UNDERSTANDING COLLABORATIVE DESIGN

Understanding Collaborative Design
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Proefschrift Technische Universiteit Delft.- met lit. opg.
Met samenvatting in het Nederlands.
ISBN 90-9020974-3
Trefw.: collaborative design , design communication, case studies

Printed by JB&A grafische communicatie, Wateringen, the Netherlands

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Proefschrift

ter verkrijging van de graad van doctor
aan de Technische Universiteit Delft
op gezag van de Rector Magnificus prof. dr. ir. J.T. Fokkema,
voorzitter van het College voor Promoties,
in het openbaar te verdedigen op dinsdag 5 september 2006 om 12:30 uur
door Maaike Susanne KLEINSMANN
ingenieur industrieel ontwerpen
geboren te Oldenzaal.

Dit proefschrift is goedgekeurd door de promotor:
Prof. dr. ir. J.A. Buijs

Samenstelling promotiecommissie:

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Dr. ir. A.C. Valkenburg heeft als begeleider in belangrijke mate aan de totstandkoming van dit proefschrift bijgedragen.

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THANK YOU!

Although writing a thesis sometimes seems a lonely journey, I would not have succeeded by my own! Therefore, I would like to thank all people that supported me.

First of all, I would like to thank Jan Buijs and Rianne Valkenburg. I think this research project is a best practice of a well-functioning collaborative team. Of course I have done the research, but you were always there to support me and to help me elaborating my ideas. The discussions with the three of us have always been constructive and fruitful. Afterwards, I was full of thoughts about how to continue. Jan, I really appreciate the time that you took for discussing the experiences I had during my case study research. During these discussions, you have made me even more enthusiastic about my research project. Rianne, you often help me structuring my thoughts, by asking the right questions! You are always concerned with both my research project and my private life. I really value that. Last but not least, I think we have had a lot of fun together, during our travels, drinks and dinners. This was also very important for me! Thx Jan en Rianne!

Without the support of many company people this thesis would not have been completed. I would like to thank all participants of my two case studies. In special, I would like to thank the product champions of the two cases: Hans Staals, Rob Briggen, Hans Zonneveld, Hans Hellendoorn, Bram Nikolai and Rene Prins. Proposition number 7 is definitely not applicable to you!

I also would like to thank my paranymfs Nicole van Leeuwen and Erik Veldhuizen. Nicole, I know you quite a long time, both as a good friend and as a colleague. You were the direct instigator of me becoming a student assistant of Jan and Rianne. We have done so many things together that I do not know what to mention. I just want to say that I am happy that you want to be my paranymf. Erik, it has been quite valuable to have a roommate who was in the same stage of writing a thesis. The saying "sharing troubles is a trouble halved" has often been applicable for us. After a day of hard work, it was always good to play squash together. I really hope that we will continue this for a long time!

There were many other colleagues in the faculty of Industrial Design Engineering that were supportive and collegial during my Ph.D. project. I think the climate in the faculty is quite good! I would like to thank my (former) colleagues of PIM for their collegiality and friendship. I especially want to name Sandra. Sandra, you are always helpful, patient and provide me with moral support when I need it. Thank you for everything you have done for me. I also would like to thank my colleagues of the design courses 1 and 3. Having other activities besides my Ph.D. project has always been a good way of keeping my mind open.

There are also a lot of people that have helped me in various practical ways. Inga, you really have helped me a lot with the IPO course! I am proud of you that you have dared to give the feed back lectures. You really did a good job! Becky, I am grateful that have done all the English corrections. I admire your patience and accuracy. I also want to thank, Remko, Dennis, Linda, Paulien, Veronie, Fleur, Hester, Marjolein and Inga for doing the research projects

together which finally have resulted a nice design game! Agnes, thank you for the many times that you helped us during our experiments.
Corrie, I would like to thank you for the good advices that you gave me for editing my book.

Although the quality time with my fiends and family has been less than normal this year, they have been the ones that reminded me that work is not the only thing in life. Dear friends you are very important for me. Thank you for helping me and supporting me one way or the other! I especially want to thank Barbara and Wanda for all the support and love they have given me. Bar and Wan, I am always looking forward to our diners, visits to the sauna and hours of shopping. Although our busy schedules, long distances and changing lives, we always find time for doing nice things together. We will definitely continue this in the future! Ester, I also owe you a special thank-you! I am very grateful to have a good friend for such a long time already. I know you are always there for me and the opposite also counts.
Mom and dad, I thank you very much for all the love, interest and support you have given me during my Ph.D. project and the time foregoing. I know that you are proud of me and I am proud of you too! Martijn, my dear brother, the geographical distance between is us huge, but we both know that we are strongly connected to each other. It means a lot to me that you, Lely and Kylie will be there during my defense. I am sure that we will have a great time! Also my other part of the family is important to me. Annie, Theo, Bastiaan, Noortje, Marjon and Dave, thank you for all the love, support and interest you have given me!
Koen you’re the last one, but you know the last ones will be the first. Thank you for all your patience, support and lots of love. You’re the one! I love you.

Maaike Kleinsmann

TEAM DESIGN IN PRACTICE 1

Introduction 1.1

An increasing competitive environment forces companies to decrease the time to market and to expand product functionality. Consider for example a telephone. From the 1940's until the 1990's, a phone did not change radically concerning product functionality and product architecture (Valkenburg, 2000, Figure 1, p. 19). However, in the last fifteen years the product has changed in many ways. The switch from a house phone to a personal phone has had a big impact on product appearance and product use. In the last few years, the product has changed a number of times. Nowadays people do not only use their phone for calling, but also for taking pictures, making movies, playing games, listening to music and as an agenda. This has changed the attitude towards the product *phone*. What once was a rather functional product has now become a product which expresses one's personality. Therefore, customers want their phone to be modern, easy to use and of a good quality. In the meantime, they do not want it to be expensive, since they like to buy a new one every two years.

For companies, these fast product follow-ups and the increasing customer demands have had a big impact on their product development processes.

These factors forced the development time to shorten and they increased the need for specific knowledge. Granstrand *et al.* (1992) found that the first generation of cellular phones in the 1980's required only electrical technical skills (looking only from an engineering point of view). In the 1990's the third generation of these phones called for knowledge about physical-, electronical-, mechanical-, computer engineering-, as well as, physiological- and psychological- aspects. In the last ten years, the functionality needed for developing today's mobile phone has increased yet again.
These developments shifted the product design process from an individual and rather unorganized activity to a systematic activity performed in a multidisciplinary team (Valkenburg, 2000), (Hoegl *et al.*, 2004). Buijs and Valkenburg (2005) called this way of organizing product development integrated product design.
Well-performed integrated product design processes may result in higher speed to the market, higher quality products that fit the market needs and the possibility of developing products with different functionalities (Griffin, 1993), (McDonough III, 1993), (Cooper and Kleinschmidt, 1994), (Langerak, *et al.*, 2005).

For companies, integrated product development compromises both organizational as well as collaborative aspects (Buijs and Valkenburg, 2005). In order to be able to organize product design processes, companies often use rational problem-solving methods, such as Stage Gate™ models (Cooper, 1988). An example of a Stage Gate model is the Delft Innovation Model (DIM) shown in Figure 1.1 (Buijs and Valkenburg, 2005). The DIM divides the product development process in five phases and separates these phases with an evaluation step, which forms the gate. During evaluation, actors in the product design project decide if the project progress and product quality are sufficient. If so they pass the gate. If these factors are not found to be sufficient, then the design team has to make an iterative loop. The end of one complete product design cycle forms the input for a new one by evaluating product use.

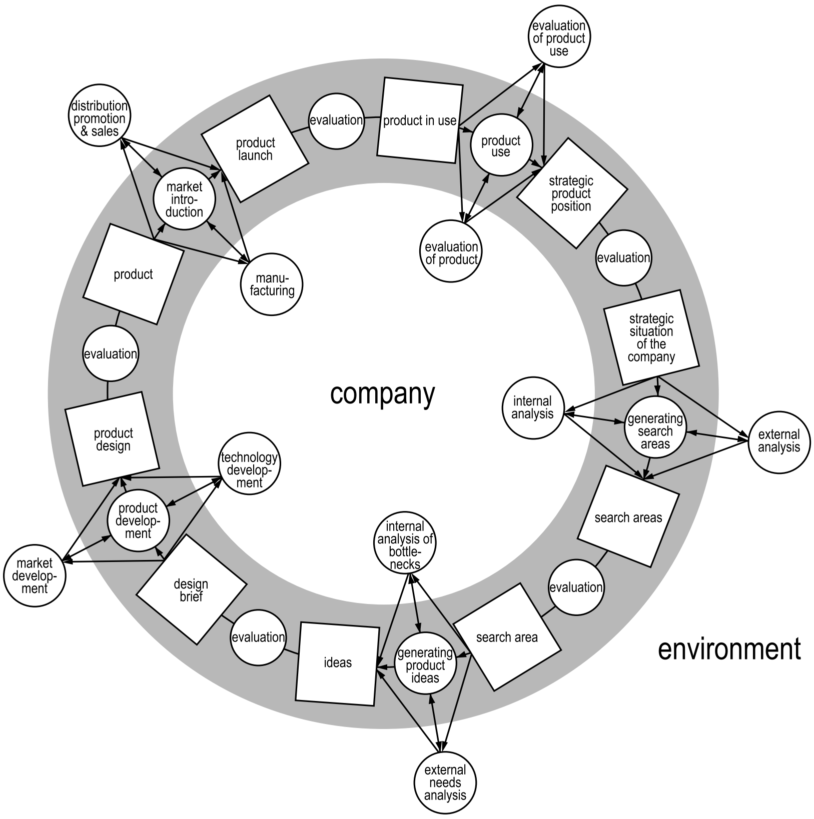


Figure 1.1
Delft
Innovation Model
(Buijs and Valkenburg, 2005, p. 391)

Stage Gate models provide clear process steps and help a Project Manager to survey which activities the team should undertake at different stages in the design project. They are also helpful for indicating and making visible task dependencies between the actors. Project Managers can use Stage Gate models for project monitoring, project control and project coordination.

However, the rationality behind Stage Gate models implies an undisturbed flow of activities. Yet, in practice we see that this is not usually the case. Actors who act in a product design process have their own knowledge, operating procedures and methods for executing their part of the design process (Buijs and Valkenburg, 2005). They are dependent on each other's process outcomes and they need each other's knowledge for fulfilling their own tasks. For a Project Manager it is a challenge to structure these different processes and to bring the outcomes into coherence. By only using methods such as Stage Gate models, a Project Manager will not succeed in managing this process. As a manager said in an interview (this quote is translated from Dutch to English):

"…There is no problem that cannot be solved technically. At least I have never experienced that personally. Finally, they solve it always. They use project management tools to map the problem and to find the solution. However, the problem is the communication between the teams. Did they understand each other and are they critical enough to each other? …" (Project Manager, Philips, 2004).

This manager explained that effective communication between the actors from different sub teams is difficult. The next example, based on a situation in practice, illustrates why this is a problem:

An Electrical Engineer got an assignment to design a circuit board for a digital handheld device. In the list of specifications, he saw the maximum amount of space he could use for the circuit board. From his experience, he knew that he was not able to put all of the components he needed in that space. The Project Leader told him that the Ergonomic came up with this specification as a result of user requirements. The Electrical Engineer asked the Ergonomic if he could change this requirement. The Ergonomic told him that this was the maximum amount of space the Electrical Engineer could use. The Ergonomic explained himself with theories of movements of the human body. He also used tables with measurements of the human body and pictures about the structure of human joints. Although the Ergonomic tried to explain his point of view clearly, the Electrical Engineer did not understand. By using drawings of circuit boards and mathematical formulas, the Electrical Engineer tried to explain to the Ergonomic the impossibility of getting all the functionality into such a small space. The Ergonomic did not understand what the Electrical Engineer was talking about. They ended the discussion with the knowledge that there was a space problem. Yet, they were not able to negotiate with one another in a productive way in order to solve the problem.

Both actors had good arguments from their professional point of view. However, they were not able to create a shared understanding during their conversation. They used different representations of the design, which only further complicated collaboration. In addition they each had different responsibilities. The Electrical Engineer had to make the hand-held device work technically and the Ergonomic needed to make an easy to use product. The interests of both actors were in conflict and they lacked a shared understanding of which design factors were most important (Ramesh and Tiwana, 1999), (Kleinsmann and Valkenburg, 2005).

This is not only the case between an Electrical Engineer and an Ergonomic, but between all team members of a multidisciplinary team, as Figure 1.2 shows. Due to their different disciplines, all actors in the multidisciplinary design team have a different view of the new product to be developed and they each address their own interests during negotiation (Bucciarelli, 1996). This hampers effective collaboration.

The actors differ in both the ways in which they view the design and in how they communicate about the design they are making. Design communication is often jargon laden and therefore difficult to understand for outsiders. It is

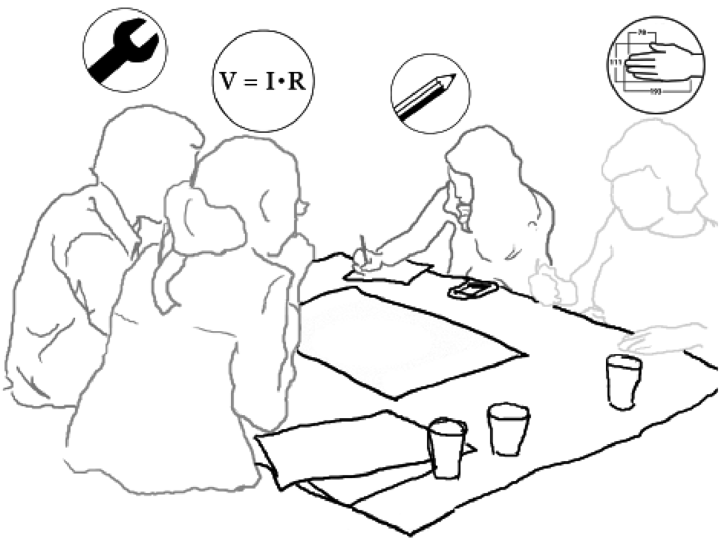
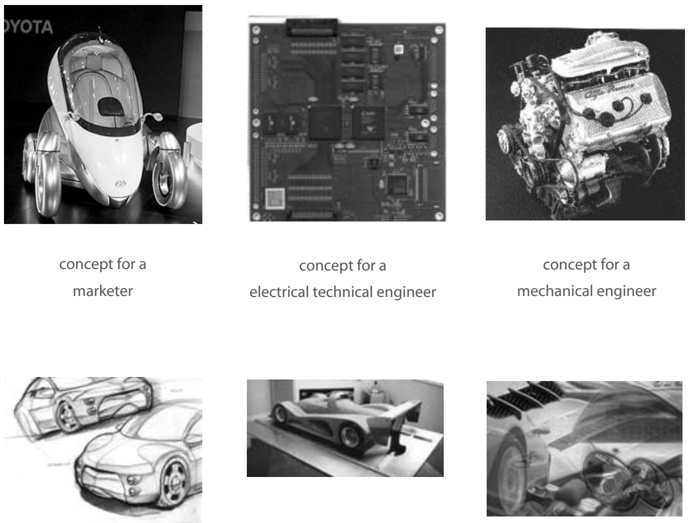


Figure 1.2
Actors with different viewpoints

different from speaking a foreign language, since the actors are familiar with the words. Even so, the meaning of the same words may differ when used by actors from different disciplines. An example of a word with many meanings is the word *concept*. Figure 1.3 shows what actors from different disciplines see as the meaning of the word concept.



concept for a marketer

concept for a electrical technical engineer

concept for a mechanical engineer

concept for a stylist

concept for a model maker

concept for a marketresearcher

Figure 1.3 Different meanings of the word concept for different specialists

These representations of the word concept differ greatly. During design communication, these differences have consequences for tuning processes between the actors, for appointments about which tasks they have to do, for the view actors have of the status of the project etc, etc. Actors in a multidisciplinary design team communicate on different tones about the design they are making, in correspondence with their different disciplines and accompanying design tasks. Consequently, for actors it is difficult to create shared understanding about the design content. This hampers collaboration. In an interview, a Project Manager gave the following answer to the question about how capable actors from different disciplines are for communicating about interdependent tasks (this quote is translated from Dutch to English):

"…Dependent from their discipline, they have a feeling for each other's discipline, but the real details… It is complex to be able to know from every discipline all parts. As a Project Manager, you really have to be aware of this. That is also the reason why I need something to monitor that…" (Project Manager, Philips, 2004).

This citation demonstrates that no suitable tools exist for helping Project Managers to cope with this problem.

This section has shown that design projects consist of an organizational and a collaborative part. In both literature and practice the organizational part of integrated product design is further developed, than the collaborative part. Project Managers and team members in practice face collaboration problems during their product design projects. These two aspects make that the focus of this thesis is on creating a better understanding of collaborative aspects in design projects. In order to have a frame of reference on which this thesis is based, the next sections describe:

- the characteristics of a integrated design process
- the organization of multidisciplinary design teams in industry
- the research background of this thesis

This chapter ends with the research objective and an overview of the remainder of this thesis.

Characteristics of the integrated product design process 1.2

In order to show what kind of processes this thesis focuses on, this section shows the main characteristics of the integrated product design process. It first describes the characteristics of the design problem. Second, it describes the way actors of different disciplines are involved in the different stages of the design process. Finally, this section portrays the nature of the different phases of the design process.

An integrated product development task involves solving a design problem. Design problems are a special type of problems and have the following characteristics (adopted from (Dorst, 2003), (D'astous et al. 2004), (Restrepo, 2004, p. 8-10)):

- Design problems tend to be large and complex.
- Design problems have both logical and creative components.
- Design problems are wicked.
- Actors search for a solution of the design problem within a certain solution space. This solution space is undetermined and the available information is incomplete, since project specifications are never complete or without ambiguity. Design problems are therefore ill defined and/or ill structured.
- During design processes, actors iterate between design problem and its solution.
- Design problems are open ended. It is often not clear when actors have solved the design problem. There is also not one best solution for solving the design problem.

These characteristics make the design process a complex process of simultaneously problem solving, problem setting and tuning between the actors. Iterations occur, as a result of unexpected outcomes of a subtask and changing environments or specifications. These iterations are inextricable linked to designing. Both the complexity and uncertainty of design problems cause that collaboration is an important aspect of design projects.

Most decisions concerning the design of the new product are taken in the first phase of the design process, but they have an impact on situations in later phases. Therefore, collaboration between disciplines is a continuous process. During integrated product design, ideally all disciplines are involved in the design process from the beginning until the end. In the beginning, of course, more actors from Marketing are involved and in the end more actors from

Production. This is illustrated by Figure 1.4. The different tones of the actors represent their discipline and the three different tables represent different phases of the design process. (Different disciplines, such as, Market research, Sales and Quality Control can also be involved in the team.)

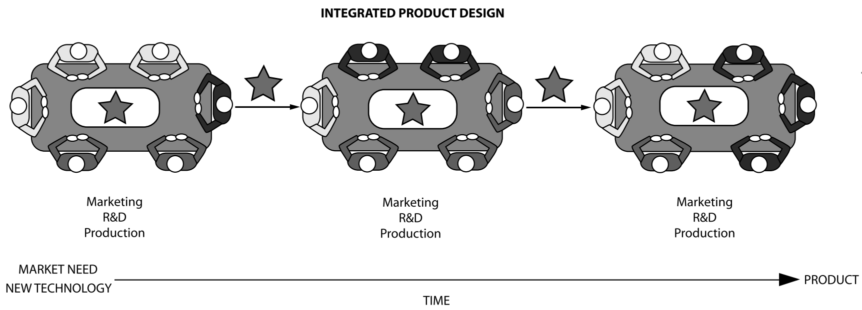


Figure 1.4
The collaborative design process

The phases of the integrated product design process do not have the same characteristics. The phases are different from each other. Rather, the characteristics evolve throughout the different stages. The beginning of the process (fuzzy font end) is uncertain, actors have much freedom and creativity is most important. During the later phases, the process becomes more certain, more fixed and progress becomes important. In the primary stages, actors must make creative decisions about the design they are making in order to reduce uncertainty and narrow the solution space. This requires tuning between the actors. A qualitative good problem setting process in the fuzzy font end helps for the project progress later in the project. Therefore, collaboration is most important in these early phases (Chiu, 2002).

Organization of multidisciplinary design teams in industry 1.3

Actors performing a design task are embedded in an organization; the company. In this section, we will show how actors that perform a design task are embedded in this organization.

Companies can structure their design projects purely functional, as a project matrix or as an autonomous team. In a functional structure the actors are grouped by disciplines and the design project is divided into phases. Each phase is assigned to a different discipline. In a project matrix the project structure is integrated with a functional structure. The actors report to both the project- as well as their functional manager. In an autonomous team actors from different functional areas are formally put together in a team. The actors leave often physically their functional locations and move to a shared location. The autonomous team has a Project Leader. The functional managers do not have a formal involvement in the team (Ottum and Moore, 1997). These different structures influence the knowledge sharing and information sharing between the actors. Research showed that a functional structure is less successful for collaboration as an autonomous team (Ottum and Moore, 1997).

Companies often cannot organize their product design projects as single team projects because new product design has become too large and too complex (D'Astous *et al*., 2004), (Hoegl *et al*., 2004). Instead, companies use collaborating (multidisciplinary) teams.

The teams are hierarchically organized and coordination takes place through overlapping membership (Gerwin and Moffat, 1997). Figure 1.5 illustrates the structure of a collaborating cross-functional team. The boxes in the figure represent the different sub teams. The lines between the boxes mean there are representatives from the lower positioned box present in the box above. Actors in the *Car team* come from different functional areas. Each team member of the *Car team* is responsible for a certain part of the development process and is Project Manager of a sub team lower in the organizational chart, such as the *Engine Team.* The structure of collaborating teams often relates to the product architecture (Gerwin and Moffat, 1997), (Chiu, 2002). For example, actors who develop an engine for a new car often come from the Engine Department. Sub teams high in the organizational chart have the most management tasks. (The left arrow in Figure 1.5 shows this.) They are

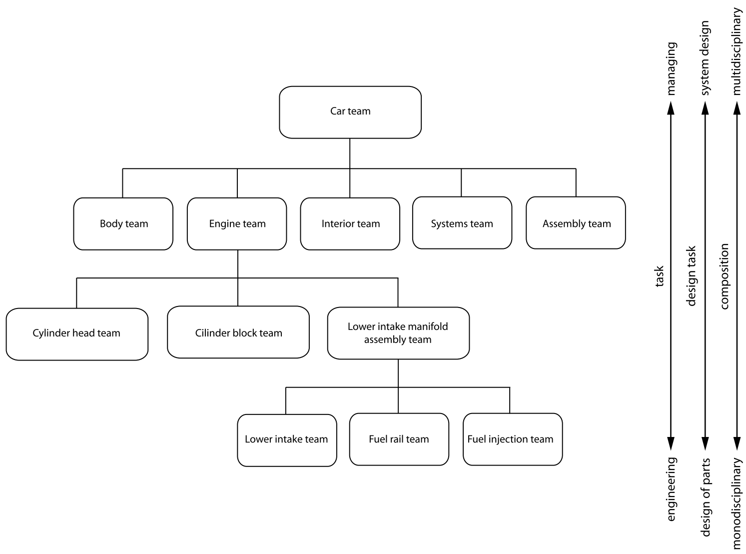


Figure 1.5
Hierarchical structure of a design team for the development of a car (based on Gerwin and Moffat, 1997, Fig1)

also responsible for the integration of the different parts (system design). Due to the fact that the team consists of representatives from other sub teams, these teams are multidisciplinary in nature. Sub teams below in the organizational chart are concerned with engineering the different parts. (The middle arrow in Figure 1.5 shows this.) They have specific design tasks and are therefore more mono disciplinary in nature. (The right arrow in Figure 1.5 shows this.)

D'Astous *et al.* characterized this way of organizing team design as cycles of distributed design combined with collaborative design phases. In distributed design actors have their own task and in collaborative design actors have a common goal (D'Astous *et al.*, 2004).

The alternation between distributed design and collaborative design occur on different levels, between the sub teams and within the sub teams.

In addition to the organizational structure on a company level, a sub team also has its internal structure in which the actors perform their actual design task. In her thesis, Valkenburg adopted the definition of Katzenbach and Smith (Valkenburg, 2000, p. 25). They defined a team as:

"… A team is a small number of people with complementary skills who are committed to a common purpose, performance goals and approach for which they hold themselves mutually accountable…"(Katzenbach and Smith, 1993, p. 45).

This definition can also be used for describing the internal structure of a sub team performing a design task in practice. This is partially shown in Figure 1.6. Around the table of Figure 1.6, six actors with different skills are situated. The different tones of the actors represent their skills. Actors can be complementary in the functional area they work in, (sub teams higher in the organizational chart of Figure 1.5), in experience, in responsibilities (managing vs. engineering) etc.

