field study that was conducted in the 2004 course "2.009 - Product Engineering Processes" at the Massachusetts Institute of Technology.

First, in order to understand better the need for a product development value stream display, the study is intended to collect data about a product development process. The focus lies in information flows. By analyzing the data, it is assumed that the findings help to understand what types of information waste are visible in information flows, how they can be identified through information flows, and whether certain representations and means of communication correlate with waste.

Second, the feedback from the students is used to develop the preliminary tool further. It is hoped to gather remarks about the tools ability to help organizing a product development process.

Third, at MIT, the study of students' interactions can only be approved if it does not hinder the subjects in any way. Thus, the tool and its use throughout the study are meant to support the students in the course.

### 6.1.1 The Dependency of Information Waste and Transfers

As stated in paragraph *1.4 Research Questions*, the main focus of this thesis is to understand what waste occurs in information transfers. Throughout the study, types of waste in information transfers are collected in order to get an understanding of their frequency. Perceiving information waste and measuring their effects is difficult and depends on the waste type, as discussed in paragraph *2.7.2 Information Waste* (p. 72). Most waste types are "hidden" within information, and become apparent only under the process perspective. Thus emerges the need to study an entire process (instead of single pieces of information).

The study tries to find a correlation between carriers of information and means of communication on the one hand, and waste types on the other. It is unclear whether such a correlation exists at all, but if it does, the best carriers and means can be recommended for the use under certain circumstances, and the development of the lean PDVSD tool would then have to take these into account.

It is sought to determine the drivers of successful, high-quality information transfer, and to clearly identify routines and communication behavior that leads to waste.

### 6.1.2 Testing the Mapping Tool

The mapping tool as described in paragraph *5.3 Paper Based Version* (p. 96) is a very preliminary version, and not expected to serve for industrial application at all. Aside from theoretical considerations, it is deemed necessary to create feedback on the general design, the outlook and the handling of the mapping tool.

Therefore, the mapping tool is used to plan weekly schedules. The users are asked to comment and suggest throughout the study, and have thus a direct impact on the design in this early phase.

### 6.1.3 Helping Students in Planning a Product Development Process

It is considered important for the study to actually help the involved students, rather than hinder or impose workload. First, it is believed that the students should have benefits in exchange for their commitment to share information; second, the readiness to cooperate is hoped to be raised thereby.

The mapping tool is used to map and display the students' schedules. They are distributed and printed out, so that they lessen the workload for supervising/integrating functions.

## 6.2 Research Setting

The study took place in the fall of 2004, in MIT's student course "2.009 Product Engineering Processes". It is a mandatory course for mechanical engineering undergraduate senior students. More information on course 2.009 can be found at http://web.mit.edu/2.009/www/.

The students have not experienced engineering team work before. Two teams out of six in 2.009 are studied. Team *A* consists of 15 students, Team *B* of 18. They are chosen, because they are advised throughout the course by Prof. Seering, who is at the same time the author's supervisor. The teams are assigned to Prof. Seering randomly.

MIT and federal regulations on confidentiality impose the necessity to obtain signed agreement of the students on participation. It is further prohibited to disclose any information obtained in the connection with the study and that can be identified with a person.

Data collection starts October 18$^{th}$ in Team *A*, and October 13$^{th}$ in Team *B*. By that point, idea generation is finished, the teams have not yet decided which product to pursue, and (physical) mock-ups have been prepared. Data collection ends on December 8$^{th}$ with the final presentation for both teams.

## 6.3 Methodology

This paragraph describes how the study is conducted, and how which data is collected. The first two sub-chapters describe the procedures; the last sub-chapter describes all criteria for which the collected data is analyzed.

### 6.3.1 Iterative Planning and Review

The student teams meet weekly with the advisors to discuss, among other topics, the last week's achievement, and to plan for the next week. The meetings take place in a seminar room, equipped both with chalk and white board, wireless LAN, telephone and plotter. Additionally, projectors can be borrowed.

The teams, with the help from advisors, plan the next week's schedule with tools of their choice. The most commonly used tool is a chalk board and subsequent transformation to paper and/or files.

To help the students, and to facilitate the study, detailed value stream maps of the previously planned schedule are drawn by the conductor after the meetings, and provided thereafter to each student. These maps make use of the technique presented in *5.3 Paper Based Version*, p. 96. Tasks are numbered; see *6.3.3.3 Identification of Tasks* (p. 105). The maps are drawn in Microsoft Excel™ and provided to the students by email. Additionally, .gif images of the maps are provided.

During the meetings, notes are taken. To help in that process, the Information Transfer Log is used (see Figure 6-1: Information Transfer Log, p. 104). The meetings are tape-recorded as well, for subsequent reference in case details are unclear.

Aside the weekly, regular meetings, several additional meetings are observed. If planning takes place, the existing maps are edited. Otherwise, information transfers are observed with the help of the Information Transfer Log, and occasionally tape recorded.

### 6.3.2 Surveying Electronic Information Transfer

To all participating students, a specially created email address is provided. They are asked to carbon-copy *any* email that is related to the course to that address, but as federal and MIT regulations rule that participation can be withdrawn from without notice, the carbon-copying is not mandatory. Thus, every sending student can choose freely to omit forwarding at will for each email. Additionally, the observant is added in the teams' mailing lists.

### 6.3.3 Criteria and the Information Transfer Log

In the following, all recorded criteria are presented. For each, it is explained why it was chosen, and how data was extracted.

Note that all criteria are non-exclusive.

The criteria are represented in the Information Transfer Log, a standardized, tabular document that was used to quickly collect data in meetings. It is shown in Figure 6-1 on page 104.

All recorded criteria of all information transfers were subsequently added to a database.

**Information Transfer Log**

# : ________

| | | | | |
|---|---|---|---|---|
| **TEAM** (section) | | | | |
| ☐ planned transfer? | | | transfer **ID**: [___] to [___] | |
| date | time | | place | |
| sender (s):<br>(circle responsible) | | | receiver (s):<br>(circle responsible) | |
| **TYPE**<br>☐ process (describe)<br>☐ content ☐ technical<br>☐ presentational<br>☐ other (specify) | | | **MEDIUM**<br>☐ conversation<br>☐ document (☐ physical ☐ electronic)<br>☐ presentation<br>☐ video<br>☐ other (specify) | |
| **MEANS** ☐ meeting (list attendants)<br>☐ email (list recipients)<br>☐ other (specify) | | | **CARRIER** ☐ alpha-numeric<br>☐ graphic<br>☐ model<br>☐ other (specify) | |
| **OBSERVATIONS** | | | | |
| **PROBLEMS** | | | | |
| **WASTE** | waste drivers | 1 | 2 | 3 |
| | cause | | | |
| **INFORMATION QUALITY** | | | | |
| intrinsic | level of detail<br>quantified data<br>other | too high ☐☐☐☐☐ too low<br>☐ yes ☐ no | | |
| accessibility | | | | |
| contextual | timeliness<br>completeness<br>☐ value ☐ enabling<br>other | ☐ yes ☐ no delay (hrs:min) ___:___<br>☐ yes ☐ no<br>☐ waste | | |
| representational | ease of understanding<br>media usefulness<br>other | very good ☐☐☐☐☐ very poor | | |

*Figure 6-1: Information Transfer Log*

#### 6.3.3.1 Identification of Information Transfers

Three criteria are used to identify information transfers and their connections.

- *ITL Number*. Each information transfer is given a unique number, in order to identify it. Thus, chains and nets of information flows can be tracked. All information transfers are archived for reference. If a log sheet is filled out for an information transfer meeting, the same number appears on the sheet. All sheets are stored in a folder. If the information transfer in question is an email, a .txt-file is made that contains all textual information given in the email (content and header), which is then saved with the ITL number in the name of the file.
- *Triggers ITL*. For every information transfer, it is ascertained if there is a direct response. If so, the ITL number of the response is given in the Triggers ITL criterion. If there is more than one direct response, only the first number is given.
- *Triggered by ITL*. For every information transfer, it is ascertained whether it is a direct response. If so, the ITL number of the initiating information transfer is given in the Triggered by ITL criterion.

#### 6.3.3.2 Setting

Data about the setting of the information transfer was recorded.

- *Date*. The date of each information transfer was recorded. The date of information transfers is not important by itself, but can be used to retroactively categorize information transfers according to different phases of development.
- *Time*. As with date, recording the time is not meant to explain the waste, but to connect items. Delay and Timeliness can be calculated based upon the recorded times.

Date and time are used to structure information transfers chronologically.

#### 6.3.3.3 Identification of Tasks

Data was recorded that facilitates to connect the information transfer with the tasks, and thereby with the mapping tool.

- *Team*. The 2.009 course consists of six teams, but the scope of the study was limited to two of them. The chosen two teams were advised by Prof. Seering, who is also the thesis supervisor at MIT. Since in this way there was no additional party, the study could be conducted less intrusive. The criterion of belonging to a team renders possible a comparison. There is a good, reliable set of additional data (grading, reviews) that compare the teams on the basis of success, e.g. meeting the requirements on the product set by the faculty. This success is seen as a quite adequate comparison to the classical product development success as determined by senior management in companies. For identification within 2.009, the teams had color codes. Another way to identify the teams is by the weekday of their weekly meetings. For reasons of data protections, they will be referred to as Team A and Team B.

- *Start Task*. For each information transfer, it is ascertained which task provided the information. Each task of each team has a unique number which is given in the mapping tools. The same task identifier is given herein. If information is sent from a task not identified in the plan, this criterion is not recorded.
- *End Task.* For each information transfer, it is ascertained which task is the receiver of the information. As with the start task value, the same numbers as in the mapping tool are used. If information is sent to multiple tasks, the cell is left blank. However, if one task (or person belonging to the task) is explicitly mentioned in the transferred information, the receiver's task number is given in as the End Task value.

#### 6.3.3.4 Planning and Execution

For each information transfer, it data was collected that can be used to determine the planning and actual execution.

- *Planning*. For each information transfer, it is ascertained whether it was planned beforehand. An information transfer is considered "planned", when it was explicitly specified in terms of time (and place, in case of meetings) either (1) on the paper-based plans, or (2) on another document that is available to both sender and receiver. In the database, it is represented as "1" (true) for planned transfers and "0" for unplanned transfers.
- *Timeliness.* For each information transfer, it is determined whether it met the agreed on time of the transfer. If no time of transfer was agreed on beforehand, it can not be ascertained.
- *Delay.* For each information transfer, it is recorded if there is a delay between request and receiving, and how big it is. There are two kinds of delay that are measured: (1) delay as slippage from the original plan, and (2) delay as the time that elapses from information request to answer. The latter value is only calculated, if the requested information is actually known to the providing task or person at the time the request is received.

#### 6.3.3.5 Sender and Receiver

Data was recorded to identify the sender and receiver of information transfers.

- *Sender*. For each information transfer, it is ascertained who is the sender. Initially, the name of the sender(s) is recorded, but that information is later codified into numbers.

  - *Responsible Sender*. For each information transfer, it is ascertained whether the actual sender is responsible for the information transfer. Responsibility is herein understood as "true", (1) if it is explicitly determined and represented in the mapping tool. In the database, "1" stands for true (responsible), whereas "0" stands for false (not responsible).
  - *Number of Senders*. For each information transfer, the number of senders is ascertained.
- *Receiver*. For each information transfer, it is ascertained who is the receiver. Initially, the name of the sender(s) is recorded, but that information is later codified into numbers.
  - *Responsible Receiver*. For each information transfer, it is ascertained whether the actual receiver is responsible for the information transfer. Responsibility is herein understood as "true", (1) if it is explicitly determined and represented in the mapping tool, (2) if the information is meant to reach everyone (e.g., schedules), or (3) if the information transfer is a response to a directed question. In the database, "1" stands for true (responsible), whereas "0" stands for false (not responsible).
  - *Number of Receiver*. For each information transfer, the number of receivers is ascertained.

#### 6.3.3.6 Type of Information

The type of transferred information was ascertained. The categorization follows paragraph *2.2 Types of Information* (p. 28), but a further detailed sub-categorization is provided. The types of information are non-exclusive, e.g. a single information transfer can have more than one type.

- *Process Type Information*, which provides information on planning, management and other process defining information.
- *Content Type Information*. This embraces technical specifications as well as customer need input, product safety requirements and other content that is neither process type nor noise type.
  - *Content Type: Technical*. This content type subcategory encompasses information that is directly related to the product and its specifications.
  - *Content Type: Presentational*. This content type subcategory encompasses information that is, or discusses, a presentation of content information across team boundaries.
- *Type: Other*. This criterion describes the content in detail, (a) if it does not fit in the above mentioned categories, (b) or just to provide additional information.