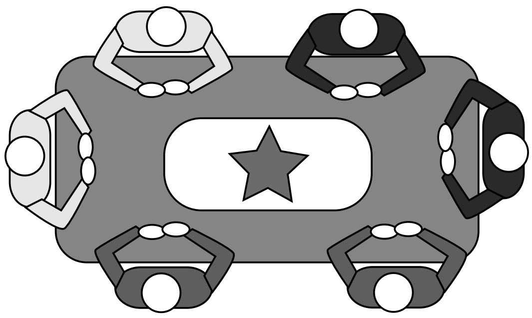


Figure 1.6
Actors in a multidisciplinary design team

In all sub teams actors are committed to a common purpose; (a part of) the new product. The star on the table in Figure 1.6 symbolizes this common purpose.

In the literature there are different names for this type of design teams. Some authors name these design teams *multidisciplinary design teams* (E.g. Finger *et al.*, 1996, Denton, 1997, Chao *et al.*, 2002), while others prefer the term *cross-functional design team* (E.g. Henke *et al.*, 1993, Griffin and Hauser, 1996 and Hoegl and Gemuenden, 2001). Both terms refer to the difference in background of the actors. Actors use the term *multidisciplinary* if they do not take into account the origin of the actors within an organization. Authors use the term *cross-functional* if they do take into account the original function that actors have within an organization. The term cross-functional shows that actors of the design team originally come from different functional areas (or departments) within the company. They are executing a design task in a design team temporarily. Since the focus of this thesis is on collaboration within design teams, we will use the term multidisciplinary team in the remainder of this thesis.

In their definition a team, Katzenbach and Smith (1993) also used the terms *mutual performance goals and approach*. The main performance goal and project approach on an abstract level are mutual among the team members. After all, actors within a sub team have to design a (part of a) new product with sufficient quality and the main project steps are the same for all actors (e.g. they all follow the same Stage Gate model). However, looking on a more micro level, actors have different interests and responsibilities because of their different design tasks. Actors also have different project approaches while performing their tasks. This will influence their collaboration process.

Research background of this thesis 1.4

This PhD research project was executed within the department of Product Innovation Management (PIM) at the Faculty of Industrial Design Engineering (IDE) at Delft University of Technology (DUT). In order to show the field in which this research project is executed, we describe in this section what the faculty of IDE at DUT means by the profession Industrial Design Engineering. We will do that by shortly describing the curriculum of this faculty. Furthermore we describe two earlier research projects of the department PIM.

The mission of the faculty IDE is summarized in the slogan *Creating successful products that people love to use*. This mission represents the profile of the profession of an Industrial Design Engineer educated at DUT. The profile can be divided in two parts: the development of products and the process of product development (Oppedijk van Veen *et al.*, 2001, p.19). The products that are developed at IDE at DUT have to fulfil multidisciplinary requirements. Therefore, our curriculum exists of courses in the following fields (Oppedijk van Veen *et al.*, 2001, p. 20):

- Engineering (as related to mechanical- and electronic engineering)
- Management of innovation (as related to management and marketing sciences)
- Design/formgiving (as related to aesthetics, form semantics, design history, perception, emotion and tactility)
- Ergonomics (as related to human engineering, including physical, sensory and cognitive aspects)
- Sustainability (as related to eco-efficiency of end-life systems, eco-design methodology and eco-efficient services and system design)

These courses lead to graduates with the following profile (Oppedijk van Veen *et al.*, 2001, p.20):

"*The MSc in IDE is a product developer who is a designer, a technologist, a marketer and is capable of doing research in the field and disciplines of IDE. The Industrial Design Engineer is expected to develop products that have the capability to satisfy the needs of individual users and take into account the dynamics of the market and technological developments as well as the needs of trade and industry. To develop products in this manner, the Industrial Design Engineer has to master different sub-disciplines: engineering, management of innovation, formgiving, ergonomics and sustainability.*"

This profile shows what the IDE curriculum at DUT comprehends.

The research group of Product Innovation Management accomplished earlier research projects related to this thesis.

In order to gain more knowledge about the nature of the product design process, Dorst (1997) did research on methods for describing the design process. Dorst showed that the design process (of a single designer) can both be described as a rational problem solving process as well as a reflective practice*, which is a more subjective approach. What paradigm suits best is depending on the kind of design activity an actor is performing. If an actor can complete his task, by using existing knowledge from information sources, than his behavior can best be described according to the assumptions of the rational problem-solving paradigm. Yet, the actor's behavior can best be described according to the paradigm of the reflective practice, if the designer adds value upon existing information. When a designer gives meaning to some piece of information (when an actor creates new knowledge), the paradigm of the reflective practice also suits best. Although Dorst looked at the behavior of a single designer, this distinction is likely to be also important for teamwork.

Partly based on Dorst's results, Valkenburg (2000) developed a method for describing team communication. She executed her study in a laboratory setting. Valkenburg showed that it was possible to record team communication by using the theory of the reflective practice. Valkenburg was also able to determine the quality of team communication. She found that shared understanding between actors in a design project improved the quality of the product developed (Valkenburg, 2000). This highlights the importance of having shared understanding in a product design team.

In this thesis we will elaborate on the thesis of Valkenburg. Valkenburg looked at communication in design teams in a laboratory setting. In this thesis, we will study collaboration within product design teams companies.

Research objective 1.5

Fast product follow-ups and increasing customer demands have changed product design from a rather unstructured process, into a systematic activity

* *The reflective practice is a constructionist theory, developed by Schön. Schön emphasized that every design problem is unique and that a designer should be capable of understanding the design problem. Through continuing reflection-in-action a designer will eventually come to a problem setting and a suitable solution within this setting (Valkenburg, 2000, p. 35).*

(Buijs and Valkenburg, 2005), (Hoegl *et al.*, 2004). Nowadays, both companies and researchers have developed the organizational aspects of integrated product design. Most companies use multidisciplinary design teams for organizing their product development processes. Next to this, they use Stage Gate models (Cooper, 1988) to facilitate their product design processes.
However, attention to the collaborative aspects lags behind these structural and organizational aspects. Both researchers and practitioners do not put much effort into developing the collaborative aspects of product design on a structural basis. Interviews with Project Managers have revealed that the different knowledge bases of the actors hamper communication. This makes that the actors are not able to create shared understanding about the design they are making. Shared understanding about the design is important because it influences the quality of the design (Valkenburg, 2000).

The preceding shows that although the attention for the collaborative aspects lags behind the organizational aspects, collaboration is an important issue in integrated product design. Both Project Managers of design projects and researchers have emphasized the importance of the collaborative aspects of integrated product design.
Since the rational side of product design has been rather developed now, the focus of attentions shifts towards the collaboration aspects. In the remainder of this thesis we will call this *collaborative design*.
The aim of this study is to gain a better understanding of collaborative processes of actors from different disciplines during the product design process in industry.
This research objective leads to the following problem area under investigation:

The collaborative processes between actors from different disciplines, who are involved in an integrated product design process within an industrial organization.

In Chapter 2, we will gather insight in these collaborative processes from earlier studies on collaborative design.

Overview and purpose of this thesis 1.6

In this chapter, we have set the problem statement of this thesis. Furthermore, we have shown how we see the field of Industrial Design Engineering. By doing this we have positioned the problem under investigation. This chapter has shown that more insight in the collaborative aspects of design is needed. Therefore, we have set up a research project, that is described in this thesis. Chapter 2 consists of a literature review on collaborative design. Based on the results of the literature review we have decided upon an empirical research project. Chapter 3 is about the research method for the empirical study. Chapter 4 and 5 both comprise an extensive collaborative design project in industry. We will compare the two studies in Chapter 6. In Chapter 6, we will also answer the research questions set. Finally, in Chapter 7, we will evaluate the research method followed. In addition, we will give implications for further design research, for design practice and for design education.

This thesis is meant for people with different interests. First, it is meant for other researchers that study design processes and –projects. This study provides them with a literature review on the main aspects of collaborative design. Furthermore, it comprises a detailed description of two collaborative design projects in practice. Since the two cases show similar results, the conclusions drawn upon these two cases can be used for future research projects on collaborative design. Finally, our research method will be interesting for other researchers, since we have been able to gather interesting data in a structured way.

The second group for which this thesis, are interesting is the actors that are involved in the case studies. They will be most interested in the empirical chapters of this thesis (Chapter 4 and 5). These chapters provide detailed descriptions of their collaborative design processes. They can learn from their own collaborative design project by reading the interpretations that we made on the base of their reflections on their collaborative design project. Yet, they can also learn from the other collaborative design project by comparing it to their own situation. In other words, they can use this thesis as a learning tool for future collaborative design projects.

The third group for which this thesis is interesting is practitioners that are involved in collaborative design projects in general. Although the empirical studies do not describe their daily practice, they can learn from the detailed descriptions of the collaborative design processes of the two cases. They will probably recognize similar situations in their daily practice from the data. This will allow them to learn from it.

The last group for which this thesis is interesting are the students Industrial Design Engineering. By reading the stories of the collaborative design projects, they get a view on the collaborative aspects of their future work. They can also use this thesis in order to learn how to investigate (collaborative) design processes in practice.

COLLABORATIVE DESIGN | 2

"*Since no actor has at any stage of the process, a comprehensive, all encompassing understanding of the design, actors have to share knowledge* (Bucciarelli, 2003)."

Introduction 2.1

In Chapter 1, we identified the need for more insight in the collaborative design projects in the industry. The aim of this chapter is to review existing literature on the field of collaborative design in order to investigate what knowledge on collaborative design is already available. Furthermore, in this chapter we will frame on what aspects we will focus in our empirical research. The research questions that we will answer in Chapter 2 are:

1. *What is the definition of collaborative design?*
2. *What are the characteristics of the collaborative design projects?*

In section 2.2, we have defined collaborative design by comparing collaboration with other forms of working together in design projects (interaction, integration and cooperation). This comparison and some definitions of other authors on collaborative design have provided insight in the elements of collaborative design. Finally, this has resulted in a definition of collaborative design that reads:

Collaborative design is the process in which actors from different disciplines share their knowledge about both the design process and the design content. They do that in order to create shared understanding on both aspects, to be able to integrate and explore their knowledge and to achieve the larger common objective: the new product to be designed.

Actors share design knowledge through design communication, which means communication about the design content (Chui, 2002), (Valkenburg, 2000).

This definition shows that collaborative design consists of the following three building blocks:

- knowledge creation and integration between actors from different disciplines and functions
- communication between the actors about both the design content and the design process
- the creation of shared understanding about both the design content and the design process

The second topic of this chapter is a literature review on these three building blocks of collaborative design. The literature review is described in section 2.3. Reviewing the existing literature on collaborative design finally results in the formulation of our research standpoint, which forms the last section of this chapter (section 2.4).

Defining collaborative design 2.2

From literature on success and failure in product design projects, we can learn that collaboration is an important factor for success, (Cooper, 1999), (McDonough III, 2000). Effective collaboration also influences the quality of the product designed (Valkenburg, 2000). There is much literature about actors working together in design projects. However, different authors use different terminology for describing the same phenomenon or they use the same term for different purposes. Another problem is that researchers investigate working together on different levels of detail. In order to make the similarities and differences clear, this section will give an overview of existing literature on collaboration. This section ends with a definition for collaborative design applied in this thesis.

Interaction versus collaboration 2.2.1

In the literature, a distinction is made between interaction and collaboration. Interaction is defined as the formal, transactional communication link and is process related (Kahn, 1996). Studies on interaction consider the product design process to be a process of uncertainty reduction and product design teams to be information processing units, which need communication to reduce uncertainty (Tushman, 1978),(Moenaert and Souder, 1990). Studies on interaction are either about the relationship between formal communication structures and their impact on product success and team performance (e.g. (Tushman, 1978), (Moenaert and Souder, 1990), (Kratzer, 2000), (Moenaert *et al*., 2000), (Simoff and Maher, 2000).) or they are about the effectiveness of information processing in relation to task dependencies between the actors. (e.g. (Tushman, 1978), (Eppinger *et al.*, 1994), (Gerwin and Moffat, 1997))
Tushman (1978) did research on technical communication in R&D laboratories. From his study, it appears that, during efficient information processing, the information processing requirements fit the information processing capability of the project team. This is influenced by both task complexity and task

interdependencies.

The studies of Moenaert and Souder (1990), Moenaert *et al.* (2000) and Kratzer (2000) show the effect of knowledge integration between actors from different disciplines on team performance. In addition to knowledge codification, knowledge credibility and transparency of the communication network team discensus also appears to be an important factor of team performance. These studies also show that organizational issues could enable or disable communication flows. Therefore, these issues have an effect on team performance (Moenaert and Souder, 1990), (Kratzer, 2000), (Moenaert *et al*., 2000).

Simoff and Maher (2000) showed in their research how they could use text analysis to analyze different aspects of participation. They were able to analyze the amount of collaboration, as well as the content of the contribution of the individual actors. By doing so, they could measure the effectiveness of team communication.

Eppinger *et al*., (1994) did research on organizing design tasks during product development. They observed that the needed information at the necessary place in time. In order to better organize the information processing process, they used task dependencies among actors as leading for the reorganization of engineering tasks. They developed the Design Structure Matrix, which captured both the sequence and the technical relationships between the design tasks.

According to Kahn (1996), the difference between interaction and collaboration is that during interaction there is only a formal, transactional communication link between the actors. He defines collaboration as an effective, volitional, mutual/shared process in which two or more departments work together, have mutual understanding, have common vision, and achieve collective goals. Therefore, interaction becomes collaboration if actors from different disciplines create shared understanding about both the design they are making as well as the process they are following.

Integration versus collaboration 2.2.2

Lawrence and Lorsch (1967) introduced the concept of integration and differentiation within an organizational context. They define integration as *"The quality or state of collaboration that exists among functions which is required to achieve unity of effort by the demands of the environment"* (Lawrence and Lorsch, 1967). In literature on design research, the term integration has another meaning. Here, integration refers to one of the key qualities of a designer and is defined by Dorst as: *"Someone is designing in an integrated matter when he/she displays a reasoning process building up a network of decisions concerning a topic, while taking into account different contexts"* (Dorst 1997, p. 35.). Differentiation is the segmentation of the organizational system into subsystems and is necessary for the successful completion of a product design project. Integration is necessary for bridging the differentiated parties (Moenaert and Souder, 1990). The more the actors within the different functions are differentiated the more difficult integration is and as a result boundaries are created. The underlying consideration is that communication among team members increases team performance.

The theory of Lawrence and Lorsch has been influential in research on new product development. Many authors have published articles about the integration of different functions within a product design project (E.g. (Allen 1971), (Kahn, 1996, 2001), (Postrel, 2002)). Terms used for describing this phenomenon are *external communication* or *boundary spanning* (E.g (Allen, 1971), (Katz and Tushman, 1981), (Lysonski and Woodside, 1989), (Ancona and Caldwell, 1992), (Sonnenwald, 1996)). Allen (1971) called actors who do boundary spanning *Gate Keepers*. The work of Allen (1971) and Katz & Tushman (1981) highlighted the importance of external communication for team performance and the role of Gate Keepers in this process.

Ancona and Caldwell (1992) did research about different strategies of external communication and the relationship with performance. They found that both the communication frequency between different functionalities and the communication strategy are important. They distinguish between three main activities of external communication:

- ambassadorial activities that provide the team with access to the power of the company as members promote the team, secure resources and protect the team from excessive interference
- task coordinator activities that provide the team with access to the workflow structure for managing horizontal dependence
- scouting activities that provide the team access to the information structure

The differences in frequency that teams deploy these four activities lead to four different strategies for external communication. These four strategies are:

- the isolationist strategy; the team does not frequently use any of the external communication activities
- the ambassadorial strategy; the team frequently uses the ambassadorial activity
- the technology scouting strategy; the team frequently uses the technical scouting activity
- the comprehensive strategy; the team frequently uses all three activities that are mentioned

Concerning communication frequency, Ancona and Caldwell label the first two strategies as less frequent and the last two as more frequent. Looking at performance measures, there are differences between the strategies within one group. Technical scouting teams, for example score low on performance measures. Teams acting according to the comprehensive strategy, on the other hand, score high on performance. With this result, Ancona and Caldwell have shown that, only looking at team performance from information processing perspective leads to a too narrow view.

Sonnenwald (1996) studied the different kinds of boundaries with which a design team is confronted. She distinguishes between three kinds of boundary spanning roles: the internal star (interaction within their project), the external star (interaction external to their project), and the gatekeeper (both inside as well as outside the project). In her study, she found five types of boundaries, which the boundary spanners try to remove. These boundaries are: organizational boundaries, task boundaries, discipline boundaries, personal boundaries and roles that support multiple boundaries. Sonnenwald proposes different boundary spanning activities for each of these five boundaries. For example, a boundary spanning activity for removing a task boundary is to ask actors to create more than one solution for a sub problem, which gives more possibilities for integration with the others.

Probably the most investigated boundary is the interface between Marketing and R&D (E.g. studies of (Gupta *et al*., 1986), (Gupta and Wilemon, 1988), (Souder, 1988), (Song and Perry, 1992) (Parry and Song, 1993), (Haggblom et al., 1995), (Veryzer, 2005)). In 1996, Griffin and Hauser (1996) reviewed and analyzed the outcomes of these studies. In their meta-analysis, they identify barriers to functional integration between Marketing and R&D. These barriers are personality, cultural thought worlds, language, organizational responsibilities and physical barriers. The research of Griffin and Hauser also suggests methods for overcoming these barriers in order to achieve functional integration. These methods are relocation and physical facilities design, personal movement, informal social systems, organizational structures, incentives and rewards, and formal management processes.

Kahn (1996) developed a framework for describing the relationship between integration, collaboration and interaction that is shown in Figure 2.1.

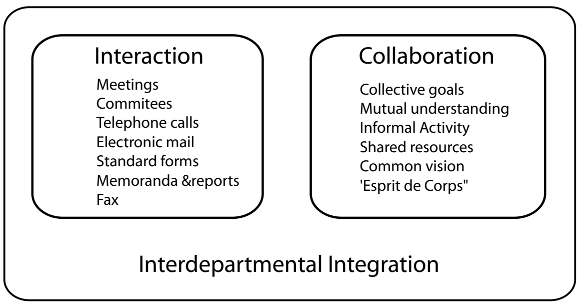


Figure 2.1
Relationship between collaboration, integration and interaction
(based on Kahn, 1996)

In this framework, Kahn combines two views of interdepartmental integration; the interaction-based view and the collaboration-based view.

The two views are considered to be distinct because they both are substantial elements of integration. The results of Kahn show that interaction is a way to establish contact and familiarity between departments and is therefore an enabler for collaboration. This is important, since collaboration has a direct impact on success. The findings of Kahn do not imply that increasing the interaction improves collaboration. Too much interaction will overload the actors.

2.2.3 Cooperation versus collaboration

Several authors use the terms cooperation and collaboration interchangeably. Yet there is a distinction between the two.

According to Smith *et al.* (1995), most definitions of cooperation focus on the process by which individuals, groups and organizations come together, interact and form psychological relationships for mutual gain or benefit. With respect to product design, Song *et al.* (1997) define: "*Cooperation is the interdependency and information sharing between various organizational units*. The desired outcome of cooperation is effective *coordination*, which will result in a higher performance (Smith *et al.,* 1995). Studies on cooperation focus on frequency of interaction and the amount of information and resources shared between functions (Olson *et al.*, 2001).

Studies on collaboration focus on the *quality* of information sharing. The creation of shared understanding about the design they are making and a shared vision about the process to be followed are important aspects of collaboration (Kahn, 1996). Chiu (2002) defines: "*Collaborative design is an activity that requires participation of individuals for sharing information and organizing design tasks and resources*." Chiu's definition contains two important aspects of collaboration: sharing and organizing both tasks and resources. Chiu named the process of sharing expertise, ideas, resources and responsibilities *design* *communication*. Design communication is about the content of the design process. Valkenburg (2000) calls this *communication about the design content*. Valkenburg, Chiu and other researchers claim that the effectiveness of design communication is critical for the quality of product design. This is valid from an efficiency point of view, as well as for the quality of the product (Bucciarelli, 1996), (Valkenburg, 2000), (Song *et al.*, 2003).

Definition of collaborative design 2.2.4

Although the definitions of Chiu (2002) and Kahn (1996) contain important aspects of collaboration and collaborative design, we would like to elaborate on two aspects.

The first aspect is the question of whether actors share information or knowledge. Court (1997) makes a distinction between these two concepts. Court offers multiple definitions of information. Most definitions focus on the aspect that information is data, which the receiver understood, or data that have a meaning for the receiver. Court also sees information as an activity of informing and becoming informed. This makes information dynamic. Knowledge, on the other hand, is a state which actors can record or register to remember later. According to Court, knowledge is more than just recorded information. It is the mental state of ideas, facts, concepts, data and techniques recorded in the individual's memory. During collaborative design, the individual actors will use these ideas, facts and concepts to perform their individual tasks. In other words, information flows restructure or change the knowledge bases of the individual actors. It is the knowledge base of an actor which influences his actions (Nonaka, 1994). Based on the preceding reasoning, the concept of knowledge sharing is preferred to the concept of information sharing in this thesis.

The second aspect is that during collaborative design actors have to share their individual knowledge bases, which is a team activity. Additionally, collaborative design is also an activity of knowledge creation and integration (Sonnenwald, 1996). The difference between knowledge creation and integration is that knowledge creation is a divergent activity, while knowledge integration is a convergent activity. Knowledge creation and integration are important for collaborative design. Therefore, both knowledge sharing as well as knowledge creation and integration should be part of the definition of collaborative design.

Keeping the preceding aspects in mind (combined with the definition of Chui (2002)), the definition of collaborative design reads as follows:

Collaborative design is the process in which actors from different disciplines share their knowledge about both the design process and the design content. They do that in order to create shared understanding on both aspects, to be able to integrate and explore their knowledge and to achieve the larger common objective: the new product to be designed.

Actors share design knowledge through design communication, which means communication about the design content (Chui, 2002), (Valkenburg, 2000).

2.3 Characteristics of collaborative design

From the definition of collaborative design it appears that the important aspects in the collaboration process are:

- knowledge creation and integration between actors from different disciplines and functions
- communication between the actors about both the design content and the design process
- the creation of shared understanding about both the design content and the design process

This section provides an overview on earlier studies about these three subjects.

Knowledge creation and integration between different disciplines 2.3.1

Figure 2.2 shows how actors have diverse viewpoints about the design they are making. To be able to develop a new product, actors have to create new knowledge and integrate their knowledge bases. The first part of this section is about how actors create and integrate knowledge. Figure 2.2 also shows that we assume that actors from the same discipline think more similarly than actors from different disciplines. This implicates

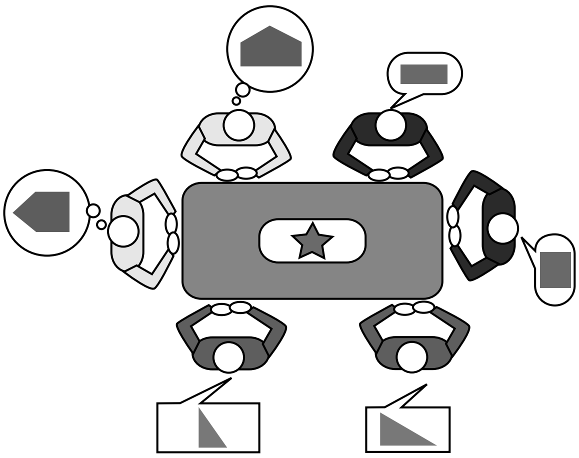


Figure 2.2
Actors in the design team have different views on the design

that knowledge sharing between actors from the same discipline differs from knowledge sharing between disciplines. The second part of this section is about theoretical concepts, which explain differences between actors. The section concludes by showing the impact that diversity has on knowledge creation and integration.

Research on knowledge creation and -integration

Davenport and Prusak (1998) define knowledge as: *"Knowledge is a fluid mix of framed experiences, values, contextual information and expert insight that provides a framework for evaluating new experiences and evaluation*."

Davenport and Prusak make a connection between what a person knows and how he uses his knowledge. This is an important aspect of collaborative design because during the design process specialists do build on their experiences using technical and scientific knowledge fluidly together (Sonnenwald, 1996).

In their definition, Davenport and Prusak also use the term *framed*. This implicates that an actor is rather attached to his knowledge and that the knowledge is explicitly present in his mind. Both aspects are important for collaboration. When an actor has built a frame of a particular piece of knowledge, it is difficult to reconcile the frame when insights of other disciplines make that necessary (Gibson, 2001). Therefore, framing knowledge can hamper knowledge integration and collaboration. However, since an actor's knowledge is explicit in his mind during the process of framing he can easily communicate his knowledge. This, in turn, helps knowledge integration (Nonaka and Takeutchi, 1995).

Actors (in a design team) can have fixed frames that hamper them continuing the design process (Schön 1983, p. 79-104). By actively discussing and criticizing the frame on hand in the design team will help reframing the design problem. Schön calls this process reflection-in action. By reframing the problem it is important that all actors of the design team see the consequences and the implications that a particular frame has. Only that they are able to continue in a sensible way.

Nonaka and Takeutchi (1995) investigated how actors in Japanese firms create knowledge. They adopted the work of Polyani (1966), who made the distinction between tacit and explicit knowledge. Explicit knowledge (or codified knowledge) is transmittable in formal systematic knowledge. Tacit knowledge is rooted in the action of an actor within a particular context. Tacit knowledge has both a cognitive- and a technical element. The cognitive element of tacit knowledge refers to the images an actor constructs about reality and what he sees in the future. The image constructed by an actor is a *mental model* about a particular situation within a certain context. The technical elements include know-how, crafts and skills. According to Nonaka (1994), the articulation of tacit knowledge is a key factor for the creation of new knowledge.

Nonaka and Takeutchi (1995) claimed collaborating actors within an organization are able to transfer tacit knowledge to explicit knowledge and vice versa. (This means that tacit and explicit knowledge are two separate entities.) This leads to four modes of knowledge conversion, which is illustrated Figure 2.3. The first mode is the *socialization* mode, which enables actors to convert tacit knowledge through interaction. In order to be able to participate in each others thinking processes, actors need shared experience. The second mode is the *combination* mode, through which actors share explicit knowledge. Actors can share explicit knowledge by using formal communication structures. Sharing explicit knowledge leads to a reconfiguration of existing information and, therefore, can lead to new knowledge. The third mode is *externalization*. Externalization is the conversion of tacit knowledge (gained from experience) to explicit knowledge. Analogies and metaphors are catalyst for this process. The fourth mode is *internalization* and is the transformation of explicit knowledge into tacit knowledge. Internalization is similar to the traditional notion of learning (Nonaka, 1994).

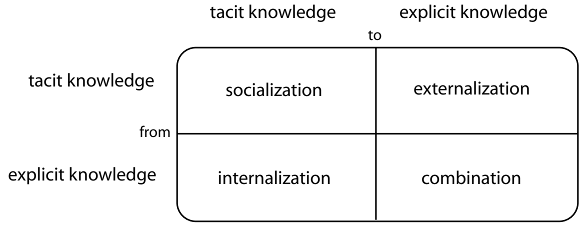


Figure 2.3
Modes of knowledge creation
(Nonaka, 1994)

Also Leonard-Barton and Sensiper (1998) investigated the role of tacit knowledge in innovation processes. Like Nonaka and Takeutchi (1995), they adopted the work of Polyani (1966). However, they did not separate tacit and explicit knowledge. They joined the original opinion of Polyani, who claimed that all knowledge has a tacit dimension. Leonard-Barton and Sensiper claimed that tacit knowledge could lead to competitive advantage because it cannot be grasped by competitors. From studies on creativity, intuition and non-analytical behavior, Leonard-Barton and Sensiper revealed three activities in which actors use tacit knowledge during innovation processes. These activities are problem solving, problem finding and prediction & anticipation. Since these three activities cover (almost) all activities of the innovation process, we conclude that actors always use tacit knowledge while they are executing an innovative task.

In their study, Leonard-Barton and Sensiper regard the innovation process as a funnel, which contains divergent and convergent phases. In the divergent phases, actors from diverse knowledge bases create their own frames of both problem and solution by applying their preferred mental schemes and patterns. These different frames lead to a cacophony of perspectives that, if well managed, result in creativity. During the convergent phases, knowledge integration has to take place and actors have to share knowledge. The degree to which actors need to share knowledge is dependent on their interdependency. According to Leonard-Barton and Sensiper, during convergence phases, three types of tacit knowledge are important. The first is overlapping *specific knowledge*. This is knowledge about the interfaces between them. Shared experiences and job rotation help this type of knowledge sharing. The second is collective *system knowledge*. This is knowledge of how individual operations in the organization fit together on a systematic level. The third type of knowledge is *guiding tacit knowledge*. This type of knowledge helps actors creating shared understanding about their project goal. In innovative projects, this project goal is often vague and not well defined or is on a high level of abstraction.

Collaboration between actors takes place if during divergent phases of the design process, knowledge sharing leads to the creation of new knowledge. Collaboration in the convergent phases takes place if actors are able to integrate their different knowledge bases. Integration should take place in a way that it provides each actor new insights and that each actor is able to fulfill his own task.

Research on knowledge sharing and creation between diverse disciplines

In the early 1980's Bucciarelli (1984) participated in collaborative design projects in practice, both as a researcher and an engineer. His research objective was to gain better understanding of the design process. At that time, the leading opinion of designing was that of a rational problem solving process, which actors could optimize by using problem solving models. However, instead of observing a rational decision-making process, what Bucciarelli saw was a process of negotiation.

This observation changed his way of looking at design. Instead of seeing design as a mechanical, process, deterministic and rational in nature, he now saw design as a social process, full of uncertainty and ambiguity. Actors within that social process had to create a common perspective in order to be able to agree on the most significant issues and to shape consensus on what to do next. Actors shared their ideas through communication. This appeared to be difficult (Bucciarelli, 1988). Different actors used different languages and different representations of the design, since they had different interests and responsibilities. Product specifications were contradicting. This resulted in competition between the actors. Negotiations and trade-offs were required in order to make actors' efforts coherent.

To be able to explain the difficulties of knowledge integration between the actors, Bucciarelli introduced the concept of *object worlds*. In his book *Designing Engineers*, Bucciarelli (1996, p. 62) defined object worlds as: "*the domain of thought and artifact within which actors in engineering design move* *and live when working on any specific aspect, instrumental part, subsystem or sub function of the whole.*"

An object world contains individual beliefs, interests, knowledge and experiences of an actor, as well as the methods and techniques he is able to use. Bucciarelli (1988) used the term *object*, because actors construct different varieties of the same object. It is the object that guides the actors through the process. Different aspects of the object and their interrelations constitute the object. Yet, but different aspects are of interest to different actors in design.

In her book *Wellsprings of knowledge* Leonard-Barton (1995, p.62) describes how actors can differ in their *signature skills*. She defines signature skills as an outgrowth and interactive expression of three interdependent preferences. These three preferences are:

- preferred type of task (refers to someone's specialization)
- preferred cognitive approach to problems (refers to someone's personality and is independent of the discipline of the actor)
- preferred technology for performing the task (refers to the tools and methods preferred by an actor)

Figure 2.4 shows these elements. According to Leonard-Barton, managers within collaborative design projects can use these different signature skills for creative abrasion.

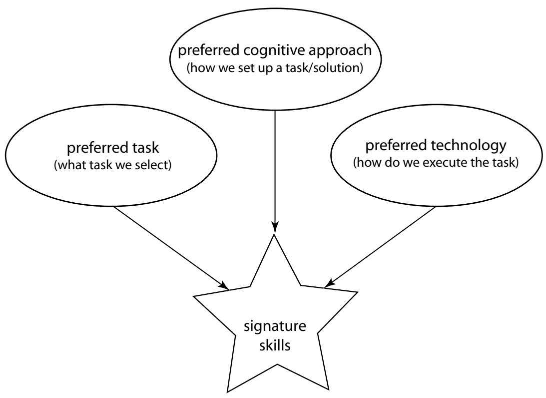


Figure 2.4 Composition of signature skills (Leonard-Barton, 1995)

While studying aircraft design, Bond and Ricci (1992) also noted the difficulties that actors in multidisciplinary teams have as a result of different working methods and viewpoint. They concluded that specialists have limited abilities to understand each other's models. According to Bond and Ricci, actors communicated using a shared vocabulary but did not necessary share technical knowledge. Therefore, the specialists among them negotiated design decisions. Actors organized and controlled this negotiation process by formulating commitment steps.

Dougherty (1992) studied functional differences between actors in multidisciplinary design teams. In her study she calls the viewpoint of an actor an *interpretive scheme*. Dougherty claims that actors from the same department have the same interpretive scheme. The scheme of one department forms a *thought world*. More precisely, Dougherty defined a thought world as: *"A community of persons engaged in a certain domain of activity who have a shared understanding about that activity. Thought worlds with different funds of knowledge cannot easily share ideas, and may view one another's central issues as esoteric, if not meaningless. A thought world evolves as an internally shared system of meaning which provides a 'readiness for directed perception' based on common procedures, judgments and methods*" (Dougherty, 1992, p.179).

Dougherty states that actors from the same department make the same conceptualizations about how they should design the new product. Dougherty defines three themes in which thought worlds can differ:

- what actors see when they look into the future
- what actors consider to be critical aspects
- how actors understand the development task itself

Departments can develop different perspectives on these three aspects. This separates rather than combines information, including cognitive orientations such as goals, time-frames and formality. Thought worlds encourage separation between departments, since actors feel more related to like-minded persons. Companies themselves often do stimulate separation of thought worlds by their organizational structure, routines and reward systems

(Griffin and Hauser, 1996). Dougherty (1992) also saw differences between the departments in the methods and procedures they used. This process aspect also separates departments, since coordination problems will occur.

Kalay (1998) compared the differences in disciplines with the differences in philosophical paradigms. He used the theory of Kuhn for developing a solution for knowledge integration. According to Kalay, Kuhn solved the differences between two paradigms by making a *super paradigm.* Actors constructed this super paradigm by persuading one actor to look at the ideas of the other actor. If an actor understands the differences and seeks to make compromises for the differences, then this will help to solve conflicts and will create a super paradigm. Kalay illustrated his ideas with the picture in Figure 2.5. The picture shows three worldviews with their own main objectives, represented by the small triangle, square and circle. The picture also shows that the three representatives have a shared super objective; the new product to be developed (represented by a star). In order to reach their shared super objective, the actors with different worldviews should communicate by using the super paradigm that they themselves had created during the project.

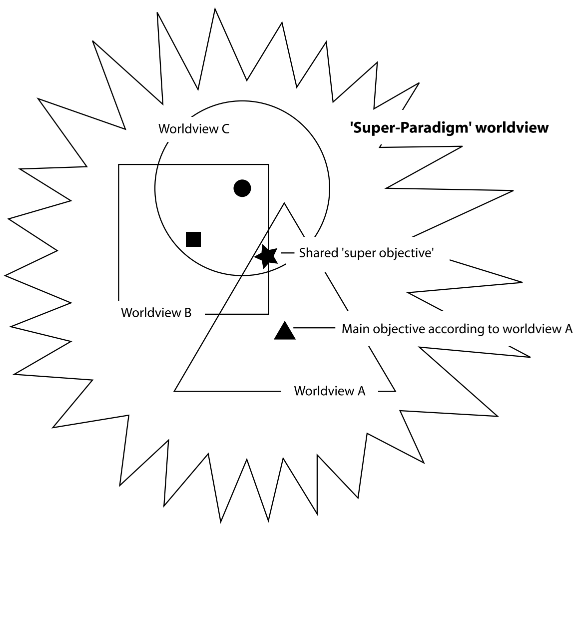


Figure 2.5 Different worldviews promote different objectives (Kalay, 1998 p. 38, Fig.1)

This section presented the theoretical concepts about why the integration between actors from different disciplines and functions in a collaborative design project is difficult. We will use one of these concepts to indicate these differences in the remainder of this thesis. We prefer a concept that is based on individual actors, since actors can differ more from each other than just on their knowledge base. They can also differ in both cognitive approach to problems and in experience (Leonard Barton, 1995, p. 62). Tsoukas (1996) speaks in this context of a *habitus*. Each actor has a habitus, which is comprised of past socializations to which an actor was subjected in the context of his involvement in several social practices. In other words, an actor's behavior is influenced not only by his knowledge but also by his experiences.

We described several concepts that were based on the individual actor. Bucciarelli focused on preferences actors have by constructing the object they have to create. Bucciarelli looked from a designer's point of view to diverse viewpoints by emphasizing the object created. The other concepts presented were less design oriented. Since this thesis is about collaborative design, we apply the term object world for the description of differences in viewpoints on the design between actors on an individual level.

The impact of team diversity on knowledge creation and -integration

Object worlds can have a positive and negative effect on the exploration and/or integration of knowledge.

Studies that look at aspects, such as team diversity and team roles related to team performance, conclude that team diversity decreases both the innovativeness of the product and team performance, e.g. (Sonnenwald, 1996), (Dougherty, 1992). Sonnenwald (1996) claims that it is difficult for actors to explore ideas together because actors have unique past experiences, specialized work language, different work patterns, different perceptions of quality, different organizational priorities and technical constraints. She states that sometimes it is easier for actors to challenge or contest one anothers' contribution, than it is to collaborate. Sonnenwald (1996) characterized this phenomenon as *contested collaboration*. Contested collaboration can lead to conflicts and has a negative impact on the quality of the design process and the design outcomes.

Contradictorily, literature about creativity and organizational processes see diverse teams as more innovative than homogeneous teams, e.g. (Weick and Roberts, 1993), (Ramesh and Tiwana, 1999) (Buijs and Valkenburg, 2005). Weick and Roberts (1993) claim that the process of knowledge integration works best in the early stages of the project. They state that at the end of a design project, the work becomes more routine, more casual and more automatic. This reduces the quality of collaboration (Weick and Roberts, 1993). Ramesh and Tiwana (1999) cite Ruggles (1998) who claims that managing knowledge in collaborative teams allows cross-fertilization among actors. It also creates networks of knowledge workers within and outside an organization.

However, most authors plead for a balance between diversity and homogeneity. Postrel (2002), in his study about the division of knowledge, supposed a balance between what he calls trans-specialist understanding and specialists capabilities. Postrel writes:

"*A team with zero trans-specialist understanding would have complete mutual ignorance, but assuming no learning capacity has been wasted, strong ability to solve separate problems in each domain. A team with perfect trans-specialist understanding would have no differentiation of knowledge among its members, but a little ability to solve domain specific problems; each individual would be a generalist, equally skilled in each domain and good at putting pieces together, but not at solving hard problems in any one area.*"

Postrel's argument fits the opinion of other researchers who suggest that an enabling condition for knowledge creation is redundancy of knowledge. According to Nonaka and Takeutchi (1995), redundancy of knowledge or experience between the actors is a condition of efficient knowledge creation. However, maintaining enough specific knowledge is also necessary. Having too much redundancy of knowledge will increase development costs or will decrease product quality (Ramesh and Tiwana, 1999, p.221). According to Henderson and Clark (1990), in order to develop successful products companies need two kinds of knowledge. They need component knowledge for high quality modules and architectural knowledge for the integration of the components. Specialists within a company are responsible for component knowledge, while generalists integrate the components. Generalists function as advisors in the process of knowledge gathering. Specialists act as *hunter gatherers* who actively seek data from a range of different sources in order to help them perform their design task (Baird *et al.*, 2000). Generalists who have knowledge integration as their primary task are *knowledge brokers* (Hargadon and Sutton, 1997), (Hargadon, 1998). Knowledge brokers integrate both thought world- and object world knowledge.

In order to have optimal collaboration between generalists and specialists, a collaborative design team needs to find a balance between autonomy and cooperation between sub teams whose tasks are interdependent. Clark and Fuijimoto call this balance *internal integrity* (Clark and Fuijimoto, 1990). Ramesh and Tiwana add to this the need for a shared vision and understanding when trying to reach a creative environment with a high degree of cross-functional collaboration (Ramesh and Tiwana, 1999).

Gibson (2001) claims that when integration between actors is moderate, actors are likely to attend to a variety of information. This facilitates innovation. Case study observations show that actors achieve an optimum of awareness when enough overlap occurs to maintain coordination, while still allowing enough diversity to conserve the willingness to look at a broad variety of information.

Postrel's argument also fits the divergence/convergence process approach of Leonard-Barton and Sensiper (1998). They claim that the differences between the disciplines could lead to creativity in the divergent phases of the innovation process. They call the differences between disciplines *intellectual conflicts.* Intellectual conflicts can lead to creative ideas because:

- they offer the actors more options, which increases the changes for a frame breaking option
- actors involved in an intellectual conflict will search beyond the obvious solution
- diversity of information improves performance in terms of creativity

In order to enhance creativity, project managers must manage the *signature skills* of the actors. Since signature skills consist of three elements, they require three management skills (Leonard-Barton, 1995). The first element is the management of specialization. Project managers are able to integrate different specialties if they have *T-shaped skills*, *A-shaped skills* or if they are *Multilingual*. Managers with T-shaped skills have one disciplinary skill and the ability to apply knowledge across situations. Managers with A-shaped skills have a deep understanding of two disciplines and can make crossovers. Managers with multilingual skills are capable of operating in more than one specialized realm and perhaps utilizing more than one style. The second element is the management of diversity of cognitive styles. By acknowledging differences in cognitive styles, managers can encourage diversity within the team. This enhances creativity. The third element is the active search for tools and methods. This element fits both specialization needs and cognitive preferences (Leonard-Barton, 1995). In the convergent phases, knowledge sharing and integration should occur. Therefore, redundancy of tacit knowledge is necessary in the convergent phase (Leonard-Barton and Sensiper, 1998).

In collaborative design teams actors have to share and create knowledge. Since the actors come from different disciplines and have different functions, they all operate from their own object world. Object worlds influence the process of sharing and creating knowledge.

In the literature, there are some authors who claim that heterogeneity only disturbs the collaborative process. On the other hand there were authors that highlighted the creative ideas that originated during collaboration between disciplines. However, most authors argue for a balance between diversity and homogeneity. Based on the work of Leonard-Barton (1995) about knowledge creation, we think that this balancing should take place between the divergent- and convergent phases within the collaborative design process. During divergent phases, actors should communicate their specific knowledge to one another. These diverse knowledge bases will lead to knowledge exploration and creative ideas.

Within the convergent phase, actors should be able to integrate their knowledge bases. To do so, companies need architectural knowledge and redundancy of (tacit) knowledge.

Collaborative design as a communication process 2.3.2

Communication is a prerequisite for collaboration because it is the way in which actors share knowledge with one another. Actors must share design information for decision-making and for coordinating design tasks (Chiu, 2002). Since the design tasks of the actors are interrelated, communication forms the basis for the actors' own actions (Kalay 2001, p. 742).

Chui (2002) did an experiment in a laboratory setting. During this experiment, actors spent between 40-50% of their time focusing on communication, 40-50% on drafting & design and 10% on other tasks. Chui's study shows that the effectiveness of design communication becomes critical for actors in a collaborative design project.

Researchers have studied communication during collaborative design on different levels of detail. These levels of detail correspond with how the researchers view collaboration between the actors. Figure 2.6, that we based on the framework of Kahn (1996), shows these different views with the accompanying research topics. Research on communication seen from the interaction viewpoint, is about communication flows and communication networks. Both concern information processing. Research on communication seen from the collaboration interaction viewpoint, is about communication about the design content. Communication about the design content deals with the creation of understanding about the design (process) between actors. Research on communication seen from a viewpoint of interdepartmental integration is about communication strategies, communication roles, internal- versus external communication, boundary spanning and coordination. These topics are all related to the integration of different disciplines.

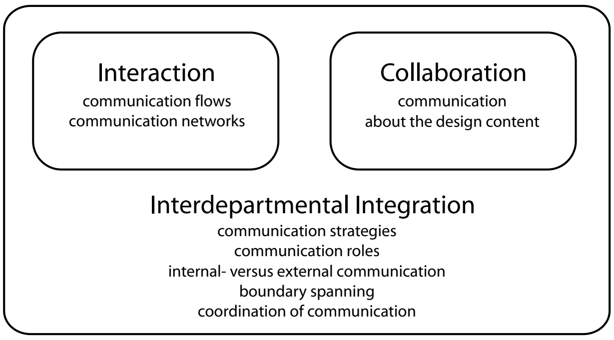


Figure 2.6 Topics of research on communication in collaboraticve design projects

Since the scope of this thesis is collaboration between actors in a collaborative design team, this section only contains earlier research on communication about the design content.

Research about communication on the design content contains three subjects. The first subject is about topics of conversation during collaborative design. The second subject is, about unraveling the team communication processes of the actors performing a collaborative design task. The third subject involves the type of communication media that is used during collaborative design.

Studies on the topic of conversation during collaborative design projects

There were several studies done about the purposes of communication. Olson *et al*. (1992) did a study about the topics of communication in product design projects. This study shows that 20% of the design meeting is about planning and monitoring of the product design process, 30% is about progress and 40% is about the design content. Their study showed that communication about the design content is the most substantial component of all communication. Chui (2002), in her laboratory research project, found an even higher percentage. However, this can be explained by the fact that organizational issues do play a less important role in a laboratory experiment.

Stempfle and Badke Schaub (2002) also found similar results during their laboratory study. Two-thirds of their communication in design groups dealt with the content, whereas one-third of the communication was aimed at structuring the group process. Though the exact percentages are not important, these percentages show us that communication about the design content is important and a substantial part of the whole communication process.

Research on describing design communication

This section is about studies that use various methods for describing content related communication. It starts with the studies of Valkenburg and Dorst (1998), Valkenburg (2000), and Strumpf and McDonnel (2001). They all used the reflective practice for describing team communication. The section continues with a series of studies Badke Schaub did with various co-authors and a study of Chiu (2002). They saw the communication process between actors as a decision making process. Finally, Peng (1994) and D'Astous *et al.* (2004) described the communication process between actors as a process of modeling and sharing representations.

Valkenburg & Dorst (1998) and Valkenburg (2000) developed a method for describing team communication, by using the theory of the *reflective practice* from Donald Schön. Valkenburg and Dorst observed two multidisciplinary design teams involved in a competition. They were able to distinguish the four basic activities Schön described (naming, moving, framing and reflecting). From their analysis it appeared that the two teams had different communication processes. The first team only searched for one best solution to fit the problem. Team two had an integrated view on the design task. They framed the design task and developed this frame by implementing new aspects in the frame. This resulted in an integrated design that contained all sub problems. Team two won the competition. The first team was not able to produce a working model, since the sub parts did not function together. With this experiment, Valkenburg and Dorst showed team communication influences the quality of the result.

Stumpf and McDonell (2002) also used the reflective practice for describing team communication as a way of gaining insight into the process of frame negotiation among actors. Stumpf and McDonell distinguished between two levels of communication. The first level was the *macro level*, in which actors transformed their individual frames to team frames. The second level was the *micro level* that comprehends the cycle of naming, moving, framing and reflecting. Stumpf and McDonell analyzed the transcriptions of the *Ivan, John and Kerry tape* of the Delft Protocol workshop (Cross *et al.*, 1996). They used the argumentation theory, called *The New Rhetoric*, to analyze the data. This method appeared suitable for finding reliable markers for detecting frame shifts because a distinction between *associations* and *dissociations* could be made. If actors introduced dissociation, then they created a new conception of reality (a new frame). During associations, actors developed new notions of reality (development within a frame). Associations served as a support for the new concept and as an explanatory mechanism if the actors perceived a gap of connection between them. Frame shifts appeared hermeneutical and actors used relevant aspects of previous concepts to inform each other about the ongoing design.

Badke-Schaub and Frankenberger (1999) identified factors that influence design work. The aim of the study was to develop a model for collaborative design work in practice. Badke-Schaub and Frankenberger did an observational study within two companies. In order to reduce the large amount of data collected, they made a distinction between routine work and critical situations. They analyzed only the critical situations. Badke-Schaub and Frankenberger distinguished different types of critical situations: goal analysis and goal decisions, solution analysis and solution decisions, solution search and additionally disturbing- and conflict management. Critical situations can be both successful and unsuccessful. Individual prerequisites of an actor, prerequisites of the group, external conditions and the design task and the design process all influence the effectiveness of a critical situation. Badke-Schaub and Frankenberger emphasized co-operation and communication as important factors for creating efficient collaboration processes.

Stempfle and Badke-Schaub (2002) coded content- as well as process related communication, within three design teams in a laboratory setting. They modeled content related communication as the decision-making process and, with regard to this process, they developed five steps; planning, analysis, evaluation, decision and control. Concerning the design content, Stempfle and Badke-Schaub distinguished between two different patterns of team communication. Following pattern one, actors jumped to conclusions without analyzing the ideas. In pattern two, actors evaluated their ideas, which increased the quality of the ideas.

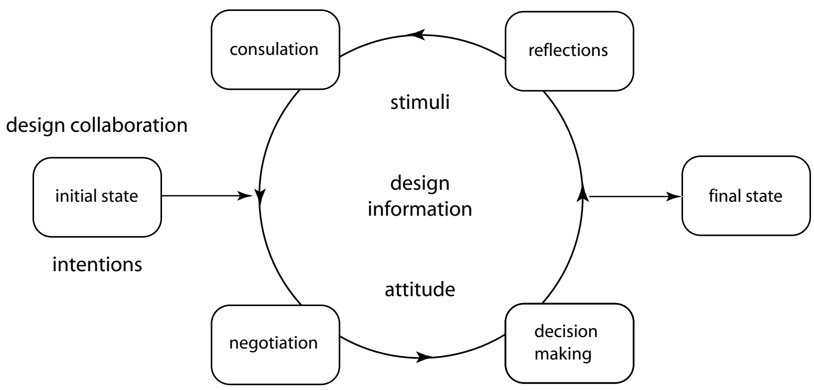
According to Stempfle and Badke-Schaub, actors within a heterogeneous team will not have shared understanding about the solutions found. Therefore, actors in heterogeneous teams will follow pattern two. This could be an explanation of why heterogeneous teams often perform better. In heterogeneous teams, analyzing ideas will occur by questioning actions and ideas of other team members. In addition, disagreement will provoke discussion.