#### 6.3.3.7 Information Carrier

Data was recorded that describes the used information carrier. For a detailed discussion of information carriers, see paragraph *2.3*, p. 33. The categorization presented below was used to quickly record data about the most used carriers in product development. Note that the verbal carrier type was not recorded specifically, but deduced from the medium conversation, as it was (rightly) assumed that there would not be verbal communication in other media than conversations.

- *Alpha-numeric*. The value is true ("1") if the information was represented in alpha-numerical form.
- *Graphic*. This value is true ("1") if the information was represented in graphical form.
- *Model*. This value is true ("1") if the information was represented in a model, as a special carrier widely used in product development. This category encompasses physical as well as electronic models (e.g., prototypes and CAD, respectively)
- *Other*. This criterion describes other carriers used for the information transfer.

#### 6.3.3.8 Means of Communication

It is recorded which means are used to transfer the information. For means of communication, see paragraph *3.4 Means of Communication*, p. 86. Note that the criteria are non-exclusive, as some information transfers are expected to use several means.

- *Meeting* is understood herein as a temporarily, physical co-location. It was not recorded whether the meeting was structured.
- *Email*. As described *in 6.3.2 Surveying Electronic Information Transfer* (p. 102), all forwarded emails were analyzed.
- *Other*. This criterion describes communication means that are not mentioned above. It is expected that their share is either low (newsgroups) or that they can not be observed (phone calls, instant messenger).

#### 6.3.3.9 Medium of Communication

Data was recorded that describes the used medium for communication (See paragraph *3.3 Media in Communication*, p. 84). The categorization encompasses, as shown below, the most common media in product development. An information transfer can make use of several media.

- *Conversation*, as an information transfer that makes use of verbal communication (e.g. a conversation or a phone call).

- *Document*. As a document is understood herein any information that has been recorded previously, and is then handed over to someone else. A document can either be physical or electronic.
    - *Physical*, if the document has in physical format (e.g., a sheet of paper).
    - *Electronic*, if the document was in electronic format (e.g., a file).
- *Presentation*. A presentation differs from a conversation in that sense that it is formalized, makes use of additional representations, and is more unidirectional.
- *Other*. For media that do not fit in the above mentioned categories, it is recorded what other form were used. Herein, it was as well specified, of what form the electronic document was.

#### 6.3.3.10 Information Transfer Issues

Several information transfer issues have a direct impact on the usability for subsequent tasks. They can be understood as certain information qualities (see *2.4.3 Specific Information Quality*, p. 43). Note, that contrary to the above mentioned observations, the usability of information and the inherent information quality can not be judged objectively, but instead is based upon considerations and comparison. For the quality of studied data, it would be best to let the receiver assess these issues, however, this would mean (1) that each student has to be instructed, and (2) a much higher workload that would interfere with their coursework.

- *Accessibility*. If the accessibility of information is critical or outstanding, a note is written; for example, if a link does not work, or if documents used during a meeting are not made publicly.
- *Level of Detail*. On a scale from 1 (too low) to 5 (too high), the level of detail is ascertained. Too low means, that the information can hardly or not at all be deduced from the given information; too high means that the actually needed information is hidden in a lot of additional, over-precise and unnecessary information.
- *Completeness of Transfer*. A yes or no box is checked to record whether the information transfer was complete, e.g. if no files or requested pieces of information are missing. Note that this criterion is not the same as the waste driver “deficient information quality (completeness)”, as the latter embraces the completeness of the information itself (data, specifications and so on).
- *Value-adding*. This criterions is certainly the most difficult to ascertain, as shown in paragraph *2.7.1 Information Value*, p. 63. For this study, the following set of rules is applied. (1) Information is valuable in the case of communicated decisions, technical specifications, precise answers to necessary questions, and risk reducing information (as testing results). (2) Information is value-enabling in the case of requested or needed process type information meant to define the process, questions on content type

information that were not previously communicated, risk made visible, and for discussions that define the product. (3) Information is waste in the case of questions on the process, unnecessary signaling of undertaken activities, motivation and fun, advice and learning, and when it turns out to be misleading, defective, or causes problems. If during a transfer more than one value-adding category applies, it is counted as belonging to be highest (most valuable) category.

- *Ease of understanding*. On a scale from 1 (very good) to 5 (very poor), the ease of understanding of the transferred information is ascertained. Many influencing factors are taken into account, like audibility of voice, readability of handwriting, quality of a scanned image and so on.
- *Media usefulness*. It is ascertained, whether the chosen medium is useful for the transfer. It is a qualitative, comprehensive criterion that is used to point out to difficulties, not for quantitative analysis.

#### 6.3.3.11 Waste Drivers in Information Transfers

In order to determine which waste drivers can be identified in information transfers, each transfer and the information contained therein is screened for waste drivers. Up to three different waste drivers and their respective cause/description are deduced for each information transfer. In order to term the types of waste consistently, the study uses the terminology provided by BAUCH [2004]. However, some exceptions apply:

- “Deficient information quality” describes inappropriate qualities of information. Note that the waste driver “deficient information quality” refers only to the transferred piece of information itself, not to the transfer (which can still be flawed, incomplete, not in time, and so on, see above paragraph).
- Waste drivers can become apparent in the information itself (e.g., erroneous data), during the transfer (e.g., over-dissemination) and from the process perspective (e.g., over-processing).

#### 6.3.3.12 Observations

For reference and potential questioning of students about the information transfers, observations have to be noted. The Information Transfer Log thus holds space to quickly write down general observations or perceived problems. They are not used for quantitative analysis, but instead for qualitative descriptions, and help to recall issues for interviews.

## 6.4 Analysis

This paragraph guides through the quantitative analysis of the collected data. Altogether 663 information transfers were analyzed, 393 (59.3%) in Team A and 270 (40.7%) in Team B.

The first paragraph (*6.4.1 Waste Drivers in Information Transfers*, p. 111) takes the lean perspective and analyzes information transfers descriptively, according to the observable waste drivers. The second paragraph (*6.4.2 Correlations of Waste Drivers*, p. 125) then analyzes the correlations of waste drivers with means of communication and planning, in order to determine in how far waste drivers are dependent on free variables. The third paragraph (*0 As illustrated in Figure 6-11* (p. 129), planning and means of communication are independent. It can be concluded for emails that planned perform better than unplanned, as described generally in paragraph *6.4.2.1,* p. 126. For meetings, the data seems to indicate that unplanned meetings perform best in respect to waste drivers, and that thus spontaneous movement is to encourage. However, only four unplanned meetings were observed. The scarcity of the data does not allow such a conclusion, but it would indeed be interesting to observe and analyze more unplanned meetings. In theory, the short feedback loops combined with few managing effort (and negligible movement in case of co-location) promise good results in respect to waste drivers.

Other Information Transfer Issues, p. 130) analyzes aspects of interest that do not belong to the waste drivers, such as the timeliness and duration of feedback loops. Ultimately, the forth paragraph (*6.4.4 Comparison of Teams*, p. 134) is intended to correlate the success of 2.009 courses with their communicating behavior.

### 6.4.1 Waste Drivers in Information Transfers

This paragraph analyzes the observations concerning waste drivers in information transfers. Generally spoken, they are problems that render information transfers inefficient. *Table 6-1: Data Analysis: Waste Drivers*, p. 112, summarizes all relevant figures for this paragraph.

The perspective presented here does *not* take into account the concept of value; an information transfer without any apparent waste drivers can still be useless from the (customer's) process perspective (the question is analyzed and discussed in paragraph *6.4.3.1 Value of Information Transfer*, p. 130).

| TOTAL | ALL | | TEAM A | | TEAM B | |
|---|---|---|---|---|---|---|
| | n | % | n | % | n | % |
| | 663 | 100 | 393 | 59.3 | 270 | 40.7 |

| WASTE DRIVER | n | % | n | % | n | % |
|---|---|---|---|---|---|---|
| Waste Drivers | 459 | 69.2 | 286 | 72.8 | 173 | 64.1 |
| One Waste Driver | 321 | 48.4 | 206 | 52.4 | 115 | 42.6 |
| Two Waste Drivers | 108 | 16.3 | 62 | 15.8 | 46 | 17.0 |
| Three or more Waste Drivers | 30 | 4.5 | 18 | 4.6 | 12 | 4.4 |
| No Waste Drivers | 204 | 30.8 | 107 | 27.2 | 97 | 35.9 |

| TYPE OF WASTE DRIVER | n | % | n | % | n | % |
|---|---|---|---|---|---|---|
| Over-Dissemination of Information | 176 | 26.5 | 115 | 29.3 | 61 | 22.6 |
| Deficient IQ | 105 | 15.8 | 63 | 16.0 | 42 | 15.6 |
| Ineffective Communication | 94 | 14.2 | 52 | 13.2 | 42 | 15.6 |
| Over-Processing | 42 | 6.3 | 25 | 6.4 | 17 | 6.3 |
| Unclear Responsibilities | 39 | 5.9 | 27 | 6.9 | 12 | 4.4 |
| Information Hunting | 31 | 4.7 | 10 | 2.5 | 21 | 7.8 |
| Waiting for Information | 29 | 4.4 | 17 | 4.3 | 12 | 4.4 |
| Erroneous Data | 18 | 2.7 | 12 | 3.1 | 6 | 2.2 |
| Unclear Goals and Objectives | 13 | 2.0 | 11 | 2.8 | 2 | 0.7 |
| Poor Synchronization as Regards Content | 12 | 1.8 | 8 | 2.0 | 4 | 1.5 |
| Poor Schedule Discipline | 11 | 1.7 | 5 | 1.3 | 6 | 2.2 |
| Poor Synchronization as Regards Time | 10 | 1.5 | 9 | 2.3 | 1 | 0.4 |
| Lack of Direct Access | 8 | 1.2 | 5 | 1.3 | 3 | 1.1 |
| Unclear Rules | 5 | 0.8 | 4 | 1.0 | 1 | 0.4 |
| Poor Verification | 5 | 0.8 | 1 | 0.3 | 4 | 1.5 |
| Excessive Data Traffic | 4 | 0.6 | 3 | 0.8 | 1 | 0.4 |
| Unnecessary Detail and Accuracy | 4 | 0.6 | 2 | 0.5 | 2 | 0.7 |
| Waiting for Capacity (People) | 4 | 0.6 | 3 | 0.8 | 1 | 0.4 |
| Limited Resources | 3 | 0.5 | 1 | 0.3 | 2 | 0.7 |
| Rework | 3 | 0.5 | 3 | 0.8 | 0 | 0.0 |
| Excessive Approvals | 2 | 0.3 | 0 | 0.0 | 2 | 0.7 |
| Inappropriate Use of Competency | 2 | 0.3 | 2 | 0.5 | 0 | 0.0 |
| Lack of System Discipline | 2 | 0.3 | 2 | 0.5 | 0 | 0.0 |
| Limited IT Resources | 2 | 0.3 | 2 | 0.5 | 0 | 0.0 |
| Insufficient Readiness to Cooperate | 1 | 0.2 | 1 | 0.3 | 0 | 0.0 |
| Waiting for Capacity (Resources) | 1 | 0.2 | 0 | 0.0 | 1 | 0.4 |
| High System Variability | 1 | 0.2 | 1 | 0.3 | 0 | 0.0 |

*Table 6-1: Data Analysis: Waste Drivers*

From 663 information transfers, a mere 30.8 percent did not reveal any waste drivers. That means that more than two thirds of all information transfers are imperfect, or positively spoken, show opportunities for improvement. This confirms the assumptions made in paragraph *1.3 Scope of Thesis* (p. 11), that information and communication do hold a great potential for lean improvement.

The great majority of information transfers show only one specific waste driver, few show two, and not even 5% of all information transfers show three or more waste drivers. In order to facilitate lean improvements, this can be seen as positive, since interdependency and thus tradeoffs are, at first glance, not frequent. However, it has to be taken into consideration that the reasons behind waste drivers are not represented herein, and as other waste drivers can lead to problems in transfers (e.g., unclear responsibilities to information hunting), interdependencies can not be disregarded. *Figure 6-2: Waste Drivers in Information Transfers* (p. 114) illustrates the share of waste drivers.