Badke-Schaub and Gerlicher (2003) analyzed patterns of decision making in collaborative design projects in practice. In this study, they identify five patterns: leaps, loops, cycles, sequences and meta-processes. Badke-Schaub and Gerlicher conclude that if iterations are necessary to build a shared mental model they are useful. Within a design team, shared mental models are after all are essential for coming to a successful decision. Therefore, sometimes a design team needs cycles. Sequences and meta-processes are more successful than leaps and loops. Leaps and loops occur when groups do not put energy into the decision making process. Then they have not spent time on connecting priorities for the formation and maintenance of a common goal. A moderator can help with focusing on the decision making process. A moderator should balance between structuring the design process (to fill the need for a structural approach) and structuring the content (by creating shared mental models). Reflections are necessary for preventing leaps and loops.

Chiu (2002) did research, in both architectural practice and in student design studios, on how the organization of the design project affects communication about the design content and how computers can support this process. Using the results of previous studies Chiu defined four types of communication problems: *Media problems*; (how to transmit communication symbols precisely); *Semantic problems* (how to communicate the original meaning); *Performance problems* (how to communicate effectively) and *Organizational problem*s (how to reach the right persons).

In order to overcome these problems, Chiu proposes a process model for describing collaborative design. This model, shown in Figure 2.7, illustrates the general process of collaborative design driven by decision-making.

Figure 2.7
A process model of design collaboration (Chiu, 2002)



The process is conveyed as a cycle of consultation, negotiation, decision-making and reflection. Before actors reach the final state, more than one cycle may be necessary. Chiu claims that negotiation is most important in this model. Chiu proposes building a computer supported collaborative environment to structure collaboration with use of the model.
Peng (1994) studied communication in collaborative design from the perspective of co-operative architectural modeling. Peng characterized communication in terms of inter-relations between common images and distributed design developments. He studied three retrospective architectural projects. Peng determined two strategies. First, actors could commonly develop architectural models. From these common models, actors developed their own domain specific images and models. Second, actors developed both their own specific models and the construct common images by integrating domain specific design expressions and they use shared constructs and operations.
D'Astous *et al.* (2004) studied activities that took place in design evaluation meetings. D'Astous *et al.* show that shared representations of the evaluated subject are a prerequisite for an effective meeting. They also show that actors should synchronize not only their ideas about the subject under study, but also about the review procedure. Synchronization both saves time and results in a shared understanding among the actors about the subject under discussion.

By analyzing the studies in which researchers describe design, we can conclude that both the theory of the reflective practice as the more rational decision making process, are valid methods to analyze the quality of team communication. Although researchers used different paradigms to describe the design communication process, they all showed negotiation and synchronizing thoughts and representations of the design are important elements of communication about the design content.

Communication methods used in collaborative design projects

Actors use different methods when they communicate synchronously or asynchronously (Chui, 2002). According to Chiu, actors use outlines of verbal descriptions, texts, sketches, orthographic drawings, tables, CAD drawings, computer rendered images and photographs during asynchronous communication. During synchronous communication, they use visual presentations plus oral explanations. Chui also mentions that language barriers are important in oral communication and that visual communication is the foundation of design collaboration. Perry and Sanderson (1998) claim, that face-to-face interaction between actors is the most effective form of communication.

According to Bucciarelli (1996, p. 90-98) and Saad and Maher (1996), designers choose a particular representation of the design because it fits their needs for abstraction. Saad and Maher separate different kinds of objects into three categories. Figure 2.8 shows that an object has three kinds of representations: *organizational* (record of administrative ownership of the information), *semantical* (functional and intentional information and semantic relationships) and *graphical* (representation of objects).

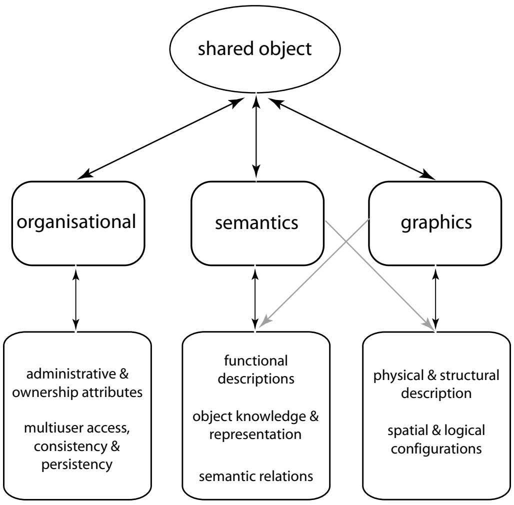
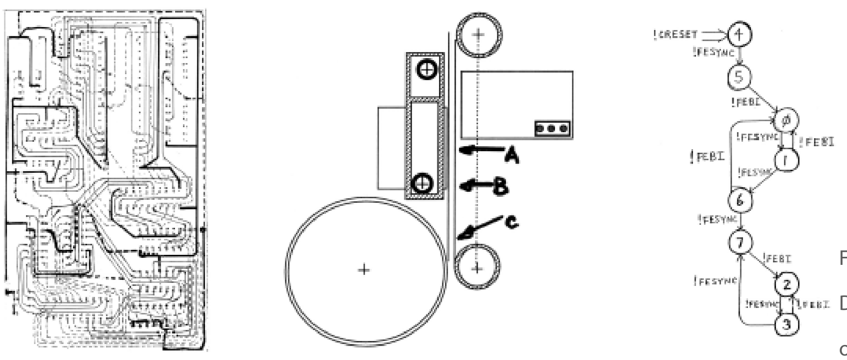


Figure 2.8 Representation forms of shared objects (Saad and Maher, 1996, Fig. 11)

The arrows between the boxes show there are relationships between the different kinds of representations. Saad and Maher used these three categories to create a base for their computer program which supports collaborative design.

Bucciarelli gave examples of different types of drawings that designers use during design communication. Figure 2.9 shows three of the examples. Drawing 1 is a drawing of an electronic circuit board. It shows both circuit topology and relative spatial location of all leads within the network. The solid lines represent the circuit on one side of the board. The dashed lines represent the other side. In this drawing, a set of meanings that must be known by both the author and the reader is coded. Drawing 2 shows mechanical hardware and is an overlay of a more formal drawing. An actor made this drawing when trying to find the best location for a particular part (A, B or C). Since it is a 2D representation of a 3D object and it does not represent all hardware, it may be hard for the actors with a different object world to read. Drawing 3 differs from the other two. An actor made this drawing in order to capture events that change over time. He made dynamic things static and assumed that this would be understood by the reader.



Drawing 1 Drawing 2 Drawing 3

Figure 2.9 Different types of drawings (Adopted from Bucciarelli, 1996)

Bucciarelli stated that the drawings themselves could not tell whether the drawings were significant within the negotiation process. They also could not tell if the drawings had stimulated them (or others) to adjust their thoughts and practices.

Sometimes, actors make drawings for more than one purpose. The correct reading of drawings requires both knowledge of the dialect of the object worlds and an understanding of the context and the moment in use. Whether drawings represent a spatial configuration, a static topology, or the dynamics of a flow process, they are sparse and abstract and symbolize only the essential features of whatever they try to convey. A reader who is able to read the symbols will not notice the abstraction.

In his thesis, Van der Lugt (2001, p. 39-49), distinguished between four types of sketching, each meant for different purposes (the first three types of sketches came from the work of Ferguson (1992) and the last came from Ullman *et al.*, (1990)):

- The *thinking sketch*, which refers to sketches designers make in order to structure their own thinking process. These sketches serve to guide nonverbal thinking.
- The *talking sketch*, which is a sketch designers make in order to support a group discussion. Talking sketches are important in the process from vision to artifact. They help designers explain technical issues because they share a common graphical setting.
- The *prescriptive sketch*, which helps designers explain decisions they have made to persons who were not involved in the process. Designers use prescriptive sketches mostly in the later stages of the design process.
- The *storing sketch*, which retains information meant for future usage.

Within collaborative design, all four kinds of sketches may be important, since actors can use them to explain to other actors the current design or a particular design solution.

Peng (1994) notes the importance of the presence of physical models during collaborative design. Working with physical models helps designers to

develop, reflect and communicate design ideas by themselves and with others. According to Peng, there are intimate relations between the production of drawings and the making of models. Designers often produce drawings as a way of developing or elaborating upon design solutions suggested during model construction. Designers also construct models for informing themselves about the consequences of design ideas explored in drawings.
Peng points out that not every drawing serves as a model by just existing. A drawing is a model and it represents modeled properties. It only has a function as a model if the sender and the receiver attribute the same meaning to the symbols. The same applies for building prototypes that can also function as communication tools between disciplines (Smulders, 2006, p.31-32). During prototyping actors from different disciplines need to actively discuss the version of the prototype on hand in relation to of the final product they are making. If there are inconsistencies or gaps between the viewpoints of disciplines, they will appear during prototyping.

We can conclude that during collaborative design, actors use various communication methods alternately, because they strengthen each other. Earlier research showed that drawings and prototypes are a powerful media for communicating content related communication (Bucciarelli, 1996, p. 90-98), (Saad and Maher, 1996) (Smulders, 2006, p. 31-32). However, they are only useful if both sender and receiver see the level of abstraction used. Furthermore, both the sender and the receiver need to know the purpose of the drawing or prototype. This might become a problem during collaborative design, since actors make sketches and prototypes for different purposes, dependent on the phase in the collaborative design process and the task they have to fulfill (Van der Lugt, 2001, p. 39-49).

2.3.3 Shared understanding in collaborative design projects

During collaborative design projects, it is important for the actors to have a shared understanding about the design they are making. This influences the efficiency of a collaborative project (Mohammed and Dumville, 2001). As Figure 2.10 shows, all actors around the table should hold the same image about the topic of conversation. (Although they share the star, parts of their knowledge remain different. This is symbolized by the different shaped of the balloons.)

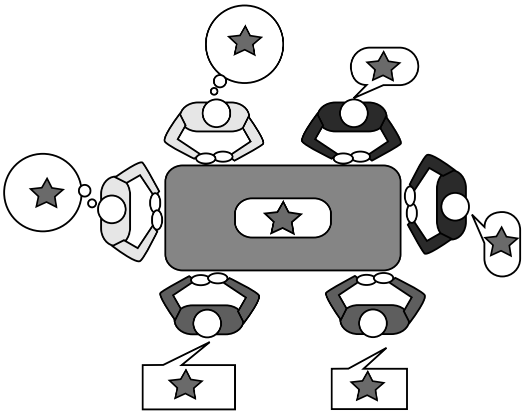


Figure 2.10 Actors have shared understanding about the design

In the first part of this section, shared understanding will be defined. The second part will describe empirical research done to detect shared understanding within collaborative design projects.

Defining shared understanding

Since the concept of *shared understanding* is difficult to define, we used (theoretical) studies in the field of *shared cognition** as stepping-stone for outlining

* *Although the research in this field is still in its formative stages (Mohammed and Dumville, 2001) and unambiguous concepts are missing, literature on organizational behavior, social- and cognitive psychology provided the stepping-stones necessary to be able to define shared understanding.*

a definition. These studies provide insight into the mental processes of the actors performing a collaborative (design) task.

Weick and Roberts (1993) developed the concept of *collective mind* to explain organizational performance in situations of continuous operational reliability. Although the field is different from product design, their theory is interesting and applicable for this thesis. Weick and Roberts used the connectionists theory that considered the mind as a *set of activities* rather than as an *entity*. This makes it possible to see the mind separate from the individual. A collective mind is the interrelated actions of the actors.

Konda *et al.* (1992) speak about *shared memory* (in design). They make a distinction between *vertical* and *horizontal* memory. Vertical memory is memory shared among members of a professional group, while horizontal memory is memory shared between groups. According to Konda *et al.*, it is the horizontal memory, which is important during design projects, since collaborative design requires integration of the knowledge of different specialists.

According to Weick and Roberts, actors in a system construct their actions (contributions) with the understanding that the system consists of actions by others (representation) and they interrelate their actions within the system (subordination). Since the interrelations between the actors are not fixed, actors construct and reconstruct them continually throughout the ongoing activities of contributing, representing and subordinating. Actors can make the connections heedful or not, which influences the quality of the collective mind. Weick and Roberts saw the interaction between the actors as a *social process*, defined as:

"…A set of ongoing interactions in a social activity system from which participants continually extract a changing sense of self interrelation and then re-enact that sense back into the system…"

Groups could loose mind, resulting in mistakes in the process of extracting and re-enacting sense back and from the system. These mistakes may result in the absence of newly generated *shared frames* and the failure of tuning between the actors.

Valkenburg defined frames as "*Sensemaking devices that establish the parameters of a problem*" (Valkenburg, 2000, p.74). Sensemaking means that actors try to make things rationally explainable for themselves and for others (Weick, 1993). On the base of this contextual rationality, actors create their own reality. Actors in a team should structure the different realities they have created together. According to Weick (1993), "*Sensemaking is about contextual rationality. It is build out of vague questions, muddy answers and negotiated agreements that attempt to reduce confusion.*" Weick emphasizes these characteristics of sensemaking in the collaborative design process. The design problem actors have to solve is ill defined. This results in an indistinct process of negotiation between actors with different object worlds, as they iterate between problem defining and problem solving in an attempt to reduce uncertainty. Therefore, the theory of Weick is applicable in this thesis.

Communication helps the actors to create shared meaning, also called shared interpretive schemes. In addition, actors structure their actions. Structuring takes place by developing structural frameworks of constraints. There is a relationship between meaning and structural frameworks (Weick, 1993). An increase in shared meaning leads to a more elaborated structure. However, the opposite is also the case. A decrease in shared meaning leads to a decrease in structure. Actors should break this downward spiral, by creating an inverse relationship between meaning and frameworks. If the creation of meaning becomes problematic, this should be a signal for actors to pay attention to (in) formal frameworks and try to reconstruct them. Frameworks can increase the shared meaning between the actors. Instead of *frames*, other authors use, the term *team mental models* or *shared mental models** (e.g. (Cannon-Bowers *et al.*, 1993), (Klimoski and Mohammed, 1994), (Mohammed

** Authors from the collective strategic decision making field prefer the term frame, while authors within the field of team dynamics and -performance prefer the terms team mental model or shared mental model (Klimoski and Mohammed, 1994).*

and Dumville, 2001), (Langan-Fox, *et al.* 2004)). Team mental models refer to a mental model shared among the whole team, while shared mental models concern dyads of actors who share a mental model (Klimoski and Mohammed, 1994). Both terms are applicable in this thesis. Sometimes it is important that all actors share a particular mental model, while in other cases only two (or more) actors have to share their mental models.

According to Klimoski and Mohammed (1994) and Cannon-Bowers & Salas (2001), the term *shared* can have different meanings. It can mean *overlapping, similar, complementary* or *distributed* knowledge. Overlapping knowledge refers to common knowledge. Similar knowledge refers to certain attitudes or beliefs that must be similar among actors in order to stimulate effective performance. Complementary knowledge means that actors complement each other. Each actor has his or her own specific knowledge. Together, they are able to accomplish their task. Sharing can also mean distributed knowledge when it refers to actors who apportion information.

Several authors have defined the concept of team- or shared mental models. (e.g. (Cannon-Bowers *et al.*, 1993), (Mohammed and Dumville, 2001), (Levesque et al. 2001)) In this thesis, we applied the definition of Cannon-Bowers *et al.* (1993), which reads:

"*Shared mental models are knowledge structures held by members of a team that enable them to form accurate explanations and expectations of the task, and in turn to coordinate their actions and adapt their behavior to demands of the task and other team members.*"

This definition is applicable here because during product design, actors with different knowledge bases need *overlapping* (shared) knowledge about what their separate tasks comprehend and about which results they have to deliver individually or together. Since their tasks are interrelated, actors have to *coordinate* their actions in order to be efficient. Accordingly, shared mental models contain components concerning both the content and the process. In reference to this aspect, Cannon Bowers *et al.* (1993) make a distinction between *taskwork* and *teamwork*. Taskwork refers to skills related to the execution of the (individual) task. Teamwork refers to skills used for identifying the need for communication, monitoring and coordination strategies (Klimoski and Mohammed, 1994).

Mohammed and Dumville (2001) also acknowledge the process component of shared mental models. They adopted the term *transactive memory*, defined by Wegner (1987) as: "*a set of individual memory systems, which combines the knowledge processed by particular actors with a shared awareness about who knows what*." Transactive memory makes it possible to develop complex products with actors from different disciplines without having too much redundancy of knowledge. In other words, effective transactive memory makes collaboration between actors with different thought worlds or object worlds possible.

Executing their (product design) task, a team constructs multiple mental models, all referring to different parts of the problem or the process (Cannon Bowers et al., 1993), (Klimoski and Mohammed, 1994). Cannon Bowers *et al.* (1993) define four different categories of mental models actors develop during general team processes. It seems that these categories can also be applied by actors in a product design process. The first category is about the understanding actors have of the equipment with which they have to extract information. The second category deals with the understanding actors have of their task and the method they use for fulfilling this task. The third category is about their contribution in relation to the contribution of others. The last category concerns knowledge about the knowledge itself, skills, abilities, preferences and other task-relevant attributes of the other actors.

Langan-Fox *et al.* (2004) state that the team *process* of the creation of team mental models is important. Team mental models represent the *shared understanding* of actors about the knowledge distributed among them. Langan-Fox *et al.* (2004) developed a model for describing shared understanding of the team about the team, task and context. Figure 2.11 shows the model called *Acquisition and Development of a Team Mental Model.* The model consists of three phases. Phase 1 consists of the team formation and initial developments. In this phase, actors build preconceptions, which are based on prior knowledge. Within this phase, actors develop a shared understanding of how the team operates and of their particular role. In phase 2, actors overcome their prior knowledge bias and they develop understandings about causal relationships. Individual models begin to overlap in this phase. In phase 3, teams perform at a high level because the operations and interactions are smooth, actors are comfortable in their roles and actors know each other thoroughly. In this phase, actors should be able to recognize patterns of behavior and retrieve old knowledge. In relation to task specific knowledge, actors should have a shared understanding about task requirements, their role within the team and the norms, processes and requirements specific to the team.

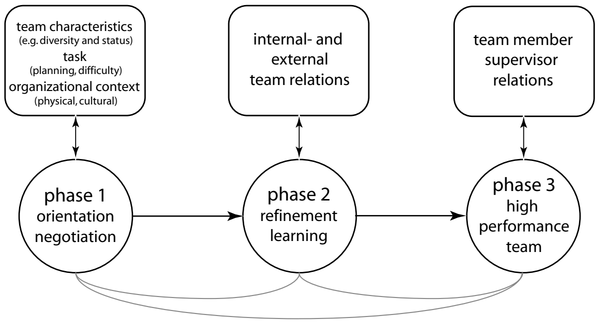


Figure 2.11 Acquisition and development of a team mental model (Langan Fox *et al.*, 2004)

Research on shared cognition provided insight into the cognitive processes that take place during collaborative design. During the process of creating shared understanding, actors together develop new frames that are based on their shared constructed reality. Next to this, theory on shared mental models shows that mental models have a process component and a component related to the content. Actors within a collaborative design project have shared understanding:

- if they have similar perceptions about the conceptualization of the design content, or

- if they are able to create an effective transactive memory system

These insights make it possible to define shared understanding. Therefore, the definition of shared understanding reads as:

Shared understanding is a similarity in the individual perceptions of actors about either how the design content is conceptualized (content) or how the transactive memory system works (process).

After this theory section, the next section will describe empirical studies on detecting shared understanding between actors within collaborative design processes.

Empirical research on shared understanding during collaborative design

Researchers in the field of cognitive and social sciences have criticized the lack of empirical studies on shared cognition (Mohamed and Dumville, 2001), (Cannon-Bower and Salas, 2001), (Langan-Fox *et al.*, 2004). In the field of collaborative design, only a few researchers have operationalized concepts of shared cognition. This section describes the studies that concern the detection of shared understanding within collaborative design projects.

Valkenburg and Dorst (1998) and Valkenburg (2000) were interested in how actors created shared understanding about the design content. They used Schöns theory of the reflective practice to describe team communication. The reflective practice is a continuous process of four activities that alternate continuously. These four activities are naming, framing, moving and reflecting. According to Valkenburg, *naming* is the activity in which actors make things that need attention explicit. During naming a designer makes a choice of the things that matter (Valkenburg, 2000, p. 73). Frames guide the design process and communication about the design content. *Frames* enclose the solution space of both the design content and to the design process. Valkenburg (2000, p. 186-189) detected different type of frames:

- frames to approach the design task

- frames to analyze the design problem
- frames to create design solutions
- frames that represent the concept chosen
- frames that represent a sub solution

In a collaborative design project, during framing, actors tune their joint activities, both on the content level as well on the process level. During framing actors are creating shared understanding on both aspects. Therefore, the framing activity is an important activity in this research project. According to Valkenburg, (2000, p. 74) *moves* are: '*activities, like generating ideas, exploring problems or looking at the consequences of design decisions, undertaken by the design team.*' Moves often contribute to reframing the design problem. Valkenburg distinguished two types of moves. First, moves inside frames, which are guided. Second, moves outside frames that seem to lack a goal.

The last activity is *reflection.* Reflection is according to Valkenburg the activity during which actors reflect on what they are doing. Next to this reflection is the activity during which actors question where their action is taking them within the design task (Valkenburg, 2000, p. 75). Actors use reflections as guidance of both project progress and project quality. Reflections can lead to reframing the problem or to new moves (Valkenburg, 2000, p. 72).

Furthermore, Hill *et al.* (2001), Song *et al.* (2003) and Dong (2005) developed a method for detecting shared understanding within collaborative design teams. They state that identifying shared understanding within a design team and gaining understanding how teams acquire and maintain knowledge are important management aids. They viewed the design process as a social process of *storytelling. Storytelling* means establishing a coherent story about the design process and the designed artifact by bringing coherence to the perspectives and interests of each design team member. Team communication is efficient when actors are able to borrow from and relate to a combined group voice.

Hill *et al.* (2001) started to develop a methodology for identifying shared understanding in design documentation. They used a computational linguistic technique called *latent semantic analysis*[*] (LSA) for conducting content analysis on documents on engineering courseware. The results of their study showed LSA to be a sufficient method for detecting shared understanding.

Song *et al.* (2003) examined the written and oral histories of eight multidisciplinary student teams by using LSA. From the results, it appeared that there were changing levels of coherence in storytelling within the teams. There was an increasing coherence with cycles of divergence during the design process. This iterative broadening and narrowing of the design possibilities was desirable because it lead to creative solutions. In the early conceptual design stages it was adventurous for a team to explore broadly. Towards the end of the process, teams had to reach coherence. Song *et al.* could measure this by linking the variation in coherence to the quality of the final design. This finding is in line with Buijs (1984, p.148-153) who found that extensively diverging lead to better end results.

Dong (2005) extrapolated the earlier studies of Hill *et al.* (2001) and Song *et al*. (2003) by analyzing protocols of the *Delft Protocols Workshop* (Cross *et al.*, 1996) and *The Bamberg Study* (Stempfle and Badke Schaub, 2002). Analyzing these protocols was more difficult than analyzing texts because the protocols contained sets of short utterances, most of which contained too few words to establish enough contexts for LSA. Therefore, Dong chose to compute aggregate average semantic coherence between utterances, which were one utterance away, two utterances away and further. From this analysis, it appeared that successful teams built upon each other's representations of knowledge and ideas as expressed through lexicalized concepts. Dong also analyzed how one's language use becomes similar to the group's overall language. Dong called this process '*knowledge convergence*'. From these analyzes it appeared that successful teams converge their knowledge. The structuring of language based communication over time played a transitive role in the formation of what Dong called *the socially held representation* of the actors. Dong believed that these socially held representations could charac-

* *For a explanation of LSA, Song et al. refer to Landauer et al. (1998)*

terize shared understanding in design. (Dong defined shared understanding as the existence of agreement by the design team of congruent thinking regarding to the product concept.) Dong concluded in his article with the claim that LSA was a proper method for decoding language based communication within the design teams in order to create an abstract semantic representation of the product being designed.
What was also interesting of Dongs study was that his computational analyses provided similar results as post-hoc reflections done by the teams on both the team behavior and individual behavior.

The work of Dorst and Valkenburg (1998), Valkenburg (2000) and the studies of Hill *et al.* (2001), Song *et al.* (2003) and Dong (2005), showed both the reflective practice, operationalized by Valkenburg (2000), as well as LSA, are valid methods to detect shared understanding within collaborative design teams.

Research standpoint 2.4

The aim of this chapter was to review existing literature on the field of collaborative design in order to investigate is there was enough knowledge available to solve our problem statement as formulates in Chapter 1. The research questions that we answered in Chapter 2 are:

1. *What is the definition of collaborative design?*
2. *What are the characteristics of the collaborative design projects?*

By comparing collaboration with other forms of working together, we defined collaborative design as:

Collaborative design is the process in which actors from different disciplines share their knowledge about both the design process and the design content. They do that in order to create shared understanding on both aspects, to be able to integrate and *explore their knowledge and to achieve the larger common objective: the new product to be designed.*

This provides us with an answer to the first research question of this chapter.