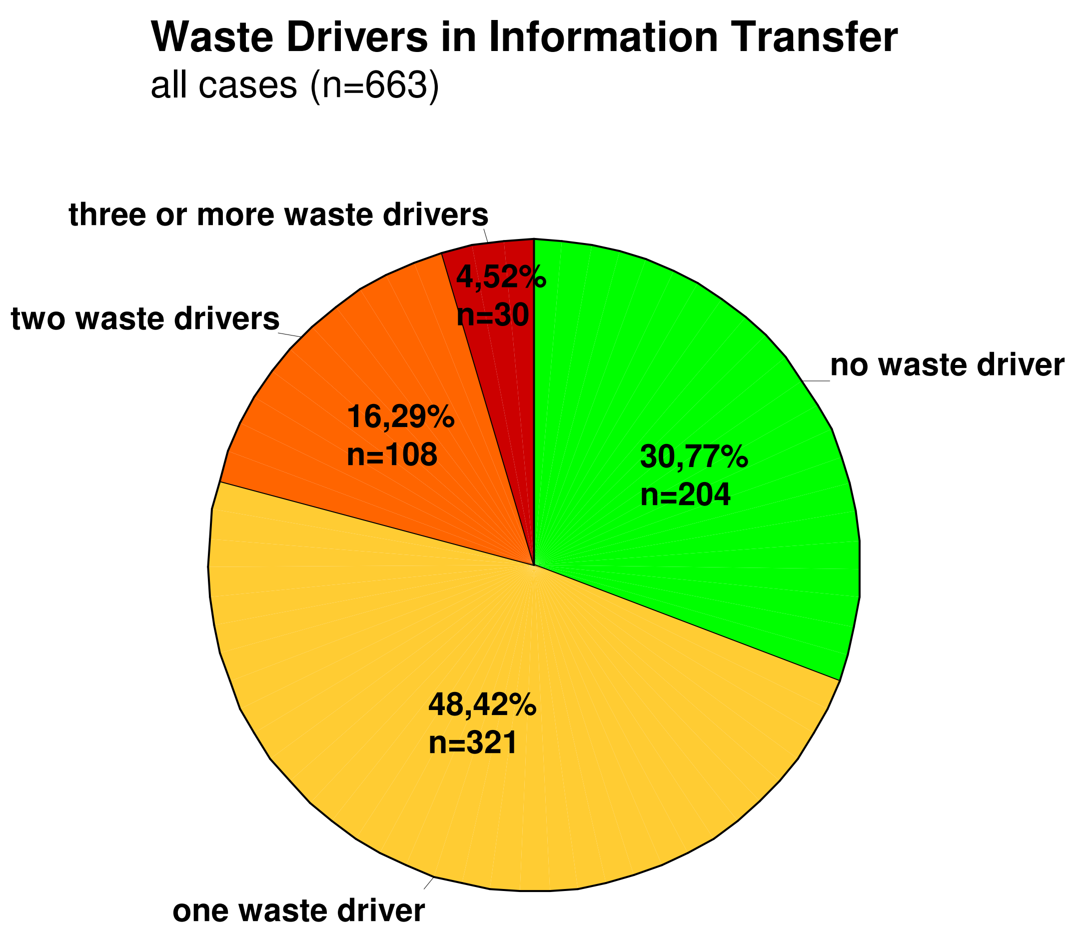


*Figure 6-2: Waste Drivers in Information Transfers*

#### 6.4.1.1 Frequency of Waste Drivers

The frequency of waste drivers varies greatly. The occurrence of waste drivers ranges from 176 cases to only 1 perceived case. Furthermore, several waste drivers proposed by BAUCH [2004] were not perceived at all, e.g. exceeding capacity utilization and task switching. This is not surprising, since the setting has unique characteristics that differ from companies. Re-invention, for example can not be observed because the student team has no design to re-use. Still, the fact that the frequency of waste drivers differs greatly justifies in retrospect the intent to study the impact of waste drivers. It is now obvious that some waste drivers are much less likely to occur, and hence lean improvement efforts can be focused to the critical types.

**Over-dissemination**

With 176 cases, more than a quarter of all information transfers show over-dissemination. As discussed previously (*2.7.2.6 Over-Production*, p. 75), over-dissemination can have negative and positive effects, and which weigh more depends on the overall amount of received information and the receivers capability to search fast and reliably through all received information. It is not always recommendable to enforce strict guidelines that limit over-dissemination. However, it stands clear that over-dissemination is indeed an important issue. Qualitative data supports this thesis; in one of the teams, concerns about apparent over-dissemination of information via email let to a serious discussion. As several team-members felt annoyed by many messages in short succession sent by a task, it affected their motivation and spirit within the team.

As an example for over-dissemination, in *Figure 6-3: Over-dissemination of Information (Example)*, an email is shown that is very typical in its structure. Instead of sending it only to the designated receivers R001 and R002, it is carbon-copied to the whole team. The information is not needed at all by anyone except the two specified in the “TO:” field, and of the two only one could be sufficient. In this case, the email is one of altogether twelve emails of a discussion which were sent to the whole team, while only six persons were participating actively. The discussion took five hours and six minutes, without generating information in between that was not known to someone beforehand, and could have been avoided if the initial request of a non-technical function would not have had to hunt for a specification.

```
ITL#0562

Date: Sat, 04 Dec 2004 23:17:32 -0500
To: R001, R002
From: S001
Subject: RE: Price/problems with vaccum insulation panels
Cc: Team

Here's the info on teh vacuum panels I found:

Good Afternoon S001,
Cost is very much dependent on size of panel. A 12 x 12 x 1
inch panel would cost about $14.06/panel.  A 20 x 24 x 1 inch
panel would cost about $33.36/panel. Plus the $150 setup
charge per size. Our normal lead is 3 weeks but with the
holidays coming it may extend to 4 weeks. To place an order
we will need an official purchase order from MIT.
Unfortunately we do not accept credit cards.
Have a good day.
Name

They were from this company called Thermal Visions Inc. As
R001 said, it's quite within our budget. If we ordered same
sized panels, then we would only need to pay teh set up fee
once and then the cost would even itself out.
```

*Figure 6-3: Over-dissemination of Information (Example)*

**Deficient Information Quality**

The second largest group of waste drivers is deficient information quality. Roughly every sixth transferred piece of information shows deficiencies (As explained in *6.3.3.10 Information Transfer Issues*, p. 109, qualities of information transfers are not subsumed to the waste driver "deficient information quality". They are discussed in paragraph *0,* p. 125). The problems that stem from deficient information quality are graver than the ones from over-dissemination, since every single deficient piece of information can cause errors, misunderstandings, and almost certainly a form of rework. Moreover, deficient information quality was identified by BAUCH [2004] as a critical waste driver, i.e. it is interdependent with many other waste drivers. It can thus be spoken of a major challenge to lean improvements. Paragraph *6.4.1.2 Analysis of Waste*

*Driver: Deficient Information Quality* (p. 122) analyzes the causes for deficient information quality in more detail, and provides some examples.

**Ineffective Communication**

The third most observed waste driver is ineffective communication. 14% of all information transfers in the teams could have performed better without changing the information itself, planning or other preparations, just by changing the way how it was communicated. As suggested by BAUCH [2004, p. 96], understanding the reasons behind ineffective communication is important to render lean product development possible. Paragraph *6.4.1.3 Analysis of Waste Driver: Ineffective Communication* (p. 125) thus analyzes the causes for ineffective communication in more detail, and provides some examples.

**Over-processing**

The forth most frequent waste driver is "classical" waste – over-processing, e.g. unnecessary, pushed information transfers. Within the study, more than 6% of all information transfers don't need to happen at all, or can be avoided by better synchronization. It thus seems important to introduce a sense of Pull to product development processes.

```
ITL#0400

Date: Fri, 12 Nov 2004 18:25:15 -0500
From: S001
To: Team
Subject: Monitors, testers, vials

Hey all,

below is the testing info I got from KC. It seems pretty
direct, and I think we have most of the stuff we'll need
(aside from the temperature chamber, unless people have
access to an over or something we can ad hoc test in). As far
as vial testing goes, we can try his suggestion, or do
something similar (i.e. buy similar-sized vials from random
places). Unfortunately, we didn't get free stuff.
```

*Figure 6-4: Over-processing (Example)*

An example for over-processing is given in *Figure 6-4: Over-processing (Example)*, p. 117. In this email, (unspecific) information is sent to the team without actual need. In this case, writing and sending could have been omitted totally, as the information sent is of importance to the sender alone.

The conclusions on over-processing, however, have to be considered carefully. As the students were evaluated by other students, which in the end led to a fraction of their grades, it is possible that some of the emails were sent just to remind others of what one was doing. It should thus be studied a product development process without that sort of evaluation in order to see whether the percentage of over-processed information transfers remains comparable. However, the same phenomenon is likely to exist in companies as well, as it pertains to motivation, a prerequisite for the generation of information by persons.

**Unclear Responsibilities**

In 39 cases (5.9%), unclear responsibilities caused flawed information transfers. Most of the resulting information transfers reveal bad process transparency; examples are uncertainty about who is in charge of a given task, and when results are to be expected. It is not observed that unclear responsibilities lead to rework and redundancy, tasks are rather postponed. Better process transparency can avoid these unnecessary transfers, the involved activities, and hence earlier commencement of tasks.

In *Figure 6-5: Unclear Responsibilities (Example)* on p. 119, an example is shown. The email was sent to request process information that should and could be known, provided process transparency existed. The answering information transfer was not observed, and it can thus not be said how long the resulting period of idle time was in this case. The average feedback duration is, however, analyzed in paragraph *6.4.3.2* (p. 131).

```
ITL#0264

Date: Mon, 08 Nov 2004 21:02:09 -0500
From: S001
To: R001 (Integration)
CC: R002, R003, R004, Team
Subject: Re: extension

somethings we should be thinking about...

we have to make this thing in the next two weeks in the
technical review (literally two weeks)

meaning, we need to buy a number of parts and we should start
to order them and starting to build this week

so, try to get me a detailed list of parts, so that hopefully
we can start ordering tomorrow

on the current state of our contract and things, does anyone
need help? so far i think i'm working on the parts list...

is someone doing the housing, i.e. "the box"? [R001
(Integration)]? or is that me? just making sure we're not
doing duplicate work
```

*Figure 6-5: Unclear Responsibilities (Example)*

### Information Hunting

Information hunting is with 31 cases (4.7%) the sixth most frequent waste driver. A variety of reasons lead to information hunting; the most frequently observed is the unavailability of figures and specifications. The problem is not only the discontinuity of the task in need of specification, but also the resources that are used during the search, and the fact that other tasks are potentially interrupted as well.

Information hunting could be reduced significantly by generally enabling access to every piece of information to everyone; however, in that case information transfer would be reduced but the requesting person would still have to search through large quantities of files. As a result, information hunting would only be less visible.

In the study, most questions for specifications are answered fast and correctly, if they are directed at the right person, which is a question of transparency.

A typical example for information hunting is shown in *Figure 6-6: Information Hunting (Example)*, p. 120. Because specifications are unknown, a task is interrupted for a non-value adding activity. Moreover, the request is sent to the whole team, and so potentially multiple tasks may answer (but where not observed in this particular case).

```
ITL#0192

From: S001
To: R001,R002
Cc: Team
Subject: RE: [Name] wants yo' numbers!
Date: Sun, 7 Nov 2004 19:56:21 -0500

Im starting now. Can someone send me the specs on the one way
valve / bellows we are using?
```

*Figure 6-6: Information Hunting (Example)*

**Waiting for Information**

Waiting for information is the seventh most frequent waste driver when observing information transfers. It stands clear, that only severe cases can be noticed, as it is unlikely to write a message about oneself waiting in the first minute after a scheduled transfer is not timely. A variety of reasons are found for the cases of waiting, which confirms it's identification as a passive waste driver in BAUCH's [2004] cause-and-effect diagram. Interestingly, poor schedule discipline could never be identified directly as a reason for somebody else to wait. However, this may stem from a tendency of process participants who cause waiting, to state other reasons than their failure to meet the schedule because of a lack of discipline.

The effect of waiting is obvious. A person is – potentially – idle, and thus resources are wasted. Reducing waiting type information transfers is difficult. Generally, the information transfer constitutes a request for another information transfer, which is basically an example for the pull principle. The problem, thus, is not the information transfer itself, but merely the fact that someone has to wait.

```
ITL#0430

Date: Mon, 15 Nov 2004 13:54:34 -0500
From: S001
Subject: 2-WEEK DELIVERY
To: R001, Team
Cc: R002

[R001] (and everyone) -
I am placing the order you just sent me for mcmaster ...
however, the part:

4  Each , 7750K433
 Black Welded Steel Butt-Weld Pipe 1" Pipe, 60" Length, Butt-
Weld X NPT Thread

can only be shipped in 2 weeks -- is that something we should
order now or not (it's pretty expensive) like $88 total

i am going to overnight the other items first, and then wait
to hear about this one from someone (I technically have until
5:00 tonight to send in an order and have it still overnight-
ed)

someone get back to me please!
thanks,
[S001]
```

*Figure 6-7: Waiting for Information (Example)*

In the figure given above, an example for an information transfer that shows the "waiting for information" waste driver is given. In that particular case, the requesting task could not be completed until much later, as an answer was sent 89 hours and 36 minutes later.

### Other Waste Drivers

Altogether 20 other waste drivers were observed in the information transfers, but neither did occur in more than 3% of the transfers. Data being scare, it is not analyzed in detail for each waste driver, what the reasons and effects are. However, from the fact that they are scare, it can be concluded that lean efforts towards information and communication should focus on the above mentioned waste drivers. Others do occur, but their impact is low.

### 6.4.1.2 Analysis of Waste Driver: Deficient Information Quality

The information transfers with the waste driver "deficient information quality" are analyzed in detail herein. It is sought to understand which information qualities are the most "vulnerable" in processes, and what can be done to prevent them.

*Table 6-2: Deficient Information Quality: Categories* shows all information transfers by the information qualities as discussed in paragraph *2.4.3*, p. 43. In the table, only one deficient information quality is ascertained per transfer; thus, the count differs slightly from *Table 6-1: Data Analysis: Waste Drivers*.

| **TOTAL** | **ALL** | | **TEAM A** | | **TEAM B** | |
|---|---|---|---|---|---|---|
| | **n** | **%** | **n** | **%** | **n** | **%** |
| | 102 | 100 | 60 | 58.8 | 42 | 41.2 |

| **DEFICIENT INFORMATION QUALITY - CATEGORY** | **n** | **%** | **n** | **%** | **n** | **%** |
|---|---|---|---|---|---|---|
| Completeness | 28 | 27.5 | 14 | 23.3 | 14 | 33.3 |
| Accuracy | 21 | 20.6 | 12 | 20.0 | 9 | 21.4 |
| Accessibility | 11 | 10.8 | 7 | 11.7 | 4 | 9.5 |
| Concise | 11 | 10.8 | 8 | 13.3 | 3 | 7.1 |
| Ease of Understanding | 11 | 10.8 | 7 | 11.7 | 4 | 9.5 |
| Objectivity | 10 | 9.8 | 5 | 8.3 | 5 | 11.9 |
| Interpretability | 7 | 6.9 | 6 | 10.0 | 1 | 2.4 |
| Relevancy | 2 | 2.0 | 0 | 0.0 | 2 | 4.8 |
| Amount | 1 | 1.0 | 1 | 1.7 | 0 | 0.0 |

*Table 6-2: Deficient Information Quality: Categories*

The categories as discussed in paragraph *2.4.3* (p. 43) differ substantially in their frequency. Six categories occur in more than 10% of the cases, but roughly half of the qualities do not appear at all. The reason that security, availability and consistent representation do not appear can be found in the research setting; the students simply did not care neither for security nor consistent representations. Believability and reputation are very hard to ascertain subjectively and are thus not found in the above table. The qualities timeliness and value-added were not captured with this criterion.

It can be concluded, that completeness and accuracy are the most important information qualities to be enhanced. In the following, two examples and further explanations are given.

**Completeness of Information**

The most prevalent deficient information quality is, with 28 cases out of 102, completeness. The vast majority (25 cases) stem from the fact that a detail or a specification is missing. Incompleteness of a given piece of information can thus reduce the usability of information greatly. Roughly the half of all incomplete information was of content, the other half of process type information.

As a result of incomplete information, successive information transfers are necessary. In the case of longer feedback loops (e.g., emails), it can thus take much more time than envisioned in order to provide all information.

***ITL#0184***

Date: Sat, 06 Nov 2004 20:12:40 -0500
To: *Team*
From: *S001*
Subject: meeting tomorrow

Hey everyone,

**Let's meet tomorrow at 5:00.** Email me to let me know if you can or cannot be there, and if you cannot, what time you are free.

*[...]*

*Figure 6-8: Deficient Information Quality: Completeness*

The example shown above in *Figure 6-8: Deficient Information Quality: Completeness* is typical for this type of waste driver, and should be quite familiar. In this specific case, a question for the place was observed to be sent two hours later, thus causing the initial sender to interrupt his work again.

Another reason for incomplete information in email transfers are missing attachments, i.e. when attachments are referred to in the email, but forgotten to attach. The problem is observed to be not very grave, though, because in all three cases the respective sender noticed the missing attachment in very few time and sent it in an additionally email. In these cases, the information always got in time to the receivers and caused no or negligible additional work.

Insufficient completeness of information can have two underlying causes. (1) The sender is unaware of the fact that something is missing, e.g. he or she simply forgets or oversees it, and (2) the information transfer was not specified beforehand, so that the sender does not know what the receiver needs. With careful planning, only type (2) can be prevented, but structuring and standardizing information transfers, e.g. in tabular form, can help to prevent type (1).

**Accuracy**

The second most observed frequent deficient information quality, with 21 cases out of 102, is insufficient accuracy. In roughly two thirds of the cases, this stems from the fact that information was not refined prior to sending. This phenomenon is only observed in emails. It embraces carbon-copied external emails, copy-and-pasted text and websites, as well as just a link to a website without specifications where to look at.

Insufficient accuracy is not causing grave problems, if the information is sent to *one* receiver by someone who happened to stumble over seemingly valuable information. To the contrary, it is causing a lot of unnecessary work if it is received by a multitude of receivers which are in need of the information, since every one of the *n* receivers has to go through the process of refinement and structuring, at least mentally, and thus potentially increasing the workload times *n*. Refining information for others is thus a task that may seem tedious at first glance, but can benefit the process at a whole in the end, if it is spread to more than one receiver. Of course, if the refining and sending person is not fully aware of the specific information needs of the receivers, this can cause valuable information to get lost.

Another cause for transfers conveying inaccurate information is the sending of preliminary information, specifically meaning that information is sent with an accompanying note stating the preliminary status, and subsequent transfers of more detailed information within a short timeframe. This is observed in three cases (of 102 deficient information quality transfers, and 663 transfers in total), and thus seems not necessary focusing lean improvement efforts on. It may even be considered as an information transfer within a task, since in all three cases the receiver was asked to comment on the preliminary status, thus potentially preventing rework. No further examination of these three cases is conducted, so the above conclusions can not be considered secured.

**Other Information Quality Deficiencies**

The other observed cases of transfers with deficient information quality are each observed in less than 2% of all information transfers. Those worth mentioning are shortly discussed in below.

- *Accessibility*, e.g. when the content of a message can not, or only with difficulties, be accessed. The most often observed problem is inappropriate subject lines, so that the receivers may not perceive information at all if he decides to skip the email containing it.
- *Concise Representation*, e.g. whether information is represented in appropriate formats. Two phenomena were observed more than once: (1) The representation of schedules in plain text, where a Gantt chart is much easier to understand, and (2) technical

descriptions in text, where a sketch or CAD-Files would yield much better understanding.

- *Ease of Understanding*, e.g. when information is not understood as intended by the sender. A multitude of reasons led to this problem.
- *Objectivity*, e.g. when information is based on assumptions and estimations, when hard facts are necessary and available. Another observed phenomenon that caused severe waste (rework, unnecessary processes) in at least one case is the spreading of technical decisions without providing information about the reasons and method of selection used to make the decision.

#### 6.4.1.3 Analysis of Waste Driver: Ineffective Communication

The waste driver "ineffective communication" is difficult to ascertain, as effectiveness is relative. However, two common problems were observed: (1) unstructured, ineffective meetings, and (2) technical discussions via email.

In attachment 2, a technical discussion by email is depicted in chronological order. In this particular case, the need for a discussion arose unpredictably, and it took seventeen hours and forty-three minutes to reach an agreement without adding any previously unavailable value to the product. Altogether five tasks were involved, only two of which were directly responsible.

Five comparable discussions are observed, with time frames ranging from three to twenty-eight hours. In each case, a meeting would have yielded faster agreements and caused much less hand-offs. However, the operational problem is that when the need for a discussion arises, the (potential) participants are unaware of the problems and possible misunderstandings. Thus, the tendency to call for a meeting is low.

The consequences are handoffs, each time new information is read and written, and noticeable slippage in schedule. The technical question to be worked on is meanwhile, in lean terminology, waiting until the decision is made.

The problem can be avoided (or at least reduced) if the participants feel responsible for the efficiency of discussions, and call for an immediate meeting whenever email communication becomes inefficient. If within short time, many emails with the same subject line are received, it is likely that the chosen means are inefficient and a meeting preferable. Yet, meeting causes movement, and requires extra planning. The waste can be reduced through co-location (or proximity) though.

### 6.4.2 Correlations of Waste Drivers

This paragraph analyzes the occurrence of waste drivers by correlating techniques, behaviors, means and teams with the waste drivers described in the previous paragraph. It is sought to understand how communication should be facilitated in order to prevent waste drivers.

### 6.4.2.1 Waste Drivers and Planning

The analysis of 657 valid cases shows that planning correlates positively with less waste drivers in information transfers. As illustrated in *Figure 6-9: Waste Drivers in Information Transfers by Planning* (p. 126), nearly the half of planned information transfers (47.5%) do not show waste drivers, in contrast to slightly more than a quarter (27%) of unplanned transfers. The improvement holds true for all numbers of waste drivers, e.g. whether information transfers show one, two, or more waste drivers.

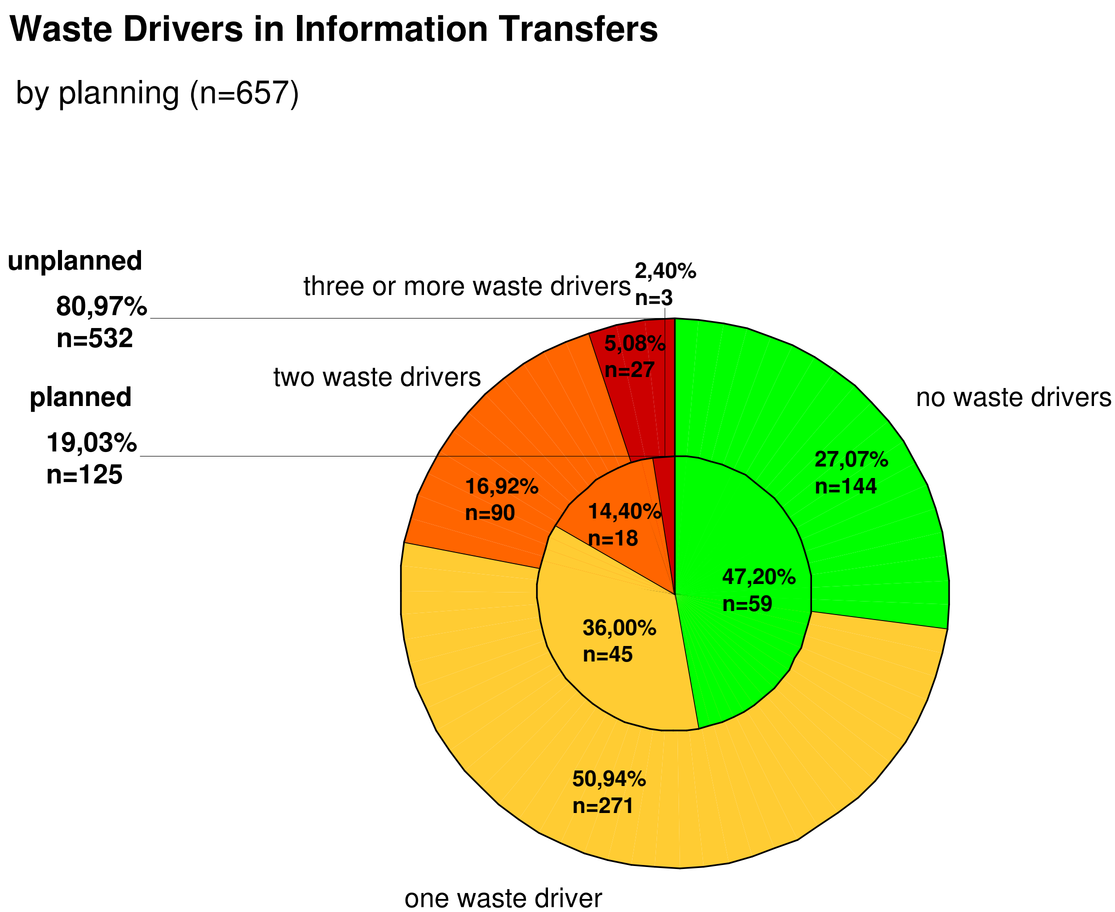


*Figure 6-9: Waste Drivers in Information Transfers by Planning*

Hence, based on the clear correlation, planning of information transfers is strongly recommended. However, it is neither feasible nor sensible to plan every transfer. First, the output of product development processes is not determined in advance. Especially in concurrent engineering, questions and problems arise that can not be predicted completely. Second, planning takes time, and does not add value by itself. Further understanding about which types or categories of information transfers benefit most from planning, without imposing too much managing waste, would be very valuable.