This definition of collaborative design shows that collaborative design consists of three building blocks:

- knowledge creation and integration between actors from different disciplines
- communication between the actors about both the design content and the design process
- the creation of shared understanding about the subjects communicated

In order to answer the second research question, we have conducted a literature review about these three components of collaborative design. This section describes the main conclusions from this literature review in order to come to a research focus.

First, the review on literature on knowledge creation and -integration shows that this process exists of a divergent phase of knowledge creation followed by a convergent phases of knowledge integration. In an efficient divergent phase, the different object worlds of the actors lead to creative ideas. In the divergent phase, actors create new knowledge by combining their individual qualities. However, in the convergent phase the actors need architectural knowledge about the whole system in order to be able to develop an optimal solution (Leonard-Barton and Sensiper, 1998). In both phases, some redundancy of knowledge between the actors is important for effective knowledge transfer (Nonaka and Takeutchi, 1995).

Second, empirical research on topics of design communication shows that communication about the design content is a substantial part of all design

communication. This justifies the earlier decision to focus on this kind of design communication in the remainder of this thesis.
Furthermore, earlier research shows that there are two methods for describing team communication:

- as a *reflective practice* (Valkenburg and Dorst, 1998), (Valkenburg, 2000)
- as a *decision-making process* (Badke-Schaub and Frankenberger, 1999), (Badke-Schaub and Gerlicher, 2003)

Both methods provide with insight in the quality of team communication. Describing team communication as a reflective practice provides with insight in the activities actors perform. Describing team communication as a decision-making process gives insight in how the sequences of the decision-making process followed-up each other and how this affects the effectiveness of team communication.

Third, the building block about the creation of shared understanding. This component of collaborative design is less extensively investigated than the other two building blocks. With the use of literature about shared cognition we defined shared understanding. The definition that we use in this thesis is:

Shared understanding is a similarity in the individual perceptions of actors about either how the design content is conceptualized (content) or how the transactive memory system works (process).

Empirical studies on the detection of shared understanding show that within collaborative design teams it is possible to detected shared understanding by using the *reflective practice* or *Latent Semantic Analysis* (Dong, 2005), (Valkenburg, 2000). Both the work of Valkenburg (2000) and Song *et al.* (2003), show that the process of creating shared understanding influences the quality of the final design. This makes it interesting to create more knowledge about the process of creating shared understanding. The work Valkenburg (2000) and Dong (2005) show that it is possible to detect shared understanding between actors involved in a collaborative design process. They also show that it is possible to describe the process of creating shared understanding.

In this thesis, we will elaborate on the studies of Valkenburg (2000) and Dong, (2005). We will focus on the factors that influence the process of creating shared understanding. In order to create knowledge about these factors, we will do empirical research. In the next section, we will formulate the research questions that we will answer by executing empirical research.

2.4.1 Research questions

We have decided upon an empirical study, in order to create knowledge on the factors that influence the creation of shared understanding. These factors will either support or hamper the creation of shared understanding. Factors that support the creation of shared understanding are called *enablers* and factors that hamper the creation of shared understanding are *barriers*.

The aim of this empirical research is twofold. First, we will investigate what the barriers and enablers are for the creation of shared understanding. We will investigate barriers and enablers that the actors involved in collaborative design processes face. We have chosen this strategy, since they are the experts of their own collaboration process. By reflecting on their own collaborative processes, they will be able to indicate what the stimulating or hampering factors were. Therefore, the accompanying research question reads as:

What factors influence the creation of shared understanding during collaborative design processes in the industry?

The second aim of the empirical research project is to find out if there is a relationship between the different barriers and enablers. If we are able to find relationships between barriers and enablers, we will investigate what the underlying patterns are. We will call these patterns *collaborative mechanisms*. Collaborative mechanisms describe what influence the barriers and enablers for the creation of shared understanding have on the three building blocks of collaborative design. Knowing the collaborative mechanisms is the first step towards implications towards improving collaborative design projects. Based on the preceding argumentation, the second research question of this thesis is:

What collaborative mechanisms influence the creation of shared understanding during collaborative design processes in the industry?

In Chapter 3 we will set up the empirical study. In this study we will investigate what the influencing factors are. Additionally we will investigate if there is a relationship between these factors.

RESEARCH DESIGN 3

Introduction 3.1

In Chapter 2, we decided upon the execution of an empirical study in which knowledge will be gathered about barriers and enablers for the creation of shared understanding. Since there is not much theoretical knowledge about the barriers and enablers for the creation of shared understanding, the empirical study will be explorative in nature.

The goal of Chapter 3 is to design a research method that will enable us to answer the research questions set in Chapter 2. These research questions read:

1. *What factors influence the creation of shared understanding during collaborative design processes in industry?*
2. *What collaborative mechanisms influence the creation of shared understanding during collaborative design processes in industry?*

Although, these two explorative *what* questions leave space for any research strategy (Yin, 1994, p.5), we choose *case studies* as strategy for this research project. The purpose of the study to gain insight into the process of creating shared understanding within collaborative design projects in practice. Based on the different typologies of case studies, Patton (1990, p. 153-155) describes this type of research as *applied research*. This means that we want to gain deeper insight into the problem being studied. In addition, we are interested in how the actors involved in collaborative design projects experience their own design process.

In the remainder of this chapter, we will present the design of the empirical study. In order to position our case study, we will explain the chosen case study approach in section 3.2. In section 3.3 we will develop the research method for our empirical research. This method is based to a large extend on the learning history method as developed by Roth and Kleiner (2000). In section 3.3, we will first explain what the learning history method comprises and for whom it has been developed. In the last part of section 3.3, we will show the research method for this case study. In section 3.4, we will describe the design of our research project. We will also set the requirements for cases that are suitable for this empirical research in this section. The last part of this section comprises the case selection. This chapter will end with an overview of the structure of the empirical research projects.

3.2 Case studies as research approach

This research project is set up as an *instrumental case study* (Denzin and Lincoln, 2000, p. 437). This means that the aim of this research is to generalize the findings and to make them applicable to other collaborative design projects. Verschuren and Doorewaard (1999, p. 163) defined a case study as: "*Case study research is a type of research during which the researcher tries to gain a profound insight into one or several objects or processes that are restricted in time and space*". In this research project the space is a company in which a collaborative design project takes place.

In this explorative case study, discovering causalities is more important than testing predetermined causalities. This attitude suits the holistic-inductive approach of case study methodology and eliminates the choice for a hypothetical-deductive approach. Within the holistic-inductive case study approach there is no distinction made between the research unit and observational unit (Yin, 1994, p.38-44). Following the holistic-inductive approach, the researcher tries to see the subject under study as a whole within its context, during both data gathering and data analysis (Patton, 1990, p. 167). This prevents the creation of a tunnel vision, caused by predetermined causalities (Verschuren, 2003). In this case study the observational unit is *the process of creating shared understanding between actors involved in a collaborative design process*.

By doing case studies, data collection is not constrained by predetermined methods of analyses. Instead the researcher has the opportunity to study selected issues in detail (Patton, 1990, p. 165). Following the holistic-inductive approach, we will use qualitative techniques as observations, interviews and desk research for collecting data. We will then use content analyses techniques for analyzing the data.

In the next section, we will describe how we will execute both data collection and data analyses. This research method is, to a large extent, based on the *learning history method* that is developed by Roth and Kleiner (2000).

The learning history method 3.3

The MIT Sloan School Center for Organizational Learning developed the learning history method (Roth and Kleiner, 2000, p. 180). Roth and Kleiner are researchers within this center. They wrote the book *Car Launch*, which is an example of a learning history (Roth and Kleiner, 2000). This book inspired us to use the learning history method in this research project.

The learning history method was developed as a response to traditional methods used for measuring, assessing and evaluating learning in teams. The researchers of the MIT Sloan School Center for Organizational Learning were critical of the traditional methods. They had the opinion that these methods hamper, rather than stimulate, learning. According to them, traditional assessments often result in hard numbers used to judge the actors involved. Therefore, actors try to fit the assessment criteria, rather than trying to improve upon their abilities. Furthermore, softer changes cannot be inquired because they are difficult to measure (Roth and Kleiner, 2000, p. 179-180). Roth and Kleiner claim that (2000, p. 201) '*Individuals within organizations will be more effective as they increase their awareness of, operate with an understanding of, and continually test the theories they hold and the underlying mental models which form their own thinking and acting.*' They also presume that more shared understanding serves the development of more collective action (Roth and Kleiner, 2000, p. 193). Learning histories could facilitate the creation of shared understanding and therefore improve learning (Roth and Kleiner, 2000, p. 199). This assumption forms the foundation for the learning history method.

The base of the learning history method is storytelling. The learning history researchers use a theory of ethnographer Van Maanen. In his book *Tales of the Field*, Van Maanen describes a form of ethnographic storytelling called *jointly told tale* (Van Maanen, 1988, p. 136-138). Jointly told tales make it possible to incorporate the experiences of the actors with the (objective) viewpoint of the researcher (Roth and Kleiner, 2000, p. 190).

In the remainder of this section, we will explain what the learning history process is. In addition, we will show for which types of audiences a learning history is best suited. Finally, we will show how we applied this method as a research method for this research project.

3.3.1 The learning history process

In their book *Car Launch*, Roth and Kleiner (2000) observe the development process of a new car. They call their case study the *AutoCo case* and the design project is called *Epsilon*. Roth and Kleiner observe the collaborative processes of the actors in AutoCo. The observations of Roth and Kleiner are analysed by both researchers and practitioners. From the observations, they select *noticeable results*. According to Kleiner and Roth (1996, p. 7-1), '*noticeable results are outcomes, activities, events, behaviours or policies which are out of the ordinary, much different than would have typically occurred before the learning project*.' Some examples of noticeable results that Roth and Kleiner (2000, p. 9) found in their AutoCo case are mechanical prototype build, team collocation, market research clinic, etc.

The noticeable results form the input for the interviews. The actors interviewed can choose from the list of noticeable results those which are most relevant and pertinent to their own experiences (Roth and Kleiner, 2000, p.189). The interview with an actor is about the noticeable results chosen by the actor. Roth and Kleiner (2000, p. 189) suggest that such interviews should be conducted by both an internal staff member as well as an external researcher. The internal staff member can help with the interpretation of the critical details and nuances, while the external researcher can ask naïve questions and come up with non-discussable issues. The interview itself is open. During the interview, an actor presents his experiences and understandings about a noticeable result.

Both the researcher and the practitioners analyse the interview. They write their interpretations down and put them on paper next to the written interview. The transcribed interview and the interpretations together form a jointly told tale. In order to verify the observations and the interviews, the researcher also consults documents and archival records (this is a form of data triangulation). Themes are then derived from the jointly told tales of the different actors (Roth and Kleiner, 2000, p. 190). Since the purpose of the learning history method is organizational learning, Roth and Kleiner (2000) formulate the themes as lessons or changes in attitude that took place during the research project. Some examples of the themes that resulted from the AutoCo case are (Roth and Kleiner, p. 3-4):

- combining engineering innovations with human relations partnerships
- process innovation in a large organization

The last step in the learning history process is the validation of the data. Validation consists of two steps. The first step concerns a check of the quotes by the actors. The second step is a series of validation workshops with interviewees and actors from elsewhere in the organization (Roth and Kleiner, 2000, p. 192). The purpose of these workshops is to share knowledge between projects.

3.3.2 The learning history audiences

Since the purpose of the learning history method is organizational learning, it is important that the results of the research are shared more broadly than just between the actors involved. Roth and Kleiner distinguished four different audiences that could learn from a learning history project. All audiences have their own particular interest. Figure 3.1 shows the four types of audiences (A, B, C, and D). Audience A is made up of the actors that were actively involved in the research project. By telling their stories about the design project, they reflect on their own process. In addition, they can read the researchers' interpretations on their stories. These two aspects help them to gain a better understanding of their individual experiences. Audience B consists of the newcomers of the team. They can use the learning histories to quickly break into the design project. Audience C is the organization as a whole. They, of course, want to know about the lessons that have been learned and which themes have been found. They use the learning histories to construct a shared vision on how to execute future projects. Audience D is the outside world. Presenting the learning history to the outside world is a critical part of organizational reflection. It provides feedback which an organization would otherwise never receive. Researchers are part of Audience D. For researchers, the learning history is a source for ongoing research about organizational learning (Kleiner and Roth, 1996, p.6-2/6-7).

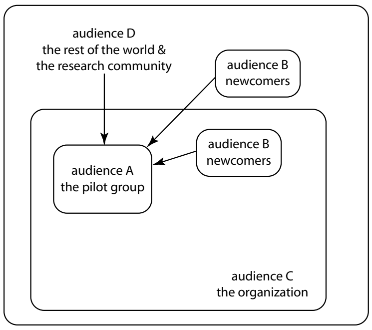


Figure 3.1
The different audiences of a learning history (Kleiner and Roth, 1996, p. 6-1)

In this research project we also have to deal with different audiences. Our first goal is to gain new knowledge about the influencing factors for the creation of shared understanding and their mutual relationship. Serving Audience D is, therefore, our main goal. However, in order to interest companies in participating in this research project, the research should also valuable for Audiences A, B and C. We will serve the Audiences A, B and C by actively discussing the results found and by giving them implications for improving their future collaborative design projects.

Learning histories as a research method 3.3.3

Although the learning history method is not set up as a research method for the purpose of this research project, we think that the learning history method is suitable for finding answers to our research questions. We have two reasons for this assumption.

First, the base of the learning histories is storytelling. According to Lloyd (2000), storytelling in design projects helps actors to relate events to each other. Since we are interested in the factors that influence the creation of shared understanding and their mutual relationship, this is important for this research project. By providing explanations of why something is happening, one will encourage others to recognize the interpretations made (Lloyd, 2000).

Since the process of creation of shared understanding is strongly related to the content of the design problem under study, the results of this research project cannot be seen as separate from this content. Storytelling can both help researchers and actors involved in other collaborative design processes recognize the situations described.
The second reason is that according to Roth and Kleiner (2000), learning histories can facilitate the creation of shared understanding. This implicates that the learning history method is a tool for indicating situations in which actors are creating shared understanding. These situations will form the noticeable results of our case study. Since actors actively create stories around these situations, we should be able to distil the factors that influence this process.
These two aspects of the learning history method made us choose for this method as the base for our research methodology.

Figure 3.2 shows the research steps that we distinguished from the learning history method by analysing the work of Kleiner and Roth (1996). We divided the learning history process into three phases: data gathering, data processing and data analyses. Each phase consists of activities and results. In Figure 3.2, the activities are represented by squares and the results are presented by diamonds.

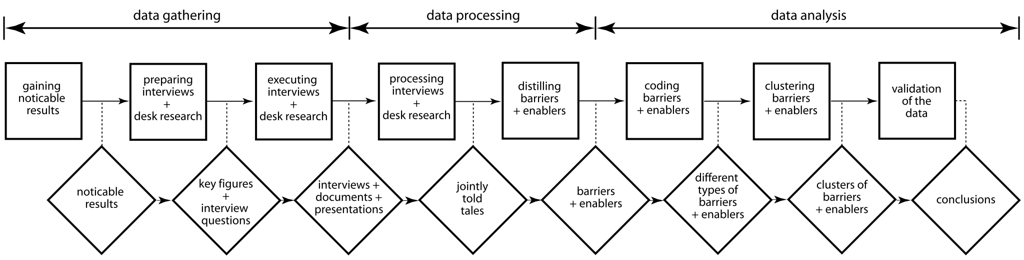


Figure 3.2
The learning
history process

During data gathering, gaining noticeable results is the first activity. The noticeable results function as input for the preparation of the interviews and the desk research. Both the selection of the key figures to interview and the set up of the interviews are results of this preparation. The last activity of the data gathering phase is the actual execution of the interviews and the desk research.

In the data processing phase, the interviews are processed and jointly told tales originate. Barriers and enablers are distilled from the jointly told tales.

The last phase concerns data analysis. This phase starts with coding and clustering the barriers and enablers. The coding of the barriers and enablers provides insight into the kind of factors that influence the creation of shared understanding. The clustering provides insight into relationships between the barriers and enablers. Since researchers have to interpreter the data during case studies, it is important to check these interpretations with the key figures. Therefore, data validation is the last activity of data analysis. After data validation has occured the final conclusions of the study can be formulated.

Our approach differs considerably from the approach of Kleiner and Roth (1996) in reference to one aspect. As stated before: *"Roth and Kleiner (2000, p. 189) suggest that such interviews should be conducted by both an internal staff member as well as an external researcher. The internal staff member can help with the interpretation of the critical details and nuances, while the external researcher can ask naïve questions and come up with non-discussable issues."*

We think that the presence of an internal staff member will substantially influence the story of an actor. Since there is a formal relationship between the actor interviewed and the internal staff member, we think that the actors interviewed will not come up with non-discussable issues such as for example controversial decisions. Therefore, we will not use an internal staff member for helping us with the interviews. We think we are able to interpret the critical details and nuances ourselves, since we are educated as Industrial

Design Engineers. Our knowledge of designing products will be sufficient for understanding all of the nuances and details of the stories. (For a description of the knowledge of an Industrial Design Engineer educated at Delft University of Technology see section 1.2)

3.4 The design of the empirical research project

An important step within the design of a case study research is case selection (Verschuren and Doorewaard, 1999, p.164), (Denzin and Lincoln, 2000, p.446). Case selection is dependent on the following aspects (Denzin and Lincoln, 2000, 446), (Verschuren and Doorewaard, 1999, p. 166-167):

- the ability to observe the phenomenon of interest
- the availability of the case
- the opportunity to learn from the case
- the level of variety between the cases

This section describes how we selected the cases for the empirical studies.

The first step in case selection is to determine in which situations the phenomenon of interest is observable (Denzin and Lincoln, 2000, p.446). In each project where actors communicate, the creation of shared understanding is observable. However, not every kind of communication is suitable to find an answer to the research questions. Therefore, the context in which the communication takes place should be determined. The context of this research project exists of three levels; the company-, the project- and the actor level. The selection of a case depends on the characteristics of these three levels. Figure 3.3 shows these levels.

The first level is the company level. Since we want to create insight in the creation of shared understanding during collaborative design projects, the case studied should come from companies that develop industrial products. Since we do not want other projects influencing the case studied, we will choose collaborative design projects to which the actors are fully committed.

The second level is the project level. It is best to do a case study concern-

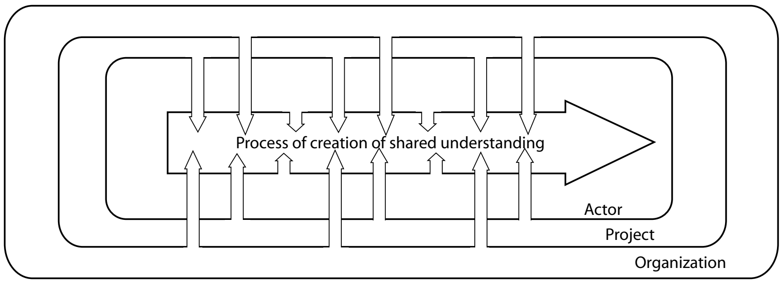


Figure 3.3
The object under study and its context

ing a complete collaborative design project since that will provide the most knowledge. However, it is important to gain detailed knowledge. Therefore, if a full collaborative design project is not attainable, then the case should include the concept phase. The concept phase is traditionally the most difficult phase for the creation of shared understanding and therefore most interesting for this study (Chiu, 2002). Furthermore, the collaborative design project should be about a product which consists of multiple functionalities (such as mechanical and electrical parts) that are highly interdependent. The last aspect on the project level is the innovativeness of the collaborative design project. The collaborative design project studied should encompass something innovative, something new (from the viewpoint of the actors involved). If there is a new aspect in the design project, then actors do not have complete shared understanding at the start of the project. Therefore, actors actively have to create shared understanding.

The third level is the actor level. Since the product to be designed consists of different functionalities, actors from different disciplines and functionalities have to collaborate intensively. Therefore, actors within the collaborative design project must have different object worlds. Furthermore, the actors should have different types of tasks and responsibilities.

Based on the analyses above, we can conclude that a case should comprise the following aspects:

Company level:

- be about an industrial product
- the actors involved should be full committed to the design project

Project level:

- an entire design project or otherwise the concept phase
- the product designed should have multiple functionalities
- the actors should have a high task interdependency
- innovative aspects

Actor level:

- actors with different object worlds should be involved
- actors with different types of tasks and responsibilities should be involved

The last criterion for choosing a case on the base of the observable unit is not only dependent upon the case itself. It also deals with the researcher executing the case study.

Since within the research project the creation of shared understanding is the observational unit, the researcher should be able to understand (the communication within) the collaborative design project. Interviews at the beginning of a case study will provide clarity on this aspect.

Another aspect that concerns the researcher is the fact that the researcher should know on which aspects he has to focus on while investigating the (complex) process of collaborative design. The nature of this study is explorative and we do not yet have much insight into the collaborative processes. This made us decide to first conduct a retrospective case study. This study will be used to get a preliminary impression of the factors that influence the creation of shared understanding and the relationships between these factors. The advantage of a retrospective case study is that a researcher is able to gather data from the entire product design project. The actors have already finished the project. They can therefore reflect on the most important issues concerning their collaboration process. This will provide us with an overview of the collaborative aspects of an entire design project, seen from the viewpoint of the actors. In a second study, we will observe a design team real time. By conducting a real time case study, we will be able to observe the actual creation of shared understanding. In the real time case study, it is the researcher that chooses the important issues and the actors that are involved in these issues reflect on it. In this way, we enrich the first case study, by adding the viewpoint of the researcher to the study. We will use the knowledge about important issues of collaborative design gained during the first empirical study.

The next step of the research design is the actual case selection. We based the selection of the cases both on the base of the criteria set and on the availability of the cases.

As stated before, case selection within this research project took place in two stages. The first stage of case selection was in the beginning of the research project. (The case selected is called Case 1 in the remainder of this thesis.) Case 1 concerned the midlife update of a midrange truck. The actors involved in this collaborative design project were fully committed to the design project. Case 1 comprised the whole design project. We did not concentrate on the entire truck. We only focused on the interior of the cabin. We chose this part of the truck since most innovations of the design project occurred in this part of the truck. In addition, the integration of different functionalities is particularly important in this part of the truck. This makes the task interdependencies between the actors high, resulting in the involvement of actors from different object worlds. Furthermore, the actors involved differed in both discipline and function.

Case 1 is set up as a retrospective case study. Case 1 functions as a pilot case from which we learn which aspects we should focus on during a real-time case study. The real time case study, Case 2 is the main study of this research project.

The second stage was the selection of the real time case. There were two cases

available for this second case study. The first case available (Case 2a) was about the development of the tunnel technical installations of the Dutch high speed train, an industrial product with multiple functionalities. The actors involved were fully committed to the design project. At the start of the case study, the project was in its concept phase. There were two new processes that needed to be integrated into each actor's normal design process. This was the innovative aspect of this case. In addition, the actors were not used doing design projects this extensive size. This resulted in a high extend of division of labor and, therefore, high dependency between the actors. The actors involved had different object worlds and their tasks varied from full-time management to full-time engineering.
The second case available (Case 2b) was about the redesign of the IC of a recordable DVD player. All actors were fully committed to the project and were co-located in three countries. At the start of the case study, the project was in its concept phase. The IC needed to be integrated into a DVD player. Therefore, multiple functionalities were represented in this design project. Since the IC is small and it has a lot of functionality, the task interdependency between the actors was high. The speed of the IC had to be increased from eight times to sixteen times the writing speed. This was the innovative aspect of this case. The time-to-market was one of the main drivers in this collaborative design project. The actors involved in this design project came from different disciplines and had different functionalities. They came from different object worlds. Most actors were involved in earlier collaborative design projects concerning the design of an IC.

Both Case 2a and Case 2b met the criteria for case selection. However, due to time restrictions, we could only execute one case. Therefore, we had to make a choice between the two cases. We based our choice partly on the third criterion for case selection: the ability to learn from the case selected (Denzin and Lincoln, 2000, p. 446). We expect that the creation of shared understanding is more difficult in Case 2a than in Case 2b. Case 2a was new for all of the actors, while Case 2b concerned a redesign. Therefore, we expect to learn more from Case 2a than from Case 2b.

Another reason for choosing Case 2a was that there was more similarity between Case 1 and Case 2a than between Case 1 and Case 2b. Most actors within the project teams of both Case 1 and Case 2a were located in one place. The design team of Case 2b, however, was co-located in three different countries. Next to this, the companies of Case 1 and Case 2a were the principal of the collaborative design project studied. The company of Case 2b had the role of Supplier. Finally, the actors within both Case 1 and Case 2a were not familiar doing a large design project with each other. The actors in Case 2b were familiar with these large design projects, because of the short cycle time of their design projects. The cycle time of the products designed in Case 1 and Case 2a were considerably longer and comparable. Case 2a is named Case 2 in the remainder of this thesis.

Conclusion 3.5

The aim of this chapter was to design an empirical research project. Since the nature of the research questions is explorative, we decided upon an explorative case study. As a research strategy, we choose for a holistic-inductive approach. This means that we will study the creation of shared understanding in its real life context in order to find the factors that influence the creation of shared understanding. Furthermore, we will search for the relationships between the factors found.

In this chapter, we developed the learning history method (as constructed by Roth and Kleiner, 2000) into a research method that was suitable for our purpose. Developing learning histories of the cases selected will enable us to detect the barriers and enablers for the creation of shared understanding (as seen from the perspectives of the actors). Since stories always show the coherence between different subjects, this will also enable us to see the relationships between the barriers and the enablers.

In order to gain reliable data, we will use our knowledge as Industrial Design Engineers during both data gathering and data analysis. During data gathering, our knowledge will help us to focus on the design content. In addition, it also enables us to pose the significant questions during the interviews. During data analysis, our knowledge will help us to interpret the data en to give feedback to the company.

The last part of this chapter concerned the design of the empirical research. The first step of the design of the empirical research was case selection. Based on the literature review, we set the criteria that a design project needed to meet in order to be eligible for this research project. We selected two cases that were comparable on almost all aspects. There were two differences between the cases. The first difference between the two cases was that Case 1 covered an entire design project, whereas Case 2 only entailed the concept phase. The second difference was that Case 1 was executed retrospectively and Case 2 was executed real-time. Clearly these differences influenced the type of data that we collected. During the cross case comparison (reported in Chapter 6) we took these differences into account.

Figure 3.4 shows the research design as we developed it in this chapter.

Figure 3.4 shows the research project exists of three phases: (1) definition and design of the case study, (2) preparation, collection and analysis of the data and (3) analysis and drawing conclusions of the case study.

The first phase concerns:

- defining the research problem under investigation
- a review of existing literature about the problem under investigation
- the selection of the cases

Figure 3.4 shows that we described Phase 1 in chapters 1, 2 and 3.

The second phase concerns data preparation, data collection and data analyses. We will execute this step sequentially. First, we will design and execute Case 1 (this is reported in Chapter 4). Case 1 is a retrospective case

study. The aim of this study is to create some preliminary knowledge about the influencing factors on the creation of shared understanding. Furthermore, we did this case study in order to create some knowledge about relationships between the factors and the accompanying collaborative mechanisms. Case 1 functioned as a pilot for the second empirical study; Case 2. Case 2 is a real time case study. In this case study we will actually observe a design team in action. The aim of this study is to gain extensive knowledge about the influencing factors for the creation of shared understanding. Additionally, we will gain insight into the relationships between the factors. This will lead to a description of the collaborative mechanisms of Case 2. Chapter 5 reports the data preparation, data collection and data analysis phase of Case 2.
In Chapter 6, we will compare the two cases in a cross case comparison. In Chapter 6, we will also provide answers to the two main research questions that are stated in the introduction of this chapter. Based on the results found in both cases, we will try to make some generalizations about other collaborative design projects. Finally, we will develop implications in order to improve future collaborative design projects. This will be reported in Chapter 7.

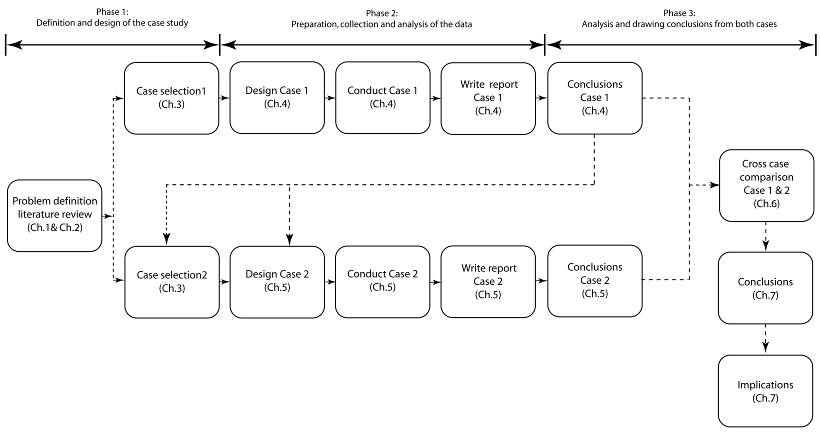


Figure 3.4 Case study design (based on Yin, 1995, p. 49, Fig. 2.5)

A RETROSPECTIVE PILOT CASE STUDY 4

Introduction 4.1

This chapter discusses the first empirical study of this thesis. This empirical case study is called Case 1. Case 1 functions as a pilot study that is explorative in nature. The goal of this empirical study is dual. The first aim is to test if the learning history method, as we developed it in Chapter 3, is suitable for the purpose of this study. The second aim is to gain some insight into the factors that influence the creation of shared understanding in a collaborative design project and the relationship between these factors. (Parts of this study have been published earlier in Kleinsmann and Valkenburg, 2003, and Kleinsmann and Valkenburg, 2005. Some parts of this chapter are taken from these publications.)

Case 1 concerns a case study in an automotive company. It was about the design process of a truck. Both legislation and increasing customer demands formed the base for the start of this design project. Since the development of a truck takes more than 600 man years, many actors were involved during the development of the truck. Since both technical- and stylistic aspects played an important role, actors from many different disciplines were represented in the design project. The tasks of the actors were closely related and the actors were highly dependent upon each other. Therefore, the creation of shared understanding played an important role in this design project. Case 1 comprised the entire design project. Since Case 1 was executed after the design project was finished and it was retrospective for the actors involved. (For a detailed description of Case 1, see section 4.3)

In this explorative case study, we will first operationalize the main research questions that were set in Chapter 2 (section 4.2). Furthermore, we will test if it is possible to detect barriers and enablers for the creation of shared understanding by using the learning history method. In section 4.4, we will further develop the activities of the learning history method as proposed in section 3.3.3. We will go into detail about how we executed the data gathering-, the data processing- and the data analysis phase. Finally, we will show in section 4.4.4 that the method proposed will deliver valid and reliable results.
Section 4.5 will show the results of this chapter. This chapter will end with a conclusion in which the most important findings of this empirical study will be described (see section 4.6).

4.2 Research questions of Case 1

By executing Case 1, we will try to find an answer to the main research questions set in Chapter 2. These research questions are:

1. *What factors influence the creation of shared understanding during collaborative design processes in the industry?*
2. *What collaborative mechanisms influence the creation of shared understanding during collaborative design processes in the industry?*

The learning history method, as proposed in Chapter 3, will be used to find the answer to these questions. Since we want to test if this research method is suitable in this chapter, the first two research questions of this chapter are related to the research methodology. These read:

> *Do the stories of the actors involved provide us with knowledge about factors which influence the creation of shared understanding?*

> *Can we identify the barriers and enablers for the creation of shared understanding for each of the actor involved?*

Section 4.5.1 and 4.5.2 present the answers to these first two research questions.

If the learning histories of the actors involved provide influencing factors for the creation of shared understanding, then we will categorize them. This will allow us to answer the first main research question. In order to create more insight into the nature of the barriers and enablers, we will categorize them in two ways: according to the project phase and according to their organizational level.

The categorization of the barriers and enablers according to the phases of the product creation process of the company will provide insight into the nature of the collaboration during the different phases. In addition, it will provide information about the most difficult phase(s) for collaboration. The accompanying research question is:

> *How do the barriers and enablers mirror the nature of the different phases of the design process?*

The answer to this question is described in section 4.5.3.

In Chapter 3, we described the context factors of the collaborative design process. We distinguished three organizational levels on which barriers or enablers can occur. The first level is the actor level. Barriers on the actor level deal with direct collaboration between two actors executing a design task. The second level is the project level. Barriers on the project level deal with project specific factors, such as planning, monitoring, budget and project organization. The third level is the company level. Barriers on the company level deal with how the company organizes their product development projects and how the company applies its resources. In order to be able to manage collaborative design projects in the future, it is useful to know to which context factor a barrier or enabler belongs. Therefore, the next research question reads:

> *What are the barriers and enablers of each of the three organizational levels?*

The answer to this research question can be found in section 4.5.4.

The second main research question concerns the relationship between the barriers and enablers found. The first step in understanding their relationship is to form clusters of the different barriers and enablers. The accompanying research question is:

> *What clusters originate if the barriers and enablers are grouped together by content?*

By analyzing the content of the clusters, we should be able to distinguish patterns within the clusters. These patterns form the collaborative mechanisms of Case 1. Finally, insight into the collaborative mechanisms will provide knowledge about how to improve collaborative design, which is the objective of this thesis. Therefore, the last research question of this study is

> *What are the collaboration patterns within the clusters of barriers and enablers?*

The answers to the last two research questions can be found in section 4.5.5.

Description of Case 1 4.3

The company behind Case 1 is a European truck company. Within the company, product design takes a prominent role. In order to be able to make high quality products, the company maintains good contact with the market. All actors within the company need to know how drivers use the product. In addition, they also have to know what the key values for the distributors are, since they are their customers. The result of this market oriented product design strategy is a product portfolio that is positioned in the high-end segment of the market. Their product portfolio exists of three product lines:

- the light line developed for regional distribution
- the midrange truck developed for national transport
- the heavy line truck developed for the long distance international transport

The company serves the transport market with these three product lines.

In order to execute product design projects effectively, the company has its own product creation process. The product creation process consists of five phases that are shown in Figure 4.1. The phases of the product creation process are: (1) the definition phase, (2) the concept phase, (3) the engineering phase, (4) the volume validation phase and (5) the evaluation phase.

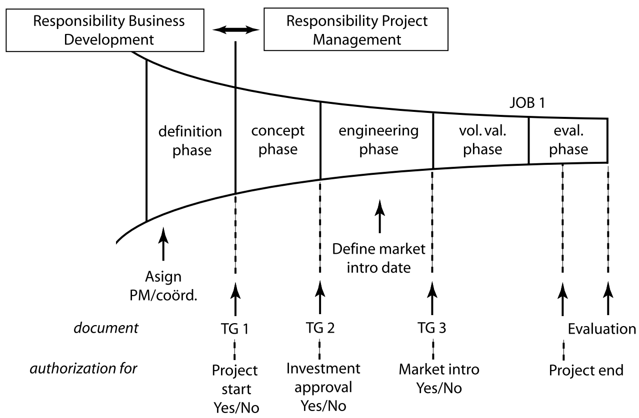


Figure 4.1 The product creation process of the automotive company

The goal of the definition phase is project definition. In this phase, the company formulates the product definition of the design project, develops the project plan and writes the business case. The Business Development department is responsible for the definition phase. The Design department and Production and Development are also involved in the definition phase. The definition phase ends with Tollgate 1, which concerns project authorization.

In the concept phase, the actors further develop the concepts chosen. In addition, they write the Program-Description-Book. The Program-Description-Book is the contract between Marketing and Development. It contains the product specifications. In the concept phase, the company also plans the investments needed and makes an analysis of the risk factors of the design. The concept phase ends with Tollgate 2, during which the Management Board gives authorization for the investment plans. The concept phase is the transition phase between Marketing and Development. Actors such as Market researchers, Program-Description-Book-makers, Designers, senior Engineers and Production personnel are involved in this phase.

The engineering phase concerns the engineering of the parts. In this phase, the actors carry out the work with many Engineers from different departments and external Engineers from Suppliers. In the end of the engineering phase, the actors also plan the definitive market introduction date. Tollgate 3 marks the end of the Engineering phase. During Tollgate 3, they define the product completely and they are sure that they are able to introduce the new truck to the market according to the specifications defined and the dates planned.

In the volume validation phase, the production of the new truck starts. The goal of this phase is to allow Production to learn how to produce the new truck. During this phase, Production takes the project control from Development. The volume validation phase is also the test phase for the product in the market. During this phase, a few vehicles were used by customers during their daily practice. What the customer did with the vehicle and the status of the vehicle were registered on a weekly basis. This test formed the input for the last changes in the design. Job 1 is the transition between the volume validation phase and the evaluation phase. At this time, the company is able to produce the product according to the intended capacity, delivery time and quality. The evaluation phase starts about ten weeks after Job 1. During this phase, the project team reflects on the completed project and they formulate lessons for future projects. (The information about the company and its product creation process come from internal company documents and Buijs and Valkenburg, 2005, p. 205-236)

Case 1, was about a mid life update of the midrange truck. At the time of the case study, the project was in its evaluation phase. Since this research project was a part of the evaluation trajectory, it was not included in this study. The other four project phases were part of the case study. During the definition phase the project team consisted of about fifty actors. This team expanded to include up to four hundred actors in the engineering phase. The core team in which all important disciplines were represented had a meeting once a month. However, actors who had to collaborate intensively with one another had daily meetings. Almost all actors worked full time to this project.
During the definition phase, a Market Researcher did some comprehensive market research. This market research formed the basis for decision-making during the remainder of the design project. "*Be the driver*" was the credo all Engineers had to keep in mind during their engineering practice.

Since it was impossible to concentrate on the whole truck, the focus of this case study was on the development of the cabin. The cabin was a clearly defined part of the truck in which functionalities were highly integrated. Both technical- and human aspects were important during the design of the cabin. In addition, both mechanics as well as electronics played an important role. For the Engineers it was a challenge to create a balance between functionality, the amount of space available and the weight of the cabin. Since the actors needed to make difficult trade-offs and were highly dependent upon one another, collaborative design played an important role in this part of the truck. The development of the cabin took place at one location. However, the production of the truck and the development of the production plant, took place at another location. The result of this design project was a high quality midrange truck, which both the drivers and the distributors evaluated positively.

The key figures (involved in the design of the cabin) selected for this research project needed to had different viewpoints of the cabin of the truck. Box 4.1 illustrates that the actors of the different disciplines actually have different viewpoints of the cabin of the truck.

Market Researcher:
"The cabin is the interior. The value of the cabin is in the eyes of the driver and the customer. This is for 70% dependent on the interior. If that is fine, the product is fine. If you built a cabin according to the heart of the driver, you did a good job. Then you only have to do a bit on the outside and you are done."

The Ergonomist:
"The cabin is the part of the truck in which the driver does his work."

The Developer:
"We have cabins that can turn over… You need this when you have to maintain the engine. If you remove the two bolts that are needed to turn over the cabin. And you take that part left you have the cabin…"

The Production Manager:
"The cabin is a composition of parts, which are assembled with bolts and are plugged in with one connector."

Box 4.1
The answers of four actors involved in the design of the cabin of the truck on the question: What is the cabin?

Box 4.1 shows the answers of the Market Researcher, the Ergonomist, the Developer and the Production Manager to the question of how they see the cabin of the Truck. By analyzing their answers, one can see that their viewpoints of the cabin are closely related to their tasks. The Market Researcher relates his answer to the driver and the customer and their value of the cabin. The Ergonomist also relates to the driver, but he mainly focuses on how he can do his job properly. The Developer and the Production Manager both relate to the parts of the cabin. The Developer refers to maintaining the cabin and the Production Manager talks about assembling the cabin. These are two different aspects that are each important to their particular tasks. These different viewpoints have an impact on their mutual collaboration process and are, therefore, interesting for this research project.

The next section shows which actors were chosen to participate in this case study. It also shows the other choices made concerning the execution of Case 1.

Research method of Case 1 4.4

This section describes the research method followed in Case 1. The learning history method (Roth and Kleiner, 2000), as described in Chapter 3, was the guide for setting up this case study. Figure 4.2 shows the learning history process as shown in Chapter 3.

This section also describes how we will execute the activities that are described in the squares of Figure 4.2 in order to come to the results that are shown in the diamonds.

This section exists of four parts. The first three parts represent the three phases of the research method; data gathering, data processing and data analysis. The last part of this section is about reliability and validity of the method followed.

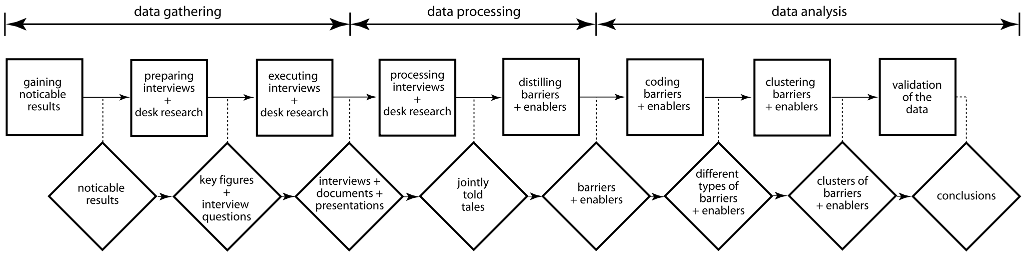


Figure 4.2

The learning history process

4.4.1 Data gathering

The data gathering phase consists of three activities:

- gaining noticeable results
- preparing the interviews and desk research
- executing the interviews and desk research

This section describes how we executed these activities in Case 1.

We gained the noticeable results of Case 1 by interviewing the Project Leaders about the entire product design project. The design project had two Project Leaders. As Figure 4.1 shows, the first Project Leader was responsible for the definition phase and came from the Business Development department. The second Project Leader was responsible for the remainder of the design project. He came from the Project Management department. An interview with these two Project Leaders revealed the noticeable results of the case study.

The first activity of the preparation of the interviews was the selection of the key figures. Together with the two Project Leaders, we made a short list of key figures. Each of these key figures had played an important role during one or more of the noticeable results. The roles of the key figures within the collaborative design team differed with respect to the department they represented, the organization level they had within the company and the design task they had to fulfill. The combined perspectives of the key actors together provide insight into the collaborative design process during the whole product creation process. Since their tasks (partly) overlapped, there was more than one perception about a particular project phase.

We saw the two Project Leaders together as the first key figure. We considered them to be one key figure, since they executed the same task in another phase of the design project. Both of them had to plan and monitor the design project and report important decisions to Management during the toll gate moments. By interviewing them both, we gained knowledge about the entire design project.

The second key figure was the Market Researcher. He interviewed many drivers and distributors in Europe about the key values of the truck. The information from these interviews formed the base for the design project.

The third key figure was the Program-Description-Book-maker. He was responsible for the translation of the requirements from the market into technical specifications. He wrote the Program-Description-Book, which was internally seen as the contract between Marketing and Development.

The fourth key figure was the Ergonomist. He was important in the design project because he had to make the cabin of the truck suitable for the driver of the future. Since more women have become drivers and men have gotten taller, the adjustment of the chair and the steering wheel have become more and more important. It was the task of the Ergonomist to make the required adjustments possible.

The Developer was the fifth key figure. He was responsible for the development of the cabin, from customer requirements until production. The emphasis of the task of the Developer was on the dashboard. Within the dashboard, the most important aspects are the heater, the ergonomic aspects and the styling aspects. Since the company did not have the capacity to develop the dashboard, some aspects were outsourced to Suppliers. The Developer was responsible for the contact with these Suppliers.

The sixth key figure was the Production Manager, who was responsible for

both the preparation of the production as well as for the actual production. It was his job to make sure that the workers could efficiency assemble the truck. In order to be able to influence design decisions concerning assembling and production, he was already involved in the definition phase of the design project. During production he was responsible for reaching the targets. These are both qualitative and quantitative targets.
The last key figure was the Software Developer. He was responsible for the electronics that the truck contained. The role of the Software Developer was important, since the share of electronics used in the truck expanded largely compared to the older products of the company.

The second activity of the preparation of the interviews is determining a research strategy. Yin (1994, p. 84-86) outlines three types of interviews, which differ in the extend of structure given beforehand. The three types of interviews are open-, focused- and structured interviews (or surveys). According to Denzin and Lincoln (2000, p.652), unstructured interviews provide a greater breadth than structured interviews. Since the aim of this research project is to gather depth knowledge about the barriers and enablers for the creation of shared understanding, an unstructured interview appears to be the best strategy. However, some structure was necessary in order to avoid too much noise in the data. We used an interview guide (Patton, 1990, p. 288) for structuring the interviews. The desk research of Case 1 did not require preparation.

The last activity of the data gathering phase was executing the interviews and doing desk research. In order to get a good view on the task of the actor interviewed, we asked each actor to describe his task at the start of each interview. Next to this, we asked him to explain the design process that he followed. The last and most extensive part of the interview was about how the actors experienced the communication and collaboration between the team members and how they achieved shared understanding with each other. Since it was important to determine the perspectives of the actors, there was no further structure given to the interviews. Each interview lasted three hours. The total duration of the interviews was more than 20 hours.

In order to be able to get a chronological view of how the design project evolved, we interviewed the actors in the order of the phase in which they were most involved in the collaborative design project. We first interviewed the Project Leaders in order to get an overall view on the design project. Second, we interviewed the Market Researcher and so on. Figure 4.3 shows the order of the interviews on the vertical axis. The phase in which the actors were involved in the product creation process is shown on the horizontal axis.

In order to be able to verify what the actors told us during the interviews, we conducted desk research. For example, we compared the market research report with the Program-Description-Book. This helped us to gain insight into how the market research revealed itself in the requirements for engineering. The company provided us with insight in the formal documents, newspaper articles and presentations that they had given to each other. The document research contained more than 250 pages of text and 150 slides from internal company presentations.

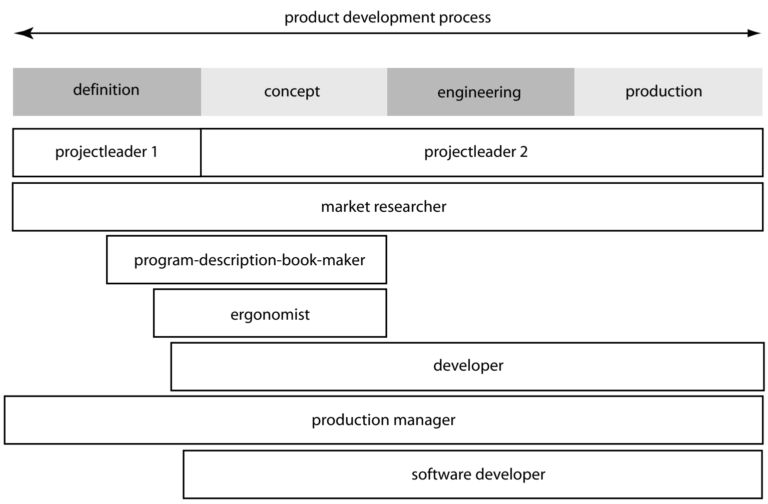


Figure 4.3
The involvement of the actors during the different phases of the design process

4.4.2 Data processing

The data collection provided rich data about the collaboration processes of the actors. The actors told us on which aspects they were able to create shared understanding and in what situations this was difficult. In order to get an overview of the barriers and enablers for the creation of shared understanding, we needed to process the data. This section shows how we unraveled and structured the large amount of data. The data processing phases consists of two activities:

- processing the interviews and desk research
- distilling the barriers and enablers

The first activity of the data processing phase was the transcripts of the interviews. This led to more than 270 pages of text. From the transcriptions of the interviews, we sorted the parts that were important for describing the collaborative design process that the key figure had gone through. The parts left out had nothing to do with the collaboration process. We ordered the relevant parts chronologically according to the formal product creation process of the company. One interview gives the perspective of one actor on (a part of) the design project. It represents his experiences and understandings. In other words, it represents his history. The next step was the analysis of the sorted parts. The relevant parts of the interview of one actor and the analysis together formed the jointly told tale of the process of one of the seven key actors. The jointly told tale of one key figure provided a good overview of the design process that he followed. It also provided an overview of the collaborative aspects within that design process. To avoid subjective interpretations, a second researcher checked the interpretations. Figure 4.4 shows an example of a piece of the jointly told tale of the market researcher. (We translated both the interview and the analysis from Dutch into English. This is the case for all empirical data used in this thesis.)

interview	analysis
Market Researcher: …After that we started thinking about it ourselves. We brainstormed a bit about… How are we going to approach this? How are we, do we approach the market research? We know enough. However, we knew soon that we did not know enough. Hmm. You start filling in the car. And what do we want to improve to gather a higher market share? To convince our customers so we can resell the car. That is not so difficult, but we wanted a higher market share. Furthermore, we had a few ideas which we needed to get rejected or confirmed. You can sit behind your desk and think of an idea, but this will not prove that your customers also like the ideas…	*Market research was needed to set the requirements for the new truck. In order to determine the questions of the market research, they considered all parts of the truck. The goal of the market research was to keep existing customers and to gain new customers by improving the existing product that they appreciate. Furthermore, they wanted to test some ideas they had with the customers.*

Figure 4.4 Example of a piece of the jointly told tale of the Market Researcher

From the jointly told tales, we sorted all the factors that influenced the achievement of shared understanding. We formulated clear statements about factors that influenced the actors' ability to gain similarity of thoughts. These statements formed the barriers and enablers of Case 1. Figure 4.5 shows another example of a part of the jointly told tale of the Market Researcher.