#### 6.4.2.2 Waste Drivers and Means of Communication

The analysis of information transfers shows that email transfers correlate positively with more waste drivers. Forty-eight percent of the observed information transfers in meetings were free of waste drivers, compared to only twenty-nine in emails. *Figure 6-10: Waste Drivers in Information Transfers by Means of Communication* (p. 128) illustrates the question.

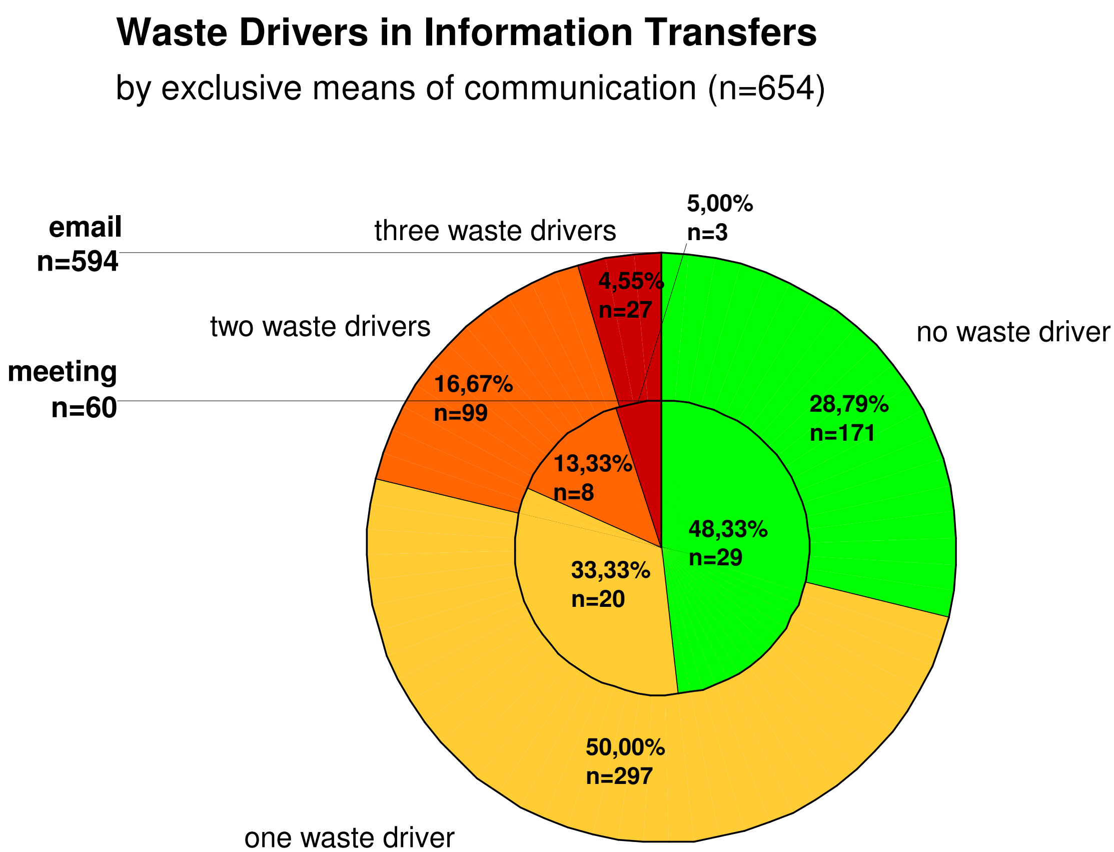


*Figure 6-10: Waste Drivers in Information Transfers by Means of Communication*

From the study, it can not be deduced one (or a couple of) clearly to identify reason(s) why meetings show less waste drivers. It is believed that direct personal contact

The types of waste drivers do not differ considerably, with the big exception of over-dissemination and over-processing. Many emails appear to be sent "just in case", while the observed meetings generally do not convey information that is not needed by the receivers. However, this may well be different in environments and cultures, where frank discussion between all participants of a meeting is restricted.

If the occurrence of waste drivers were the only measure of an effective process, it would thus be advisable to hold meetings instead of sending emails whenever possible. Yet, the large number of over-processed emails, the required time and resources for a meeting, and the resulting movement impede this kind of general proposition. Hence, meetings are to prefer, when a) feedback is expected and/or necessary, b) the resulting movement can be justified, and c) the resulting delay is not critical to the process. If information is not of high importance, and does not require feedback, it should be decided whether the transfer is necessary at all (thus preventing over-processing and over-dissemination). If so, emails can work fine - provided the receiver reads them in time. An alternative are phone calls, since they are direct and provide feedback. It would be of high interest to conduct a similar study for that kind of communication means as well, yet the necessary effort is high.

#### 6.4.2.3 Waste Drivers, Planning and Means of Communication

The two previous paragraphs show that both planning and the use of meetings correlate positively with less waste drivers, but it is not analyzed whether planning and means of communication are dependent. Thus, this paragraph differentiates between the two criteria.

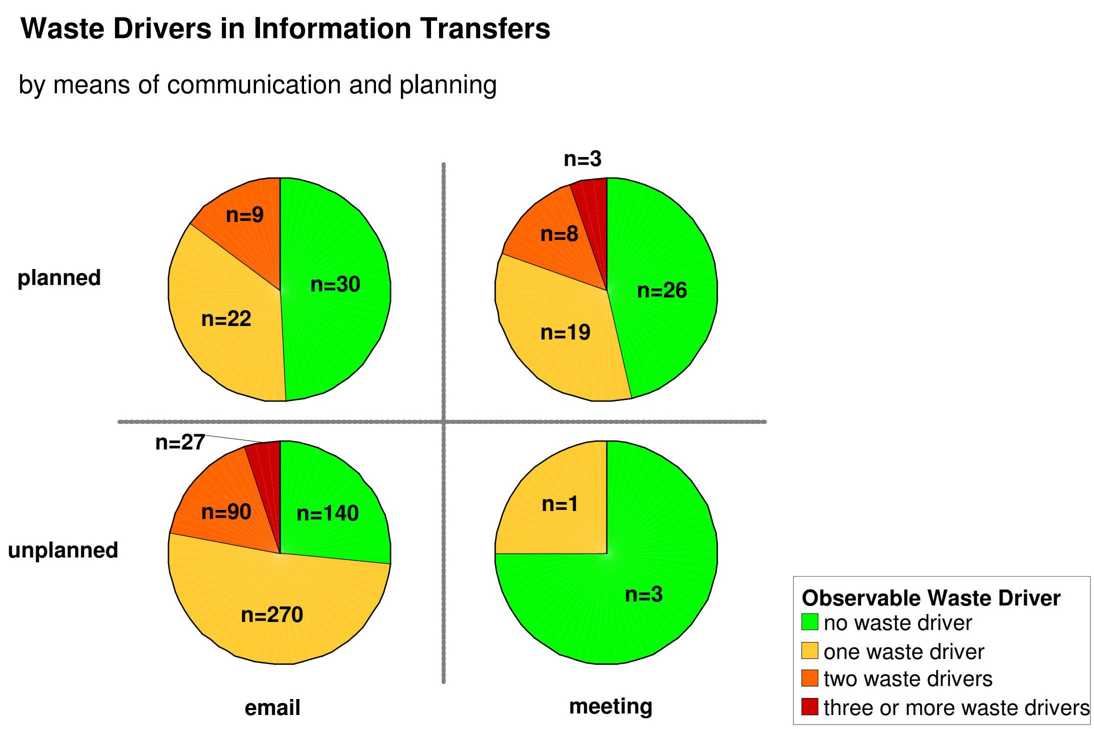


*Figure 6-11: Waste Drivers in Information Transfers, by Planning and Means of Communication*

As illustrated in *Figure 6-11* (p. 129), planning and means of communication are independent. It can be concluded for emails that planned perform better than unplanned, as described generally in paragraph *6.4.2.1*, p. 126. For meetings, the data seems to indicate that unplanned meetings perform best in respect to waste drivers, and that thus spontaneous movement is to encourage. However, only four unplanned meetings were observed. The scarcity of the data does not allow such a conclusion, but it would indeed be interesting to observe and analyze more unplanned meetings. In theory, the short feedback loops combined with few managing effort (and negligible movement in case of co-location) promise good results in respect to waste drivers.

## 6.4.3 Other Information Transfer Issues

Aside the waste drivers, and as a byproduct of the study, data is collected that grants a deeper insight into information transfers and the concept of value in product development.

### 6.4.3.1 Value of Information Transfer

For all information transfers, it is ascertained whether they add value to the overall process (The definition of value adding, required not value adding, and not value adding information transfers used herein can be found in *6.3.3.10 Information Transfer Issues*, p. 109).

Only 77 out of 562 (valid) cases emerge as truly conveying value adding information. This equals 11.8%, which is indeed very close to the 12% of value adding activities that MORGAN [2004, p. 15] finds for a typical aerospace engineering job. MORGAN has, though, a different approach (estimations of employees vs. field study), setting (aerospace company vs. student project) and indicator (time vs. information transfer). The figures for required not value adding information transfers are not comparable at all (39.7% vs. 11% required not value adding activities in MORGAN). As a result, it can not be concluded that 12% of value adding transfers/time is a generally valid figure for product development. However, it seems justified to state that real value is scant in product development, whatever the circumstances.

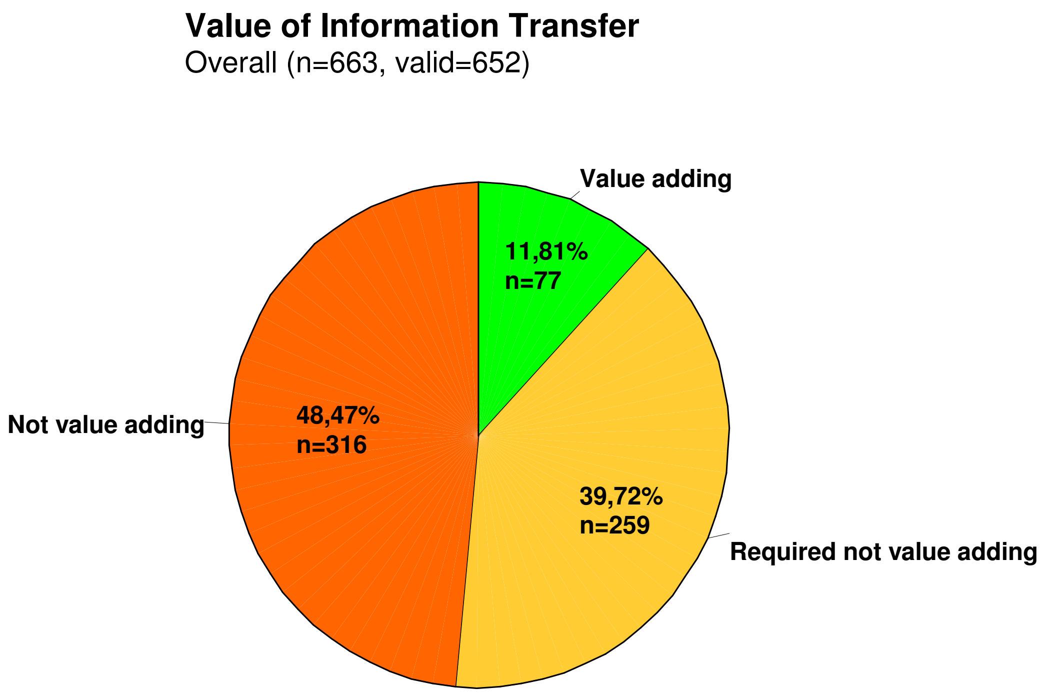


*Figure 6-12: Value of Information Transfers*

#### 6.4.3.2 Duration of Feedback Loops in Email Communication

As times of sending are recorded, the duration of feedback loops (responses) can easily be analyzed. Durations of feedback loops is understood herein as the time span between the sending of an unplanned email from person *A* to *B*, and the sending of a response in reference from person *B* to *A*. Due to the methodology, it is unknown how long it takes (1) from the point in time when the information need arises to the sending of the initial email, and (2) for the response to be received, noticed and read. For a rough estimation it can be assumed that the unknown time spans (1) and (2) are comparable to the one captured below, as the vast majority of responses does not convey information that was unknown to the receiver when the initial email is sent. Hence, the duration of the *whole* feedback loops, from information need to received and processed answer, is believed to be roughly twice the recorded time span.

The time span for feedback loops in meetings was not ascertained, as it is negligible.

*Figure 6-13: Delay in Unplanned Email Transfers* (p. 132) encompasses unplanned emails only. In planned information transfers, it can rather be spoken of slippage, as feedback is in most cases not expected (nor planned). This question is analyzed in paragraph *6.4.3.3 Timeliness and Slippage of Planned* Information Transfers, p. 132.

The mean duration for feedback loops (sending to sending) is two hours and forty-seven minutes, with very slight difference between the two observed teams. With roughly six hours, the standard deviation is quite high, so that a time frame in which a response could be expected can not be ascertained. In the case of the maximum of fifty-seven hours, as a side note, the response had not to be processed – it is the sender's telephone number.

| TOTAL | ALL | | TEAM A | | TEAM B | |
|---|---|---|---|---|---|---|
| | n | % | n | % | n | % |
| | 198 | 100 | 126 | 63.3 | 72 | 37.7 |

| Characteristics | (hh:mm) | (hh:mm) | (hh:mm) |
|---|---|---|---|
| Mean | 2:47 | 2:47 | 2:49 |
| Std. Deviation | 6:07 | 6:23 | 5:38 |
| Minimum | 0:00 | 0:00 | 0:00 |
| Maximum | 57:09 | 57:09 | 30:07 |
| Range | 57:09 | 57:09 | 30:07 |

*Figure 6-13: Delay in Unplanned Email Transfers*

How long a feedback loop for unplanned emails can be expected to last in any given environment can not be deduced from the data. It would be interesting to see whether a company's success to meet the product development schedule correlates with the mean duration of this form of communication, but unfortunately this would require a rather huge amount of research effort – unless automated measurements are devised and implemented.

### 6.4.3.3 Timeliness and Slippage of Planned Information Transfers

As one of the main goals of Lean Thinking is to speed up processes, an interesting question is which means of communication correlate best with meeting the schedule.

Of exactly 100 planned information transfers, 68 occurred in time. It has to be taken into account, that planning took place on a weekly basis so that the figure is not comparable to projects were meticulous planning defines the whole project at the beginning.

Whether the scheduled time was met or not, depends to a great extend on the used means of communication, and to a lesser on the team. If information transfers are planned for meetings, in roughly three quarters of the cases, the schedule is met, in contrast less than two thirds for email transfers. The timeliness correlates, however, with the teams as well; in the study, team *B* performed slightly better than team *A* in this respect. *Figure 6-14: Timeliness of Planned Information Transfers by Teams and Means* (p. 133) illustrates this.

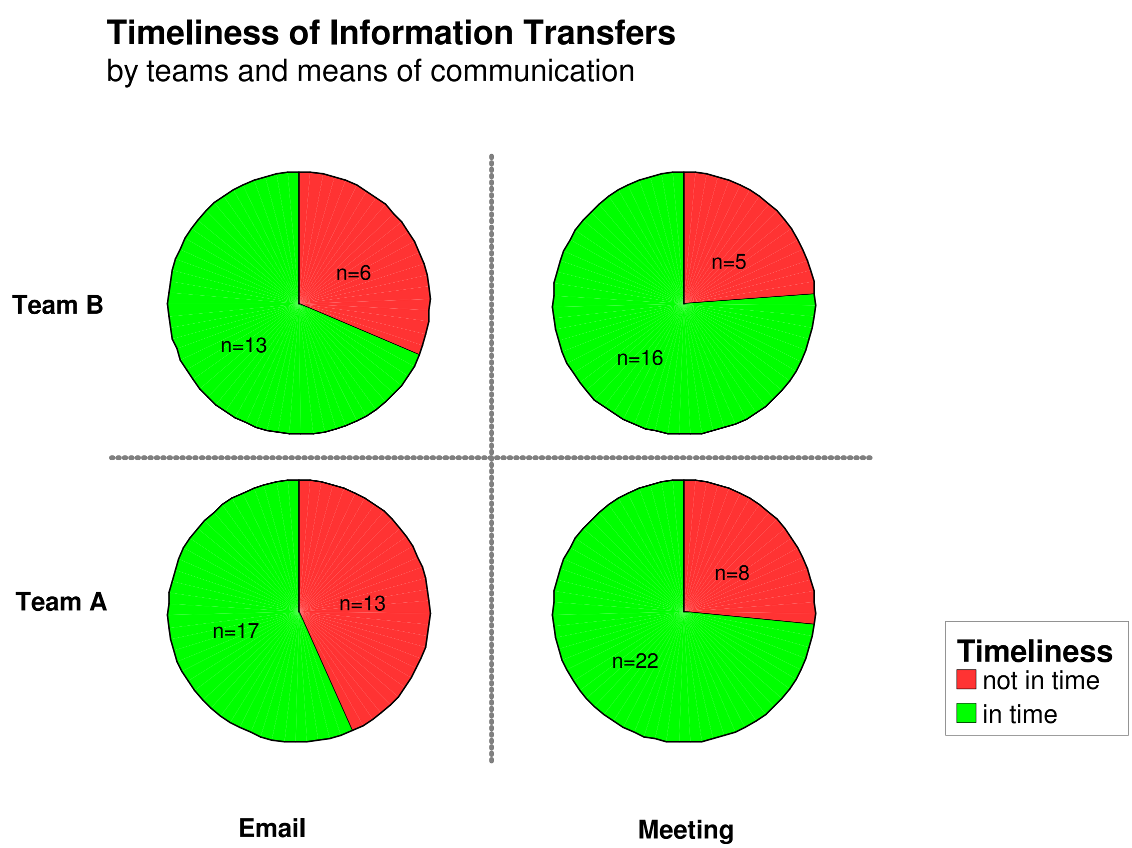


*Figure 6-14: Timeliness of Planned Information Transfers by Teams and Means*

Whatsoever, the question of meeting the schedule encompasses not all aspects that are of interest from the perspective of overall process performance.

First, sending emails is, at least in the surveyed setting, possible any time; in contrast, movement (and accessibility) issues may potentially delay a transfer by meeting in a way that it is timely, but would have been transferred faster by email. Unfortunately, studying this issue was not possible with the chosen methodology.

Second, knowing whether or not a transfer is timely does not hold any value by itself unless it is known how big the slippage is. This question is analyzed in the following.

In *Table 6-3: Slippage of Planned Information Transfers* (p. 134) emails and meetings are analyzed according to the time span between scheduled and actual time of transfer, for all planned transfers (timely and not timely). The number of valid cases (n=71) differs herein with the one of *Figure 6-14* (n=100) because a calculation of slippage was not possible in all cases (e.g., if the actual time of transfer could not be determined).

| **TOTAL** | **ALL** | | **Email** | | **Meeting** | |
|---|---|---|---|---|---|---|
| | **n** | **%** | **n** | **%** | **n** | **%** |
| | 71 | 100 | 23 | 32 | 48 | 68 |

| **Characteristics** | **(hh:mm)** | **(hh:mm)** | **(hh:mm)** |
|---|---|---|---|
| Mean | 5:42 | 16:30 | 0:31 |
| Std. Deviation | 17:42 | 27:39 | 2:53 |
| Minimum | 0:00 | 0:00 | 0:00 |
| Maximum | 96:00 | 96:00 | 20:00 |
| Range | 96:00 | 96:00 | 20:00 |

*Table 6-3: Slippage of Planned Information Transfers*

The mean slippage time is considerably less for meetings, with half an hour in contrast to sixteen and a half hours for emails. Planned transfers by email thus emerge as very critical in respect to timeliness.

## 6.4.4 Comparison of Teams

The previous paragraphs have outlined an analysis of waste drivers and other information transfer issues, but what is ultimately of interest is to understand whether success of the development process and a certain communication behavior correlate. The study was limited to two very similar teams, and thus the transferability to other circumstances of all following conclusions is to be considered very questionable.

Team *B* performed, in respect to grading, better throughout the course. They scored considerably better in early phases (for example, team *B* scored second of six teams in the mock-up presentation, while as team *A* scored last). For the final presentation, *B* scored better than *A*, but all six teams were very close.

The previous paragraphs have shown that differences in information transfers exist between the teams. Remarkable differences will be summed up in the following.

- In team *A*, considerably more information transfers than in team *B* are observed. Due to the research setting, it is unsure, whether in team *A* actually more information transfers take place, or if in team *B* less information transfers are made public. The great difference in the number of observed cases (270 vs. 393, a rise of 45%), and the fact that the difference is quite consistent throughout the duration of the course, indicate that there is indeed a considerable difference in actual number of transfers. This indicates that more information transfers correlate negatively with success. However, it is not known, or rather very unlikely, if the correlation is steadily linear. It may well be that there is a maximum peak of number of information transfers in relation to success, and that team A is over the peak on the declining side on a curve of unknown shape.
- In team *A*, more information transfers show waste drivers than in team *B*. As illustrated in *Table 6-1: Data Analysis: Waste Drivers* (p. 112), 73% of all information transfers of team *A* show one or more waste drivers, in comparison to 64% in team *B*. That indicates that success correlates negatively with occurrence of waste drivers (which is, as a side note, not surprising, since this is exactly what Lean Thinking theory claims).
- In team *A*, proportionally more information transfers show the waste driver "over-dissemination" than in team *B*. In actual numbers, 115 cases (29%) in team *A* stand in contrast to 61 (22%) in team *B*. Over-dissemination of information thus seems to correlate negatively with success, as theory suggests.
- In team *A*, proportionally more information transfers show the waste driver "unclear responsibilities" than in team *B*. In actual numbers, 27 cases (6.9%) in team *A* stand in contrast to 12 (4.4%) in team *B*. Unclear responsibilities as observed in information transfers thus seems to correlate negatively with success, as theory suggests.
- In team *A*, proportionally less information transfers show the waste driver "information hunting" than in team *B*. In actual numbers, 10 cases (2.5%) in team *A* stand in contrast to 21 (7.8%) in team *B*. Information hunting thus seems to correlate positively with success, which is rather surprising. In theory, information hunting is considered a not-value adding activity – waste. Wasting resources deteriorates process performance, so it is believed that information hunting is leads to the same result and should be avoided (preferably by preventing the need for information hunting). However, information

hunting can be understood as a product development type of a pull-action. In this light, it can be understood why processes and team cultures that encourage requesting information, and if then in these teams the requested information is provided in reasonable time and effort, correlate with success. This fact is deemed very interesting and worth further analysis in other studies.

- In team *A*, proportionally more information transfers show the waste driver "unclear goals and objectives" than in team *B*. In actual numbers, 11 cases (2.8%) in team *A* stand in contrast to 2 (0.7%) in team *B*. Unclear goals and objectives as observed in information transfers thus seems to correlate negatively with success, as theory suggests.
- In team *A*, proportionally less information transfers show the deficient information quality "completeness" than in team *B*. *Table 6-2: Deficient Information Quality: Categories* (p. 122) illustrates the differences of teams for this and other information quality issues. In actual numbers, 14 cases (23.3% of transfer with deficient information qualities) in team *A* stand in contrast to 14 (33.3%) in team *B*. Incomplete transfers as observed in information transfers thus seems to correlate positively with success, which is at the first look not in compliance with (Lean) theory and thus surprising. However, the waste driver "deficient information quality: completeness" does not differentiate between preliminary incomplete information transfers and the ones that are detailed further in later transfers. Thus, it can be understood that incomplete, preliminary transfers can facilitate coordination, and ultimately simultaneous processes. This waste driver is, thus not a helpful indicator for success, unless it is captured whether incomplete transfers are preliminary and specified within reasonable time frames.
- In team *A*, proportionally more information transfers are deficient in respect to the information quality "concise representation" than in team *B*. In actual numbers, 8 cases (13.3% of transfer with deficient information qualities) in team *A* stand in contrast to 3 (7.1%) in team *B*. Not sufficiently concise representation of information transfers thus seems to correlate negatively with success, as theory suggests.
- In respect to timeliness of information transfers, team *B* performs slightly better than team *A*, which is illustrated in *Figure 6-14: Timeliness of Planned Information Transfers by Teams and Means* (p. 133). Timely transfers thus seem to correlate positively with success, as theory suggests.

Along aspects from other paragraphs, the above given considerations will be refined to recommendations for communication in product development in paragraph *6.6.1* (p. 139).

## 6.5 Feedback on the Lean PD VSD tools

This paragraph gives account on the feedback on the Lean PDVSD tool that are used in course 2.009 for the purposes of the study, and as outlined in chapter *5 Development of a Lean PD Value Stream Display* (p. 94).

### 6.5.1 Feedback on Paper-based Lean PDVSD

The tool is used throughout the whole study. Feedback on the used paper-based tool is obtained occasionally from the persons in charge of planning and supervising effort of their respective team.

All of the students agree, that using the paper-based version is

- Helpful for planning, as it shows interconnectivity of tasks better than a Gantt-chart.
- Useful as a reference for people working in the process.
- Deepens the understanding of resources and workload.

However, several issues are reported that limited the overall usefulness of the tool.