The part of the interview that is shown in Figure 4.5 is about the formulation of the questions of the market research. It was sometimes difficult for the Market Researcher to pose the right questions to the customer. It appeared that the Market Researcher and the user speak different languages. This hampered the creation of shared understanding. Therefore, the barrier accompanying this part of the interview reads: *Users and the Market Researcher use different jargon about the car, which hampers the understanding of the client*. The fact that the Market Researcher indicated that the user could not answer all of the questions asked implicated that this was hampering the creation of shared understanding. Therefore, we code it a barrier and not an enabler. The sign (-) in the third column of Figure 4.5 shows it is a barrier. (If it was an enabler there would be a sign (+) in the third column of Figure 4.5.)

interview	analysis	barriers or enablers
Market Researcher: The Market Researcher about the users: "They could not answer all questions. A famous one is styling. Asking: Do you think styling is important? They all said: No! But somewhere in the interview, or when you walk to the car outside, they all say: This car looks nice, doesn't it? For them, styling is important but they don't know our language. What is styling? They don't even know what styling is! What we mean with styling. But they all say a nice looking car is important."	*For the Market Researcher it was sometimes hard to pose the right questions. The users talk in different terms about the car. For example, the users didn't talk about 'styling' but about 'a nice looking car'.*	**(-)** **Users and the Market Researcher use different jargon about the car, which hampers the understanding of the client**

Figure 4.5 Example of a piece of the jointly told tale of the Market Researcher with distilled barrier

4.4.3 Data analysis

We interpreted the data, during data analyzes. First, the barriers of the key figures were analyzed and categorized. Second, the barriers and enablers of each key figure were clustered. The last aspect was the validation of the interpretations. This section describes how we realized these steps.

First, we categorized the barriers and enablers according to their phase in the design project and according to their organizational level. The coding was done with three researchers. One of the researchers executed the interviews. She knew the company and their product creation process well because she had already done another case study with this company together with the second researcher. Therefore, the second researcher also had a good understanding of the company. The third researcher was familiar with the company from earlier lectures that they had given and the case study reported in Buijs and Valkenburg (2005). However, his knowledge was less extensive than the knowledge of the other two researchers. This influenced the results of the multi-coder process.

The first categorization was according to the phase of the product creation process in which the barrier or enabler had occurred. Since the researchers were (to a greater or lesser extend) knowledgeable about the product creation process of the company, they were able to categorize the barriers and enablers according to that product creation process. When a barrier or enabler occurred in more than one phase, they put it in a category called the phase independent category. All three researchers coded the barriers. The researchers coded 52% percent of the barriers the same. Of another 47% of the barriers, two researchers agreed. The three researchers coded 1% of the barriers differently. The two researchers who agreed were the same two researchers who had a better knowledge of the product creation process of the company. In order to make the definitive categorization for the barriers, the three researchers had a discussion about the differences in coding. During this discussion, all barriers were categorized according to the phase in the design project in which they occurred. After coding and discussing the barriers, these two researchers then coded the enablers together.

The second type of categorization was coding on the organizational level on which the barrier or enabler was manifested. There were three organizational levels; the actor-, project- and company level. Barriers and enablers on *the actor level* dealt with the knowledge and experience of an actor and his perception about the content of his design task and design process. An example of a barrier on the actor level is: *The Developer does not know how to interpret the information from the Ergonomist, which he needed to fulfill his task*. This example shows a communication problem between two actors from different disciplines. This communication problem makes executing the design task difficult. Barriers and enablers on the actor level are defined as: *Barriers and* *enablers on the actor level deal with how the actors create shared understanding while executing their design tasks.*

The project team, in which the actors are organized, forms the context for the actors while they execute their design task. There are also barriers and enablers that occur due to this context. We regard these barriers and enablers as being on *the project level*. Barriers and enablers on a project level are related to project management factors, such as time, money, quality, information and organization of product development projects. Barriers and enablers on this level have to do with the planning, organization and control of the design project. An example of a barrier on the project level is: *A key figure of project X leaves the project*. The knowledge of the key figure is gone and within the team tasks need to be reshuffled. A new communication structure is needed. In addition, the project structure needs to be redefined. This change does not concern the whole organization, but it changes the project team. Barriers and enablers on the project level are defined as: *Barriers and enablers on a project level deal with the allocation of project specific factors such as time and money or factors of an organizational nature specific to a single design project.*

The project itself also has a context; the organization. The organizational context may also cause barriers and enablers. These are barriers and enablers on *the company level*. Barriers and enablers on the company level are related to organizational issues within the company. An example of a barrier on the company level is: *The location of the production plant is 80 kilometers from the development department.* This complicates communication between Production and Development because the distance hampers face-to-face contact between the two departments. This leads to less communication and interpersonal activity. Another problem is that informal talks around the coffee machine do not take place, which delays decision-making. Barriers and enablers on the company level are defined as: *Barriers and enablers on the company level deal with organizational issues that are specific to the company, yet not specific to a certain project or person.*

The coders of the data used the definitions of the three levels to code the

barriers and enablers. The three researchers coded 30% of the barriers equally. The two researchers, who knew the company well, coded another 64% of the barriers the same. The three researchers coded 6% of the barriers differently. The coding of the barriers was difficult for the third researcher who did not know the design project well. He often missed the context in which the barriers occurred. The researchers discussed the differences in coding between them. During this discussion, three topics of disagreement arose. The first topic was barriers in which the linguistic subject of the barrier was the company. The third researcher coded these barriers as barriers on the company level. However, sometimes the content of the barriers was project specific. Therefore, a coding on the project level better suited these barriers. It could also be the case that the barriers illustrated an interaction problem between two actors. In that case, the barriers belong to the actor level. A second topic of discussion was about barriers that were about the knowledge of a procedure. Although two researchers coded these barriers on the actor level, after discussion they became barriers on the project level. This was because these procedures influenced the course of the design project. The third topic of discussion was the wording of the barriers. Sometimes, it was unclear exactly what the barrier was and what was the result. Underlining the most important part of the barrier solved this problem.
The two researchers that know the company well categorized the enablers. They agreed upon 63% of the enablers. After a discussion, they categorized all enablers according to the three levels.

The second activity of the data analysis phase was the clustering of the barriers and enablers. The two researchers that know the company well clustered the barriers and enablers. During this activity, the barriers and enablers of the jointly told tales of the key figures were clustered together according to a central issue. One researcher clustered all barriers and enablers, without knowing what kinds of clusters would originate. This researcher gave the titles of the clusters to the other researcher, who once again categorized all barriers and enablers according to these clusters. After discussion, both researchers agreed on which barriers and enablers belonged to which cluster.

The last activity in the data analyses phase was the validation of the data by the key figures. Data validation comprised two steps. The first step was a check of the jointly told tales by the key figures. No major changes were necessary after this step. The second validation check was a workshop with all of the key figures and the researchers. During that workshop, we presented the results of the case study to the key figures and some actors from the Management Board. This workshop provided insight into the interest of the barriers and enablers. For the company, it was a moment of reflection on their design project. From the results, they outlined the key lessons concerning collaboration for their future design projects.

4.4.4 The validity and reliability of the research method followed

In this section, we will describe how we ensured that both data gathering and data analysis were conducted in a valid and reliable fashion. For gaining the noticeable results and for selecting the key figures, we interviewed the two Project Leaders. Since there is a subjective component in the selection of the noticeable results and the key figures, this decreased the construct validity. However, for this explorative research it is the only suitable method. Observations in this stage of the research project would not have led to better results because we did not yet know on which aspects we needed to focus.

In order to improve the construct validity during data collection, we used multiple sources of evidence. We interviewed multiple actors and we did desk research (Yin, 1994).

The construct validity is also important during the analyses of the data. Two important aspects Yin mentions are maintaining the chain of evidence and the check of the interpretations made by the key figures. The first step of the data analyses was the construction of the jointly told tale. In this research step, the validity of the study was ensured by the fact that the second researcher checked the interpretations made by the first researcher. The chain of evidence between the raw data and the interpretations was maintained by the representation method chosen for this case study. Figure 4.6 shows a page of a learning history of one key figure.

The first column of Figure 4.6 shows the sorted parts of the interviews. Each part has a code. With this code, one can retrieve to which piece of the interview the part belonged, in which phase of the project it occurred and what situation it described. The second column comprises the analyses of the sorted interview parts. The detected barriers and enablers are put in the third column. The last column describes the organizational category to which a barrier or enabler belongs. By providing a lay out like Figure 4.6, transparency is preserved in all of the research steps to be taken.

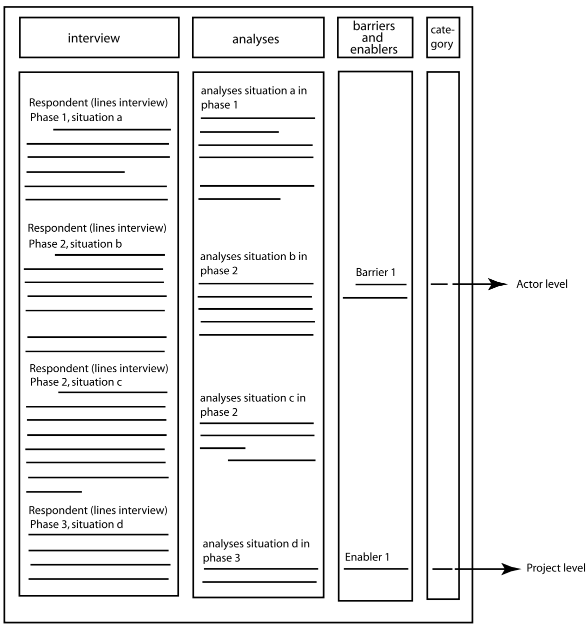


Figure 4.6
A page of the learning history in Case 1

By forming the clusters, the barriers and enablers of the different key figures are combined. In the report made for the company, we showed them the barriers and enablers that belonged to a cluster. The key figures all read this research report. Furthermore, they checked our interpretations by reading their own learning histories. No major changes were made in the interpretations of the data afterwards, which shows that our interpretations were valid.

In order to create a reliable case study, Yin advises making case study data bases. We made several case study data bases. The first was a data base in which we imported all interviews and coded them according to the project phase to which they belonged. This helped us to put the interview parts that belonged to the design process of an actor in chronological order. Furthermore, we made data bases that consist of the coded barriers and enablers. In addition, we wrote several research reports and papers about this case study (E.g. Kleinsmann and Valkenburg, 2003 and 2005).

4.5 Results

This section describes the results of Case 1. The first section provides examples from the learning histories of different key figures. Section 4.5.2 describes the number of barriers and enablers per key figure. The sections 4.5.3 to 4.5.5 describe respectively the categorizations of the barriers and enablers per project phase, per organizational levels and according to their content*.

4.5.1 Learning Histories

One of the results of this case study is the learning histories of the key

** In this section we use graphs in order to explain patterns that we found in our data. We are aware of the fact that the definite numbers are not telling how often a certain aspect occurs. However, they do say something about the differences and similarities between aspects that we found in this study.*

figures. In this section, we will show some parts of these learning histories (see Figure 4.7- 4.13). By showing parts of the learning histories of the key figures, we provide an answer to the first research question of this empirical study, which reads:

> *Do the stories of the actors involved provide us with knowledge about factors that influence the creation of shared understanding?*

As examples, we use parts of the learning histories that had barriers and enablers on different organizational levels. These parts of the learning histories are represented in the four column format. This is the same format that we used when we presented the learning histories to the company. The examples of the parts of the learning histories show how we interpreted the interviews. They also show the barriers and enablers distilled. The fourth column shows to which organizational category a barrier or enabler belongs. (Not every part of the learning histories of a key figure comprised a barrier. Some parts of the learning histories described process steps of the collaborative design process, without influencing factors. If that was the case, then the third and the forth column remained empty. Since the parts with barriers and enablers were the most interesting parts, we chose only the parts with a barrier or an enabler.)

Figure 4.7 shows a part of the learning history of the Project Leaders. In this example, Project Leader 1 explains in the interview (first column) which disciplines are involved in the definition phase. Our interpretation of this part of the interview is that the project team was multidisciplinary from the project start (second column). Since the project team starts with representatives that suit their complete design task, this is a positive aspect for creating shared understanding. Creating shared understanding between disciplines could start directly. Therefore, we labeled this as an enabler (third column). The decision to organize their product design projects into multidisciplinary teams is made on the company level. Accordingly, this enabler belongs to the company level (fourth column).

Figure 4.7
A part of the learning history of the Project Leaders

interview	analyses	barriers (-) & enablers (+)	category
Project Leaders R:(120/140) **Code: Definition phase** PROJECTLEADER 1: In the definition phase, all stake holding departments and disciplines are involved. E.g Development, Production, Purchase, After-Sales, the Design Center, Financial Analysts and Business Administrators, Business Development, Product Planning, Project Management, so as broad as possible…	*The project team is from the project start multidisciplinary.*	**(+)** **From the start of the project all disciplines involved form one project team.**	**company**

Figure 4.8 is a part of the learning history of the Market Researcher. The Market Researcher explains in the interview that the design team is constantly growing. He explains that this is the reason that the distribution of market information occurs gradually. This makes that the information transfer is time appropriate. Since this is positive for the creation of shared understanding, we labeled this factor as an enabler. This enabler influences the information transfer of the design project. Accordingly, it is an enabler on the project level.

Figure 4.9 shows a part of the learning history of the Production Manager. He explains in the interview that the last 2-3 prototype trucks are put on the assembly line. He also explains that the work is transferred from the prototype builders to the workers. This transformation period takes place during Q-validation. So, during the Q-validation phase, the prototype builders transferred their knowledge to the workers by assisting them with assembling the truck. Since this enabled the creation of shared understanding between them, we labeled this as an enabler. It is an enabler on the actor level, since it concerns the direct knowledge transfer between the actors from two disciplines.

interview	analyses	barriers (-) & enablers (+)	category
Market Researcher R(486/504) **CODE: Phase independent**			
MARKET RESEARCHER: Now everyone knew what we were doing. It is not that a project expands from zero to 100 people. When I was outside, there were people in the Development Department who did self-education. If there was a new project, what would we change? Production delivers information about what they need to know when we build a new medium line. They also say what changes they want to facilitate learning. Purchase comes with new possibilities for purchasing. We could combine things. There are more departments working on the project.	*The number of actors involved in the project grows constantly. Therefore, information is transferred gradually. During market research, Development does self-education about their requirements for the project. In addition, Production and Purchase provide information. All requirements are combined.*	**(+)** **The transfer of market information is time appropriate, because the number of actors in the project team grows constantly.**	**project**
RESEARCHER 1: But you have your own piece of information. How did you transfer that? Did you talk to people? MARKET RESEARCHER: That is a continuing process. You don't do something else. You start with a small group, who you inform continuously. My manager informs his managers. Sometimes we give a presentation to the board of directors; the project board.	*The market information transfer of the market researchers is a continuous process. He informs actors, who then inform other actors.*		

Figure 4.8
A part of the learning history of the Market Researcher (I)

interview	analyses	barriers (-) & enablers (+)	category
Production Manager R (406/412) **CODE: Engineering Phase** PRODUCTIONMANAGER: The final 2-3 prototype trucks are put on the line. The work is transferred. The prototype builders tell the workers what part they have to take and where they have to assemble it. Yes. And from Q-validation the prototype builders only observe. They take care of the materials being in place. And the employees start learning. We only interrupt if he does something wrong. This continues during the whole Q-validation. During volume validation, they should be able to assemble it.	*The last prototype trucks are assembled on the assembly line. From this moment, the employees are broken in and the prototype builders only observe from the background. They assist the workers. During volume validation, a worker has to know his new job.*	**(+)** **The prototype builders transferred their knowledge to the workers by assisting them with assembling the truck.**	**actor**

Figure 4.9 A part of the learning history of the Production Manager

Figure 4.10 shows another part of the learning history of the Market Researcher. The Market Researcher explains in the interview that the customer had complaints about the previous truck. For his market research, the Market Researcher formulated questions about these complaints. However, these questions were formulated in his own jargon. This was different from the language that was familiar to the customers. Since this initially hampered the creation of shared understanding between the Market Researcher and the customer, this was a barrier on the actor level. The fact that the Market Researcher recognized this problem and was able to translate the answers of the customers into answers to his original questions enabled the creation of shared understanding between him and the customer. Therefore, this was an enabler on the actor level.

interview	analyses	barriers (-) & enablers (+)	category
Market Researcher R(305/321) **CODE: Definition Phase**			
MARKET RESEARCHER: The customers came up with the complaints. We knew their complaints. They came up with them. First, we considered a number of questions. "What do you think of the materialization?" I said immediately "they will not recognize this." They do not know what we are talking about. However, from answers… From their complaints about what was wrong about the car, we could conclude fast that their complaints about parts scour along each other and hard plastics etc., etc. were about what we called materialization. They knew about it well. They only called it different. They were talking about a box of LEGO with a cracking and squeaking dashboard in the morning. That was true though. The parts became warm and expanded and then crrcrrcrrcrr. These kinds of things you often come across.	*It quickly became clear that the considered questions did not suit the market research. The drivers could not understand them. However, from the stories of the customers, the complaints about the current vehicle became clear. The Market Researcher knows the car and therefore he knows what the customers are talking about.*	**(-)** **Customers speak about the car in different jargon than the Market Researcher** **(+)** **The Market Researcher speaks the voice of the customer**	**actor** **actor**
RESEARCHER 1: Was it difficult for you to interpreter those things properly?			
MARKET RESEARCHER: No, no, no you know the car. Most of the time, you know what they mean. After a few words, you know what he is going to talk about. Often this is true.			

Figure 4.10 A part of the learning history of the Market Researcher (II)

Figure 4.11
A part of the
learning history
of the Ergonomist

interview	analyses	barriers (-) & enablers (+)	category
Ergonomist: R(654/678) **CODE: Concept phase**			
ERGONOMIST: The accelerator. The accelerator, that was a difficult one because within the company there were people completely attached to the old type of accelerator. We always used that one. Many people wanted to keep it. Especially in the beginning, they kept on saying: "Stop with it, what we have is okay." That became a difficult trajectory. And we made it. That was the remarkable thing. ERGONOMIST: The people, who were talking about it, said it was okay. And of course the people who did not have pain in their ankles. These are people with average ankles. They do not bother. They say: "I have no troubles, so for me it is okay." They do not see the advantages of the new accelerator. They know the advantages of the old accelerator. And they say, why leave these advantages if I do not receive new advantages. Certainly, if they… They had the knowledge and experience of a few competitors with a wrongly designed accelerator. That stays in their minds. What we have is okay and the competitors are wrong. I see that because I drove these cars. And for me it was wrong. es, how do you have to say that? They drove the wrong competitors' cars. Yes, this is a pity. This caused the frame: the old type of accelerator is good and the new type is wrong.	*Within the company, there was resistance to the new type of accelerator at the cost of the existing accelerator. This was because the company people did not face the complaints. They only saw disadvantages of the new type of accelerator because they knew bad designed examples made by the competitors.*	**(-)** **The advantage of a new accelerator as opposed to the old one was not clear to the actors within the company because the frame of reference was not properly communicated.**	**actor**

Figure 4.11 shows a part of the learning history of the Ergonomist. It is about the design of a new type accelerator. Within the company there was resistance to a new type of accelerator, since some actors saw no problems with the old one. Therefore, they could not see the advantages of the new accelerator. The actors did not create shared understanding because actors in the company had different frames of reference. Accordingly, this is a barrier on the actor level.

Figure 4.12 shows a part of the learning history of the Program-Description-Book-maker. It is about a layout drawing. The aim of this drawing is to provide an overview of the construction of all parts that are engineered. The Program-Description-Book-maker explains that some Engineers do not want to update this drawing, since they think it is too much work. The Program-Description-Book-maker agrees, yet he also emphasizes the advantages of the drawing. The drawing is a proper way to exchange information between the Engineers. Since the Engineers lack the discipline to maintain the drawing, knowledge exchange is hampered. This is a barrier on the project level because it is project specific and deals with the management of knowledge exchange.

Figure 4.13 is a part of the learning history of the Developer. It is about the way Development gets involved in the design process. According to this Developer, Development gets involved when the Program-Description-Book is ready. From the Program-Description-Book, the head of Development gathers the content of the design project. Then, he gives his Engineers the task of verifying the aspects mentioned by communicating to the other disciplines. According to the Developer, this process is unstructured. It caused many iterative loops, since the actors did not have shared understanding about the content of the design project. This is a barrier on the company level, since it deals with an organizational aspect that is not project specific.

Figure 4.12
A part of the learning history of the Program-Description-Book-maker

interview	analyses	barriers (-) & enablers (+)	category
Program-Description-Book-Maker R(739/755) **CODE: Concept Phase**			
PROGRAM-DESCRIPTION-BOOK-MAKER: (about maintaining a layout drawing.) No, you have to enforce this. That is difficult. The opinions are mixed. Some say it costs more effort. I do not think so. Maybe it costs a bit more effort, but the advantages are huge. The work is immediately properly imported. Everyone can use it. For your piece, which you can import, that is good. What suits you also suits another person. If he needs a part, he will gain it. That is often the difference… Look, at a certain moment the chassis has to be put in the drawing and the U-levers you got already. Front axis and an axis suspension. These are the essential parts of the car. It is often the case that the actors from the other departments have to yield. These parts have to be there. For example, the motor installation department. They are situated under the cabin in front of the engine. They are around the engine and around the chassis. They come across wheel suspension. Therefore, they need an outline of the environment, to be able to make a construction there and to use the parts. Thus, they will be more willing to draw very carefully because they need it themselves. That is a part of education.	*Some Engineers think the maintenance of the layout drawing costs extra effort. The Program-Description-Book-Maker agrees. However, he emphasized that there are many advantages because all actors can use the drawing. One condition is that all actors need to maintain the drawing properly. It is often the case that the Engineers of the main parts do not maintain the drawing. For them the interest is smaller. They are not as interested. The Engineers of the smaller parts are more interested because they are dependent on many other actors. Therefore, they are more neatly to maintain the drawing.*	**(-)** **The Engineers lack discipline to maintain the layout drawing, which hampers the knowledge exchange between disci-plines**	**project**

interview	analyses	barriers (-) & enablers (+)	category
Developer R(1420-1456) **CODE: Concept phase**			
DEVELOPER: The head of the department gets the Program-Description-Book. He goes through it. With a marker, he selects the parts that involve Development. Then, he approaches a few of his Engineers and tells them it seemed that they wanted something with the accelerator. Go and talk to them. You talk during the meetings about planning with your own people. You ask them: do you know what they want. They want this and this and this. Then I tell this is a lot. We should report it. Then ad hoc reports appear, which describe the plans, or about the technical content. Subsequently, I can ask an Engineer to make a planning or talk to a purchaser or someone calculation estimating. Because I think, it would be expensive. This happens and then we have an idea about what our plans cost. This you report to the project coordinator. You tell him, a new accelerator costs this and the cost-estimating department groups that. They collect all the work of the Engineers. Financially and what the causes are for the product price and the investments. They collect this for the complete project and rapport that to the project coordinator, Project Leader 2. Yes and if the costs are too high, a new accelerator as an example than he rings the bell and tell us this is crazy. What is it about? What does the customer want? No painful feet. Can't we optimize the current accelerator, until his feet do not feel painful anymore?	*When the Program-Description-Book is published, the head of the department scans the document. He asks his Engineers to deliver information about the subjects of the Program-Description-Book. This information forms the input for planning. Purchase and Calculation Estimating are involved to make estimations about the costs. The information from this report is grouped and Calculation Estimating reports this to the Project Leader. If the investments are too high, which was the case for the accelerator in the example then the changes of the parts are reconsidered. As a result the Engineers do not start a development project optimally. They start by defining the points of departure. The beginning of design projects is unstructured for Development.*	**(-)** **Development is not well prepared at the start of their part of the design project. This hampers the efficiency because many iterative loops are necessary.**	**company**

Figure 4.13 A part of the learning history of the Developer

Continuation Figure 4.13 A part of the learning history of the Developer

interview	analyses	barriers (-) & enablers (+)	category
Yes, so you have to make many iterative loops. But actually we are not prepared enough when we start. We should start to position ourselves better. We should formulate our point of departure and pose our conditions. If we take this part of the Program-Description-Book, we pose until here and not further. This is the amount of time we can spend on it and this is the amount of money we can spend on it. It is making your own target. On a certain moment you communicate this and you hear wheater or not you are able to continue or that someone says no this is not how we do it. A bit unstructured in the beginning.			

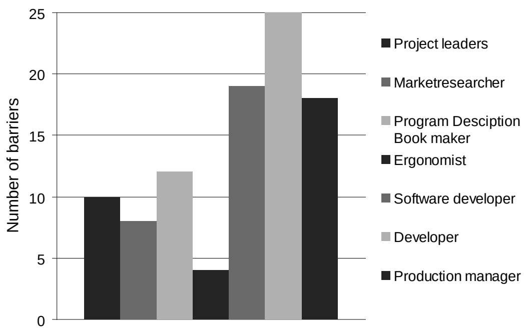
The examples shown in Figure 4.7- 4.13 show some of the content of the interviews and the analyses we made. The examples also show that by using the learning history method, we could distill barriers and enablers for the creation of shared understanding from the stories of the actors. Furthermore, the examples also show that, by representing the learning histories in the four column format, the transparency of all research steps is preserved.