- Encoding in Excel-files is not practicable at all, and requires far too much work, especially for changes.
- Information carrier Excel-files is not sufficient; some students required gif-images as well.
- Representation is too static, especially for quick changes in plan.

As a result, the students in charge of making schedules do not encode them in the tool at all. Drawing value stream maps in this way (in Excel) is not deemed worth the effort. However, the students do welcome the help by the supervisor to provide these plans.

### 6.5.2 Feedback on Computer-based Lean PDVSD

The computer-based version is introduced to the students in the second half of the course with the intention to provide an easier to use planning and controlling tool. Initially, it was hoped that the students would use the tool without further help from the research conductor thereafter. In team *A*, however, the introduction of the tool to the other team members by the integration task fails, and is not referred to later. In team *B*, the tool is used for planning of just one week. In interviews, the responsible students are asked why the tool was not used to a greater extend.

On the positive side, both team members state concurringly that the general layout in boxes and arrows is reasonable and useful. However, several issues are of concern, which altogether led to the decision to not use it at all:

- Serious concerns about the security / rights management are expressed. The cause for this is the fear, that people might (unintentionally) change the plan or delete parts thereof. Adjustable user rights were proposed. These concerns are the main reason of not using the tool further.
- The interface is criticized, because it (a) makes changes is too difficult, (b) scrolling forth and back in the process window is annoying, and (c) finding data / tasks is not easy. An internal search engine is proposed and may help in respect to that issue.
- Different views are suggested. This embraces (a) a list of available resources / people at a given moment, (b) a re-categorizing in terms of people ("click on person and see where he/she is working at"), and (c) switching to Gantt-chart easily (in same tool)
- The need for a timeline is expressed.

Most of the issues were previously known. Nevertheless, the insight is valuable, because the team was unaware of the grave concern for security and rights management, as well as of the necessity for a re-categorization in terms of people.

## 6.6 Findings

The analysis of the data obtained throughout the study has brought several findings for information transfers in product development. They are discussed in more detailed in the respective paragraphs, and condensed to the following statements.

- Waste drivers differ greatly in frequency. It is thus not worth pursuing all of them at the beginning of lean efforts.
- The most frequent waste drivers are over-dissemination of information, deficient information quality, ineffective communication, over-processing, unclear responsibilities, information hunting and waiting for information. The lean PDVSD tool should thus focus primarily on these.
- Incomplete information transfers and inaccuracy (lack of refinement) are common problem for deficient information quality. To help preventing the common problem of incomplete information, the further development of the lean PDVSD should implement and test early practicable ways to ensure complete information transfers.
- Planning enhances the performance of information transfers for emails greatly. Unplanned meetings seem to perform very good as well, but the gathered data is very

scarce (only 4 cases of unplanned meetings could be observed). Spontaneous meetings thus need to be studied further.

- Information transfers in meetings show less waste drivers than in emails. However, the required movement for meetings may reduce this advantage.
- Emails are found to cause massive numbers of handoffs and slippage in schedule, if used for technical discussions and decision making.
- Generally spoken, when means of communication are used for occasions that are not favorable to their qualities, the occurrence of waste drivers rises considerably.
- Meetings are timely more often than emails, and the mean slippage in schedule is considerably less (in the research setting, half an hour in contrast to sixteen hours).
- The two observed teams appear to behave different in respect to information transfers. As the success (as indicated by grading) differs as well, it stands to reason that communication has an influence on process performance and ultimately success. Conclusions for future 2.009 teams are deduced (see paragraph below).
- Only a small fraction of all information transfers is valuable to the end user. In the research setting, this number is twelve percent. The theory behind waste and lean processes is thus applicable to information in product development. However, certain aspects of Lean Thinking have to be thought of carefully. Seemingly wasteful activities like information hunting and spontaneous meetings may be necessary due to the uniqueness of product development, wherein not every aspect and result is known in the planning phase and prior to actual work and results.

### 6.6.1 Recommendations for Communication in Product Development

Concluding from the previous paragraphs of analysis, the following recommendations can be made for future teams of course 2.009; the validity of the recommendations for general product development processes has still to be confirmed by future research. More communication is not generally better; instead the quality of information transfers matters. Information transfers should be planned, if possible. Whenever discussion is to be expected or emerges, the transfer should be facilitated through means with small feedback loops like meetings (for more than to communicators) or phone calls. Team members should be aware of the long feedback loops of emails, in contrast to meetings. In the case in mere handing over of information, and if the receiver has a close understanding and background, planned transfers by email cause much less movement and are thus to prefer. Waste drivers should be avoided by all team members, and attention in that respect should focus on over-dissemination of information, deficient information quality and ineffective communication. Responsibilities as well as goals and objectives have to be transparent to all team members. Timeliness of transfers is important. Despite the need for planning, unplanned information transfers that pull information should be encouraged. These transfers should, however, preferably be directed to responsible receivers only. Preliminary information transfers can enhance overall process performance only if they are used for better coordination in simultaneous processing, in contrast to sequential processing.

## 6.7 Conclusions for a Computer-Based Lean PDVSD

Findings and feedback suggest that the next step of development of the envisioned lean PDVSD tool should be focused on three aspects.

First, it has to be developed to a state that is usable and accepted as such by people responsible for planning. The major concerns security, views, interface ergonomics and the implementation of a timeline have to be addressed before further valuable insight of its use can be gained from deployment in other teams (and settings). If not implemented yet, interfaces with other planning tools must be smooth.

Second, the tool can and should initially focus on the gravest problems in product development information transfers. Planning has to be facilitated so that is easy to set up an initial plan as well as to change it if necessary. The representation must convey responsibilities and goals at a glance. By statement of informational needs for every task, over-dissemination may be reduced. It should be possible for users to state requirements on information quality.

Third, the tool should take into account the findings on information transfers and Lean Thinking for itself as well. If used for communication, feedback loops have to be as short as possible. The tool should not be a back-up solution, but rather a first reference.

Aside all possible planning and waste reduction, the tool is not a guarantee for efficient transfer and success. It serves a process best, if it motivates to transfer information efficiently and with less waste, and if process participants are convinced that the effort to maintain such a system pays off in terms of success of the process.

# 7 Outlook

This chapter can be understood as a collection of bridges across the boundaries of the thesis. The first paragraph takes a look on future research in related fields of lean product development, and provides ideas therefore (p. 141). The second paragraph (7.2 Development of PDVSD, p. 142) focuses on the future development of the lean PDVSD. Ultimately, in *7.3 Reflections*, p. 143 the author evaluates the project and thesis from a personal point of view.

## 7.1 Research

It would be very valuable for the analysis and conclusions discussed in *6.4 Analysis*, p. 110, to be able to verify or falsify them by means of a study in a different setting. Ideally, only one characteristic (like duration of project, level of education, number of team members, average distance between team members, importance of project, etc.) would be changed for a set of data, and as much settings as possible analyzed and findings thereupon gathered. Another, much more feasible way would be to study a completely different setting with, for example, highly skilled professionals, very small team sizes, co-location and industrial collaboration. It is believed that some problems (like over-dissemination of unstructured, unplanned emails) are persistent. If these persistent problems could be identified, generally applicable recommendations for product development processes could be deduced. Initially, this thesis was planned to encompass such a study as well, but due to the workload imposed by the sheer amount of data from course 2.009, as well as due to planning difficulties, it could not be conducted within the envisioned timeframe.

Lean product development has not yet a sound theoretical basis, as the comparison to integrated product development makes clear. Thus, further research is necessary to foster understanding, to clarify objectives, and to identify concrete improvement possibilities. Above all, the theories have to be put into practice, in order to evaluate their effect, limitations and possible flaws. As well, industrial circumstances may differ greatly from some of the proposed lean product development tenets, and in this case industry and research need to be engaged in an intense, reciprocal discussion.

In Prof. Seering's team at MIT, a wider perspective on value in product development processes is taken by other members. Of interest are the constraints for value stream displays in large scale (aerospace) projects as well as the question of value identification and maximization. Publications thereupon can be expected in 2005 and 2006 respectively.

## 7.2 Development of PDVSD

Both the paper-based and the computer-based lean PDVSD are still to premature to be used successfully in an industrial context. Several issues that have to be addressed before industrial introduction are pointed out in paragraph *6.7 Conclusions for a Computer-Based Lean PDVSD*, p. 140. Additional issues without reasoning from the study are presented in the following. To the author's belief, they are very important and have to be resolved and tested thoroughly.

Balance between the level of detail and the complexity of the model is required to foster widespread use and ease of introduction on one hand, yet usefulness on the other hand. This could be enabled, for example, through an architecture that is adaptive to the employed level of detail, and adjustable according to experience, complexity and other project specifications.

The difficulty of implementing a timeline is discussed briefly in paragraph *5.3.1.2 Timeline*, p. 97. The issue is restated herein, as it is believed – in concordance with feedback from the student group – to be of paramount importance. In OPPENHEIM [2004] and [SÖDERLUND 2002, p. 419], the reasoning takes different approaches, but conclude in similar statements. It is proposed hereby to evaluate the possibility of an adaptive, scalable timeline. Points in time would be represented in chronological order, as well as durations could be marked. But to assure interpretability, the timeline would be shortened automatically for sequences with few explicitly defined points in time, and enlarged for periods in time where many dates and times happen in short succession. Shortened and enlarged periods would coexist within the same document or rather view.

The computer-based application of the PDVSD elements offers the great opportunity to integrate the system with computer-based communication systems like email, instant messaging, voice-over-IP, and video conferencing. Moreover, existing product data management systems have similar elements. The vision is to establish interfaces from and to all of these tools, and eventually integrate all of them into a software based product development process representation that encompasses lean process representation, product data management, and communication systems.

For the acceptance of the tool in future, it is believed that its introduction to a product development environment has to be integrated in strategic planning efforts, as a study of the adoption of information and communication technologies (ICT) by SPANOS et al. [2002, p. 671] shows for all types of communication systems. The introduction of future test versions of the PDVSD will show both problems and good strategies. These problems and strategies need to be documented, analyzed and refined, so that they can help each subsequent introduction, to a point where guidelines can be established.

## 7.3 Reflections

This paragraph is a personal reflection on the work at MIT's Department of Mechanical Engineering. It is intended for the persons that facilitated, supervised and collaborated in the work, as well as for the author himself.

The organizational circumstances of the authors stay at MIT where found to be bipolar. On the positive side stand the quick and reliable help from Prof. Seering and the International Students Office, as well as the friendly and helpful advice from the department of product development at TUM. Difficulties arose from factors out of reach – visa constraints, immigration issues, and the complex and absurdly high requirements on financial resources. Very fortunately, the Lean Aerospace Initiative could help in that respect. The circumstances are not expected to improve over time, and thus future projects of German students at MIT will have to face them. It is strongly recommended to plan early and very meticulously, and with a great deal of individual initiative.

The work conditions were found to be very good and conducive. The proximity to other team members as well as to Prof. Seering has facilitated a vital exchange of ideas, and is deemed very valuable for the author's insight into the research. Moreover, it motivated to take a look into other approaches and fields of study. The rooms and their technical equipment are adequate, the libraries are vast and very well equipped, and ultimately the possibilities offered by the MIT community are endless.

In respect to the research content, the whole project was found to be very interesting indeed. First, the concepts of information and communication are so universal, that the insights are adaptable to a multitude of fields, even outside professional work and research. Second, as Lean Thinking takes an approach very distinct from the Integrated Product Development taught and pursued at TUM, the author was able to gain a lot of new insights. This, however, led to the necessity to sometimes "go the extra mile" in order to reach an appropriate understanding of tools and methods. For possible future students from TUM, it is recommended to start studying literature beforehand.

The scope of the thesis is considered to be too vast for the short amount of time. Even with an additional month of work, the sheer amount of data from the field study that had to be recorded for analysis rendered the last three months of the project a very work intensive time. To future students, it is recommended to restrict the scope early and rigorously, as content can later still be added. The restriction to 120 pages of content on behalf of TUM could not be met, as the thesis already contained more pages at the point in time it was realized by the author.

The supervision of the thesis was difficult. On the one hand, Prof. Seering at MIT did not have means to evaluate the research in accordance to TUM requirements. As the author had not conducted a diploma thesis before, he could not help much in that respect. On the other hand, the supervision by Dipl.-Ing. H. Stricker at TUM was difficult due to the absence of face-to-face communication, as well as due to the fact that the research content differed from work at TUM.

Both aspects will hold true for future projects, and thus it is advised to show flexibility, effort and certain independence.

The research culture at MIT is considered to be quite distinct from the one at TUM – it has a faster pace, demands a much higher personal effort, is closer to practice, and is much more intuitively. It took some time for the author to adapt, but the process and the insights gained thereof are considered to be very valuable.

Ultimately, in respect to personal gains, the whole stay at MIT is considered to be a very valuable project. The author had the possibility to improve his skills in English language, to learn and understand another culture, to visit a lot of interesting places, to enjoy a warm summer and a colorful autumn, and above all to meet a lot of people and gain them as friends.

# 8 Summary

Within this thesis, all aspects of information and communication under the perspective of lean product development are explored, discussed by literature review, and analyzed by a field study. As the thesis is embedded into the development of a lean value stream product development display, requirements for such a tool are gathered systematically alongside the theoretical discussion.

At the beginning, the focus of the thesis in the context of lean product development is justified. It is sought to understand which types of waste constitute the most frequent in information transfers, how means of communication and their use correlate with the occurrence of waste, and whether recommendations can be made for communication in product development.

Different definitions of the term information are discussed, and a multi-dimensional concept is deduced thereupon that facilitates discussion for the development of the PDVSD tool across professions. The concept of an information carrier is introduced, which helps to understand the interdependency of representation and physical structure. Different information qualities are discussed, which results in many requirements for the lean PDVSD. Generation and flow of information are discussed. Facilitating the flow of information emerges as pivotal to lean product development; insight into problems and limitations is gained. Concluding, information is juxtaposed with the concept of value and waste. Strategies to improve value creation are presented. Different types of waste are adapted to information, which constitutes a basis for the field study. Ultimately, limitations of the concept of value are discussed; it emerges as difficult to identify value and waste unerringly in product development.

The discussion of communication in product development is restricted to the understanding of information transfers across tasks. Under the lean perspective, media and means of communication are discussed. The question of feedback loops emerges as important to short development cycles, and is considered worth further investigation in the field study.

Very briefly, value stream mapping in general, and the development of the PDVSD in specific are described. The considerations thereupon explain a paper-based, preliminary version of a PDVSD tool that is used in the field study to plan, map, and analyze information flows in product development.

A field study of information transfers in a student course for product development is conducted, in order to connect theory with practical insight. Over-dissemination of information, deficient information quality, and ineffective communication are identified as the most frequent waste drivers. Planning information transfers is found to enhance the performance of transfers. Communication by emails, in contrast to meetings, is found to correlate with slippage in schedule. The average duration for feedback loops in emails is found to be nearly three hours. Recommendations for communication in lean product development are made. For the further development of the lean PDVSD, the field study and student feedback suggest to focus on user right management, a timeline and ergonomics.

# 9 Appendix

The appendix to this thesis contains a Glossary (p. 147), a list of figures (p. 149), a list of tables (p. 150), literature references (p. 151) and a list of attachments (p. 156).

## 9.1 Glossary of Used Terminology

The most important terms used in the thesis are presented below in a compact overview. This paragraph is meant to serve as a reference for this thesis, and points to chapters which discuss the terms in more detail.

**Means of Communication**

Means of communication are understood as “tools” of communication, which actually transfer one or more media. Examples for means of communication are phone calls, meetings and emails. For further discussion, see *3.4 Means of Communication*, p. 86.

**Medium**

A medium is defined as physical containers for information carriers. This thesis, for example, is an example for the medium “document”, and contains many information carriers like text, tables and figures. For further discussion, see *3.3 Media in Communication*, p. 84.

**Information**

The term information has far too many co-notations of importance to the thesis as to define it in a short sentence. To avoid misinterpretations, the term is specified throughout the thesis (see below); yet for the sake of readability a default definition is used, which is “informational unit in form of encoded knowledge, produced intentionally by a person for a person”. In *Chapter 2.1 Definition of Information* (p. 18), all below mentioned aspects are discussed in great detail.

Two aspects help to specify the focus:

- *View on information* as the perspective under which a given piece of information is analyzed. For lean product development, the most important view is information in processes (e.g., a message). Other views in product development are product view and tool view information.
- *Derivation of information* as classification of the structure of information. Any information is build upon signs and data, and can be used to generate knowledge. In

common tongue, data, information and knowledge (of process view information) are seldom distinguished.

Once the focus is clarified, other terms are helpful to characterize a given piece of information further; the most important are:

- *Type of information* as the intent of information. Process type information is, generally spoken, information that facilitates processes. In product development, a common example is a schedule. Content type information, on the other hand, is the information embedded within process type information and, in product development, generally the reason for the process to exist.
- *Carrier of information* is the physical structure of a given piece of information. It serves the technical functions of storage, transport and display. Intertwined with the physical structure is the representation of information; i.e. which representation is possible with a given carrier.

**Information Transfer**

An information transfer is the exchange of content and/or process type information from the process perspective. Wherever information is generated for others, information transfers are necessary. Information transfers make use of a means of communication, and consume resources (e.g., time). Information transfers can be planned, and often encompass more than one type of information. They can exchange more than one piece of information (see below). Information transfers can be wasteful by themselves, and if inappropriate, additionally affect the quality of the transferred information.

**Piece of Information**

A piece of information is the information itself, from the process view. It is generated, sent and received intentionally. It serves a purpose, and needs one or more carriers and media (e.g., text and figures in a print-out document like this thesis) in order to be physically represented.

## 9.2 List of Figures

## 9.3 List of Tables

## 9.4 References

AHMED, S.; BLESSING, L.; WALLACE, K.
The relationship between data, information and knowledge based on a preliminary study of engineering designers
Las Vegas, NV: Proceedings of the ASME Design Theory and Methodology Conference (1999)

ALLEN, T. J.
Managing the flow of technology: technology transfer and the dissemination of technological information within the R&D organization ($2^{nd}$ edition)
Cambridge, MA: MIT Press (1984)

BICHENO, J.
The Lean Toolbox
Buckingham: PICSIE Books (2000)

BICHLMAIER, C.
Methoden zur flexiblen Gestaltung von Entwicklungsprozessen
München: Lehrstuhl für Produktentwicklung, Dissertation (1999)

BAUCH, C.
Lean Product Development enabling display: Making Waste Transparent
Munich: Technical University of Munich, diploma thesis (2004)

CHASE, J. P.
Value Creation in the Product Development Process
Cambridge, MA: Massachusetts Institute of Technology, Department of Aeronautics and Astronautics, master thesis (2001)

CLARK, K.; FUJIMOTO, T.
Product Development Performance: Strategy, Organization, and Management in the World Auto Industry
Boston, MA: Harvard Business School Press (1991)

EHRLENSPIEL, K.
Integrierte Produktentwicklung
München: Hanser (2002)

ELLIOT, A.C.; SWAIN, E.; WRIGHT, I.C.
Managing product development resources through the use of product quality mapping
Proceedings of the Institute for Mechanical Engineers 217 (2003), pp. 1229-1241

EPPINGER, STEVEN D.; ULRICH, KARL T.
Product Design and Development
New York, NY: McGraw-Hill (1995)

FISCHER, L.; WISWEDE, G.
Kommunikation und Medienwirkung. In: Grundlagen der Sozialpsychologie
München: Oldenbourg (1997)

HERKNER, W.
Lehrbuch Sozialpsychologie
Bern: Huber (1991)

IRLINGER, R.
Methoden und Werkzeuge zur nachvollziehbaren Dokumentation in der Produktentwicklung
Aachen: Shaker (1999)

KLUWE, R.H.
Gedächtnis und Wissen. In: Lehrbuch Allgemeine Psychologie (2. Auflage). Spada, H. (Herausgeber)
Bern: Huber (1992)

LEAN AEROSPACE INITIATIVE
Website
http://lean.mit.edu/

LINDEMANN, UDO
Methoden der Produktentwicklung, Umdruck zur Vorlesung
München: Lehrstuhl für Produktentwicklung, TUM (2001)

LINDEMANN, UDO
Methodische Entwicklung technischer Produkte
Berlin: Springer (2005)

MCMANARRA, D.S.
Website
http://csep.psyc.memphis.edu/cohmetrix/readabilityresearch.htm
Memphis, TN: University of Memphis, Department of Psychology (2004)

McManus, H. L.
Outputs of the Summer 1999 Workshop on Flow and Pull in Product Development
The Lean Aerospace Initiative Working Paper Series WP00-01, January
Cambridge, MA: Lean Aerospace Initiative (2000)

McManus, H. L.
Product Development Value Stream Analysis and Mapping Manual (PDVSM) - Beta Draft
Cambridge, MA: Lean Aerospace Initiative (2004)

McManus, H. L.; Millard, R. L.
Value Stream Analysis and Mapping for Product Development, In: ICAS Congress 2002
Cambridge, MA: Massachusetts Institute of Technology (2002)

Millard, R. L.
Value Stream Analysis and Mapping for Product Development
Cambridge, MA: Massachusetts Institute of Technology, Department of Aeronautics and Astronautics, master thesis (2001)

MIT Course 2.009 - Product Engineering Processes
Website
http://web.mit.edu/2.009

Morgan, J. M.
High Performance Product Development: A Systems approach to a Lean Product Development Process
Michigan, MI: University of Michigan, doctoral thesis (2002)

Oppenheim, B. W.
Lean Product Development Flow
Systems Engineering 7 (2004) 4, pp. 352-376

Pahl, G.; Beitz, W.
Engineering Design: A Systematic Approach
Translated by Ken Wallace, Luciënne Blessing and Frank Bauert
Springer: London (1996)

Peters, G. A.
Technical communication: assessment of how technical information is communicated
Technology, Law and Insurance 2 (1997) 4, pp. 187-190

Reinertsen, D.G.
Managing the Design Factory
Munich: Hanser (1998)

RÖMER, A.; PACHE, M.; WEIßHAHN, G.; LINDEMANN, U.; HACKER, W.
Effort-saving product representations in design—results of a questionnaire survey
Design Studies 22 (2001) 6, pp. 473-491

ROTHER, M.; SHOOK, J.
Learning to See. Value Stream Mapping to add value and eliminate muda.
Brookline: The Lean Enterprise Institute (1999)

ROTHERY, B.
ISO 9000, 2nd Edition
Gower Press: Aldershot, Hampshire (1993)

SCHULMEISTER, R.
Grundlagen hypermedialer Lernsysteme (2nd Edition)
München: Oldenbourg (1997)

SCHWANKL, L.
Analyse und Dokumentation in den frühen Phasen der Produktenwicklung
München: Technische Universität München, Dissertation (2002)

SHOOK, J.; ROTHER, M.
Learning to See. Value Stream Mapping to add value and eliminate muda.
Brookline, MA: The Lean Enterprise Institute (1999)

SLACK, R. A.
The Application of Lean Principles to the Military Aerospace Product Development Process
Cambridge, MA: Massachusetts Institute of Technology, master thesis (1999)

SPANOS, Y. E.; PRASTACOS, G. P.; POULYMENAKOU, A.
The relationship between information and communication technologies adoption and management
Information & Management 39 (2002), pp. 659-675

SÖDERLUND, J.
Managing complex development projects: arenas, knowledge processes and time
R&D Management 32 (2002) 5, pp. 419-430

SPEAR, S.; BOWEN, K.
Decoding the DNA of the Toyota Production System
Harvard Business Review (1999) September, pp. 95-106

STRONG, D. M.; LEE, Y. W.; WANG, R. Y.
10 Potholes in the Road to Information Quality
Computer 30 (1997) 8, pp. 38-46

THOMAS, A.
Grundriss der Sozialpsychologie, Teil 1: Grundlegende Begriffe und Prozesse
Göttingen: Hogrefe (1991)

TOMAS M.; HULT, G.
An Integration on Thoughts on Knowledge Management
Decision Sciences 34 (2003) 2, pp. 189-195

WHEELWRIGHT, S.; CLARK, K.
Revolutionizing Product Development. Quantum Leaps in Speed, Efficiency, and Quality
New York, NY: The Free Press (1992)

WIKIPEDIA
Website
http://de.wikipedia.org/wiki/Information (2004a) (German)
http://de.wikipedia.org/wiki/Watzlawick (2004b) (German)

WÖGERBAUER, H.
Die Technik des Konstruierens, 2. Auflage
München: Oldenbourg (1943)

WOMACK, J.P.; JONES, D.T.; ROOS, D
The Machine that changed the world. The Story of Lean Production
New York, NY: Harper Perennial (1991)

WOMACK, J.P., JONES, D.T.
Lean Thinking. Banish Waste and create wealth in your corporation. 2$^{nd}$ Edition.
London: Simon & Schuster (2003)

ZUMPE, S.; ESSWEIN, W.
Simplification of Knowledge Discovery using "Structure Classification"
In: Classification, automation and new media: University of Passau, March 15-17, 2000. Gaul, W.; Ritter, G. (eds.)
Berlin: Springer (2002)

## 9.5 List of Attachments

1 – List of Requirements for a Lean Product Development Value Stream Display

2 – Ineffective Communication (Example)

3 – Example of PDVSD (paper-based)

4 – Executive Summary