4.5.2 The amount of barriers and enablers per key figure

This section will provide an answer to the following research question:

> *Can we identify the barriers and enablers for the creation of shared understanding for each of the actors involved?*

Figure 4.14 shows that we can answer the second research question of Case 1 positively. In Case 1, we found 96 barriers and 47 enablers. Figure 4.14 shows the barriers and enablers per key figure. (The order of the key figures is according to the product creation process of the company.)



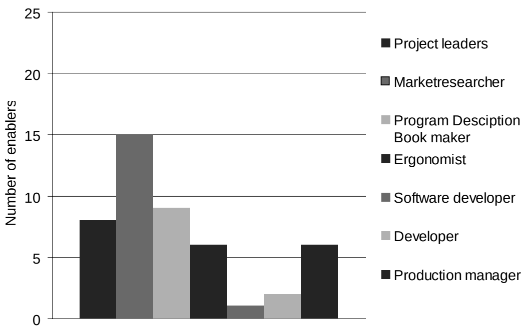


Figure 4.14
The amount of barriers (up) and enablers (down) per key figure

Analyzing the two graphs, there are two remarkable things that stand out. The first thing is the division between the amount of barriers and enablers. The last key figures have almost twice as many barriers as the first key figures. However, the first key figures have more than double the amount of enablers as the last key figures. There are two possible explanations, both confirmed by the actors of the company. The first explanation is that the Project Board had to stop the design project during the definition phase because the top management of the company had to approve the project. The actors used this time to communicate intensively about the design project. Additionally, it is also in the philosophy of the company to have a thoroughly executed definition phase. This becomes visible by looking at their motto, which is "*Plan superbly and run like hell*". Due to the extensive communication in the beginning of the project, the key figures recognized positive aspects in their collaboration process. Accordingly, most enablers occurred in this phase. Another explanation provided by the key figures was that team members pushed their design problems forward. Therefore, in the later stages in the project, they popped up and then became barriers.

Second, some key figures have more barriers and enablers than others. The Market Researcher had many enablers and very few barriers as compared to the other key figures. An explanation for this is that the Market Researcher had already worked a long time for the company. He started his career as a factory worker and then became a test driver. Subsequently, he got a job as a Market Researcher. His career experience enabled him to communicate with both the market as well with Development and Production. He was able to translate the voice of the customer into engineering language. Another aspect is that within the company, one of their key competitive values is carefully listening to the market. Therefore the actors involved were willing to learn from the Market Researcher.

The Ergonomist had a low amount of barriers. This was because the team around the Ergonomist had done a comparable project earlier. The team used the knowledge and experience from that project. Therefore, they were able to avoid barriers. In addition, the work of the Ergonomist and his team was more or less a solo project, which made this key figure not so suitable for this study after all. The Software Developer faced many problems during the design project. This was because it was the first truck in which the designers put in software so prominently.

4.5.3 Categorization on the project phase

This section describes in which phase of the design project the barriers and enablers occurred. This description provides the answer to the third research question of Case 1, that is:

How do the barriers and enablers mirror the nature of the different phases of the design process?

First, we will show the distribution of the barriers and enablers among the phases. Furthermore, we will describe the nature of the barriers and enablers in each phase. Finally, we will show in which phase each of the key figures had their barriers and enablers.

Figure 4.15 shows that the amount of barriers in each phase is almost equal.

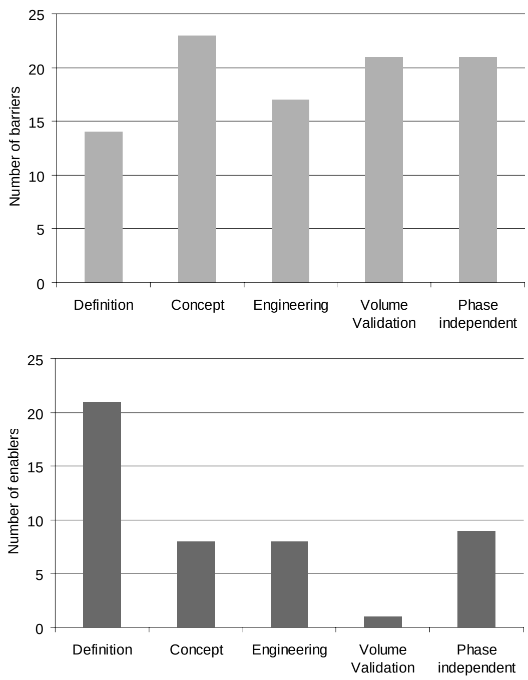


Figure 4.15 Number of barriers (up) and enablers (down) per phase of the Product Creation Process

However the enablers are less equally divided among the phases. In the analysis below, we discuss the nature of the barriers and enablers. This will provide more insight into the distribution of the barriers and enablers.

In the definition phase, there were the minimum barriers and maximum enablers. This is a merit of the company because they took much time for the definition phase. In this phase, the barriers and enablers dealt with the organization of the design team and the allocation of resources. Furthermore, the actors determined the content of the design project and they created a project vision that was largely based on the results of the market research.

Most barriers occurred in the concept phase, which is traditionally the most difficult phase for the creation of shared understanding. As in other design projects, it is the phase in which the transition is made from market research to product specifications and the new products architecture. The barriers in this phase concerned the creation of shared understanding about the content of the Program-Description-Book, which contained the specifications. Also, the formulation of the specifications led to problems with the creation of shared understanding, especially in the software development trajectory. Another aspect in the concept phase was the involvement of Suppliers in the design project. The Suppliers lacked the experience necessary for being involved in such an early phase of the design project. This also hampered the creation of shared understanding between the Developers and the Suppliers. The enabling factor in this process was the strong link between the Program-Description-Book-maker and the Market Researcher.

In the engineering phase the developed concept is further specified. The barriers in this phase concern most of the design changes (that were not communicated properly), the design of product details and the integration of the parts. There were also problems that concerned the different approaches of the Suppliers and the design team. In addition, the co-location of the Suppliers and the difference in native languages hampered the creation of shared understanding between the Suppliers and the design team.

In the volume validation phase, there was only one enabler, yet many barriers. The reason for this is that the project team postponed dealing with collaboration problems from earlier phases. They became real problems during the product quality validation (which took place in the volume validation phase). In addition, since many different parts were integrated and tested in this phase, all of the misinterpretations became visible.

Finally, the phase independent barriers and enablers concerned general issues, such as the planning and monitoring of the design project, the organization on the project (team) and the allocation of resources.

The graphs of Figure 16 a-g represent in which phases the barriers and enablers occurred for each key figure. We added up the barriers and enablers, since the phase the key figures referred to was more important than if the aspect hampered or stimulated the creation of shared understanding. In addition, we left out the phase independent barriers and enablers because only the barriers and enablers occurring in one phase were important for this analysis. This analysis shows that the key figures had barriers and enablers related to their own tasks.

Figure 4.16a shows that the two Project Leaders had most barriers and enablers in the definition phase. (One of them was responsible for the definition phase.) The definition phase was eventful, due to management issues. Furthermore, there were some collaboration issues in the volume validation phase because all aspects came together in that phase and production started.

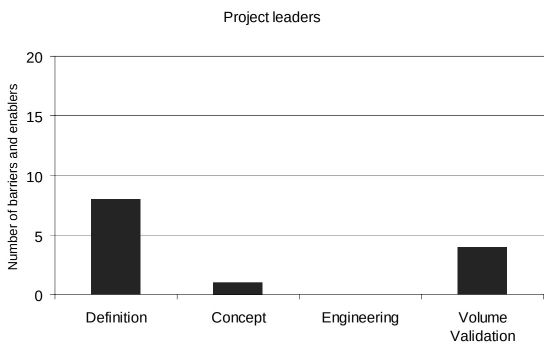


Figure 16 a. Number of barriers and enablers of the Project Leaders divided among the phases of the product creation process

The Market Researcher also had most barriers and enablers in the definition phase. The barriers and enablers in the other phases dealt with the transfer of the market research to actors from other departments, such as Development and Production.

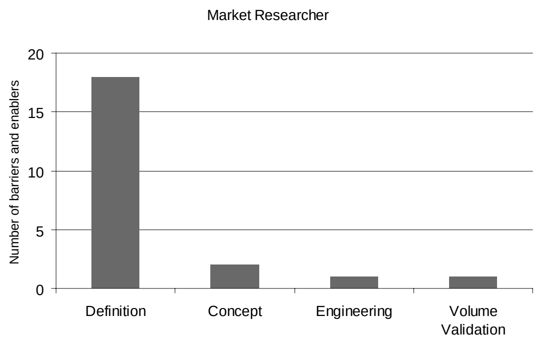


Figure 16 b. Number of barriers and enablers of the Market Researcher divided among the phases of the product creation process

The Program-Description-Book-maker had most barrier and enablers in the definition-, concept- and engineering phase. The Program-Description-Book-maker wrote the program description book during the definition phase. The document became final in the concept phase. The Engineers used the Program-Description-Book frequently during the engineering phase, which caused barriers and enablers.

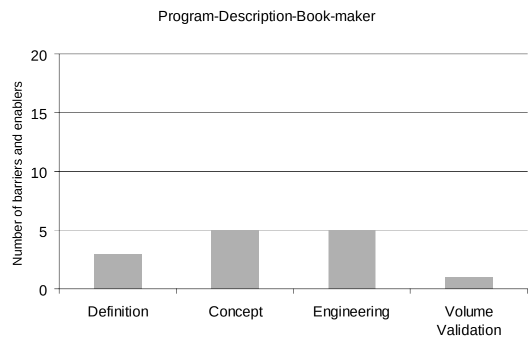


Figure 16 c. Number of barriers and enablers of the Program-Description-Book-maker divided among the phases of the product creation process

The Ergonomist executed his task from the end of the definition phase until the concept phase. The barriers and enablers of the Ergonomist occurred in these phases. The barriers of the Ergonomist are about difficulties with the creation of shared understanding about some ergonomic issues with drivers and the design team. The enablers came from the fact that the Ergonomist had a lot of experience with his task.

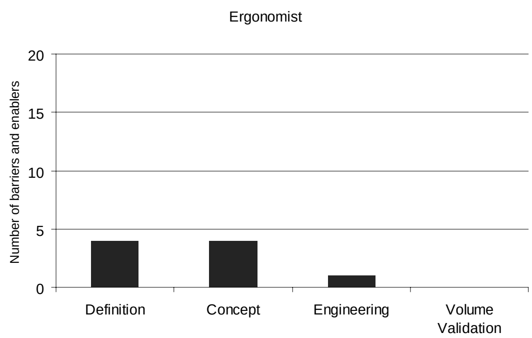


Figure 16 d. Number of barriers and enablers of the Ergonomist divided among the phases of the product creation process

The Developer had some barriers and a few enablers in the concept- and engineering phase. Most barriers and enablers concerned the collaboration process with the Suppliers.

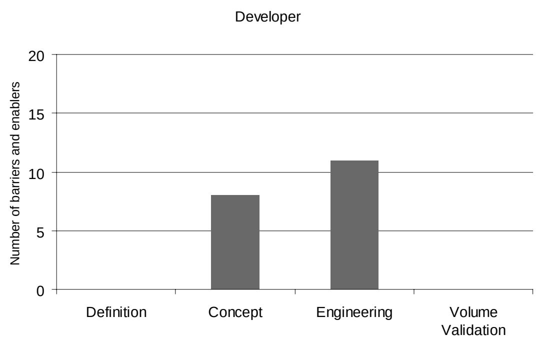


Figure 16 e. Number of barriers and enablers of the Developer divided among the phases of the product creation process

The Software Developer was involved from the beginning until the end of the design project. The concept phase was for the Software Developer the most intensive phase for collaboration. He had to create shared understanding with the other actors form different disciplines. Since he had to introduce some new technology, he had to explain to the rest of the project team how he wanted to develop this, what information he needed from them and what he could deliver. For the Software Developer, the Volume Validation phase was also intense because the technology had to reach its definitive status during this phase.

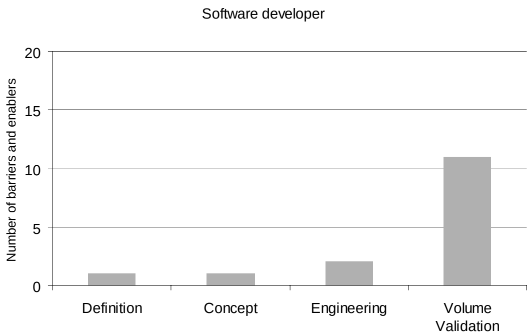


Figure 16 f. Number of barriers and enablers of the Software Developer divided among the phases of the product creation process

The distribution of the barriers and enablers of the Production Manager showed that he had had some issues when he was involved in the definition phase. Yet, the engineering- and the volume validation phase were more important for him. In these phases, the truck went from the drawing board to the production plan

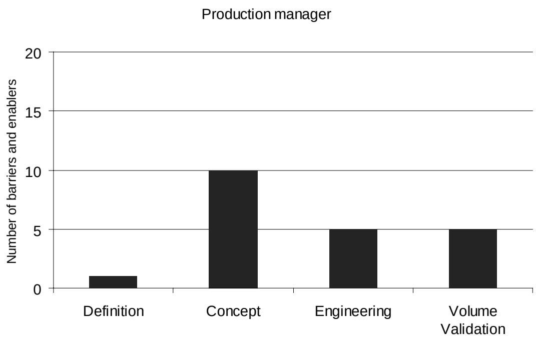


Figure 16 g. Number of barriers and enablers of the Production Manager divided among the phases of the product creation process

In this section, we showed that kind of barriers and enablers we found were closely related to the nature of the project phase in which they occurred. In the definition phase, the barriers and enablers dealt with the allocation and organization of resources and the development of a project vision. In the concept phase, communication about the design itself became more important. The barriers and enablers dealt with the transformation of the results of the market research into product specifications. Furthermore, the early-supplier-involvement and the design of the product architecture caused barriers and enablers to occur in the concept phase. The engineering phase had barriers and enablers about the creation of shared understanding about product details and the integration of the parts. In addition, design changes and unsolved design problems were important issues that caused barriers and enablers. Finally, there was the Volume Validation phase. In this phase, the barriers and enablers were about the testing- and the integration of the parts. Furthermore, collaboration problems that occurred earlier in the design process were expressed in this phase.
The second result presented in this section was the analysis of the distribution of the barriers and enablers of the key figures among the phases of the design process. This analysis shows that the barriers and enablers the key figures mentioned were directly related to their own tasks. Accordingly, the data came from them, which is an expression of reliability.

Categorization of the barriers and enablers on the organizational level 4.5.4

This section presents the results of the categorization of the barriers and enablers according to their organizational level. The first analysis will show how many barriers and enablers were found in each category. In addition, we will show examples of the barriers and enablers. We also analyzed in which phases of the design project the barriers and enablers on the different organizational levels occurred. Finally, we will show the organizational levels of the barriers and enablers of the key figures.

In this section, we will give an answer to the fourth research question of Case 1. This research question is:

What are the barriers and enablers on the three organizational levels?

In Case 1, we distilled 44 barriers on the actor level, 32 on the project level and 20 on the company level. There were also 23 enablers on the actor level, 17 on the project level and 7 on the company level. Figure 4.17 shows the amount of barriers and enablers on the different organizational levels. Most barriers and enablers were on the actor level. This was not remarkable since it was the focus of the interviews.

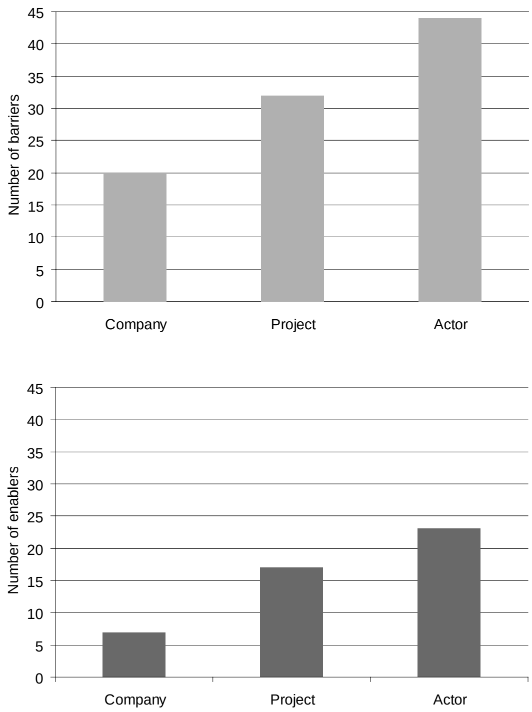


Figure 17 Number of barriers (up) and enablers (down) on the different organizational levels

This section describes some examples of the barriers and enablers on the different levels. The company confirmed the explanations given about why a barrier or an enabler occurred.

An example of a barrier on the company level is: *At the end of the development* *process, problems are not solved adequately because Engineers are no longer dedicated to the project.* At the end of a collaborative design project, the project entered the implementation phase. The implementation phase involved fewer actors and different actors than those who had been involved in the collaborative design project. This complicated communication between Production and Development because there was less contact between the two departments. This indirectly hampered the achievement of shared understanding.

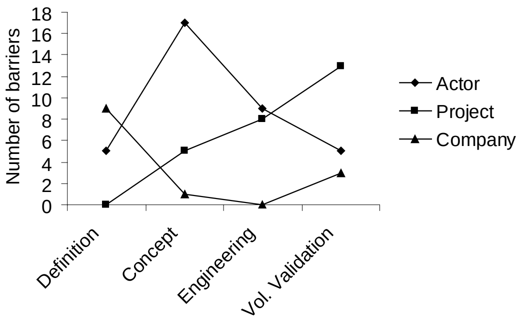
An example of an enabler on the company level is: *At the start of the project actors from different disciplines were put together in a team.* This multidisciplinary team took all requirements from the different departments into account early on in the project.

An example of a barrier on the project level is: *The project was delayed, due to the long decision-making process concerning the project authorization.* The project had a strict deadline, so the Engineers had less time to fulfill their tasks after project authorization. On the other hand, the project had started and actors were already involved in the project. Since they were dedicated to the project, they had a lot of time. The company used this extra time to intensify the information supply. This led to the following enabler: *Due to the long decision-making process concerning the project authorization, plenty of time was spent on discussing decisions.*

An example of a barrier on the actor level is: *The Developer did not know how to interpret information from the Market Researcher, which he needed in order to fulfill his task. He did not know exactly for which purpose the new car should be developed.* This example shows that there was no shared understanding between the Developer and the Market Researcher. The Developer was not able to properly fulfill his own task because he did not have the information he needed.

An example of an enabler on the actor level is: *The Market Researcher was capable of explaining the application of the truck to the Developers.* Since the Market Researcher previously had a job in Production, he was able to translate the market information in a way that the Developers understood.

A combination of categorization on the organizational level and the project phase lead to the graphs of Figure 4.18. These graphs provide more insight in the kinds of barriers that occur in a particular phase.



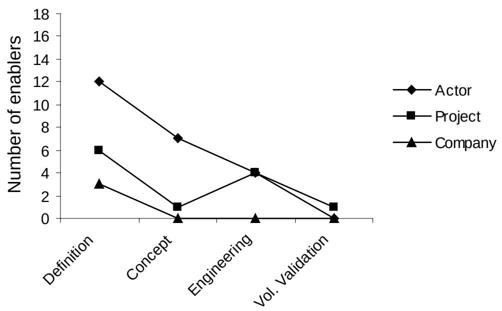


Figure 18
Number of barriers (up) and enablers (down) on the different organizational levels within the phases of the design process

Figure 4.18 (up) shows that the most barriers on the actor level occurred in the concept phase. As stated before, in the concept phase, the product only exists in the different representations of the actors and there is no physical object of the whole truck. This hampers the creation of shared understanding. This is also intensified by the different object worlds of the actors. This complicated the achievement of shared understanding.

The barriers on the project level increased during the project. This was mainly due to the quality problems manifested later in the project, during the integration of all parts.

Barriers on the company level occurred most in the definition phase and in the volume validation phase. The collaboration process with the company was most intensive in these phases because the project team was set up in the beginning of the design project and the actors went back to their regular tasks in the end of the design project.

Figure 4.18 (down) shows that enablers on the actor level decreased in each phase. The definition phase of this design project caused many enablers on all three levels. The design team spent a lot of time on communication in the definition phase. Furthermore, the company involved actors in this phase who were used to working in different phases of a design project. These actors could make transitions of knowledge, which enabled the creation of shared understanding in this phase. The communication in the remainder of the design project was less extensive, which resulted in few enablers. Only the engineering phase had a lot more enablers on the project level than the concept phase. This was because they used a prototype to see the progress of the design project, which enabled the creation of shared understanding within the design team.

Figure 4.19 shows the number of barriers and enablers of the key figures as categorized according to their organizational level.

In Figure 4.19, we ordered the key figures according to the degree of their

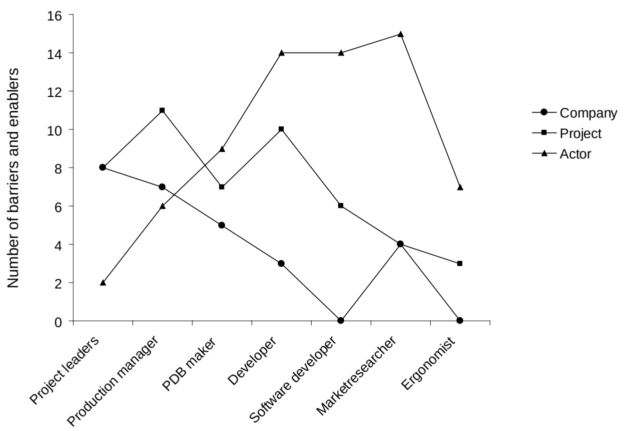


Figure 4.19 Barriers and enablers on the different organizational levels per key figure

management tasks. The Project Leaders had the most management tasks and the Ergonomist had the least.

Figure 4.19 shows that the number of barriers and enablers on a certain level depends on the degree of management task or engineering task a key figure had. The number of barriers and enablers on the company level and the project level decreased as the management task decreased. The amount of barriers on the actor level increased as the key figure had more engineering tasks. Only the Market Researcher had barriers and enablers on the company level. This was due to the fact that his task was in the beginning of the project when there was a link with the organization. The Ergonomist did not have many barriers on the actor level. This was because he did not need to collaborate closely with the other disciplines. The Program-Description-Book-maker did not have many barriers and enablers on the project level because he did not have a task that required much coordination with other disciplines.

4.5.5 The categorization of the barriers and enablers according to their content

In this section, we clustered the barriers and enablers according to their content. We grouped the barriers and enablers that related to the same topic. By doing so, we will find an answer to the following research question:

> *What clusters originate if the barriers and enablers are grouped together by content?*

Table 4.1 shows that, by grouping the barriers and enablers together, five clusters and a remainder category originated. Looking at the titles of the clusters, one can see that they all concern a different interface. According to Smulders (2006, p. 9), an interaction pattern between actors is an interface if two (groups of) actors work to a large extent separately, yet share a common boundary. As a result of this common boundary, they must interact with each other. This means that the tasks of the actors are interrelated in design projects. One (group of) actor(s) needs to share their knowledge with each other in order to share and create the knowledge necessary. The interfaces found in Case 1 are:

1. The interface between Marketing and Development
2. The interface with Suppliers
3. The interface between Project Team and Organization
4. The interface between the Market Researcher and the market
5. The interface between Software Development and the design team

Table 4.1 also shows that an interface consists of barriers and enablers on more than one organizational level. This implies that the barriers and enablers are interrelated. In the remainder of this section, we will analyze the collaborative mechanisms with each interface.

Interface	Barriers				Enablers			
	A	P	C	tot	A	P	C	tot
The interface between Marketing and Development	11	4	1	**16**	8	1	0	**9**
The interface between the design team and the Suppliers	16	4	0	**20**	0	2	0	**2**
The interface between the design team and the organiza-tion	0	6	14	**20**	3	8	6	**17**
The interface between the Market Researcher and the market	6	1	0	**7**	8	1	0	**9**
The interface between Software Development and the design team	8	5	2	**15**	0	0	0	**0**
The remainder category	6	12	0	**18**	4	5	1	**10**
Total	**47**	**32**	**17**	**96**	**23**	**17**	**7**	**47**

Table 4.1 Barriers and enablers per type of interface

We will try to find an answer to the last research question, which is:

> *What are the collaboration patterns within the clusters of barriers and enablers?*

We will answer this question by describing the collaboration processes that take place in the interface. For each interface, we will describe the relationship between the parties in the interface. In addition, we will show:

- the knowledge that the actors have to share and create within the interface
- what communicated processes took place between the actors
- the relationship between the barriers and enablers within each interface

The interface between Marketing and Development

Marketing and Development have to translate the information gathered during the market research into technical specifications.

Marketing and Development need to share the knowledge gathered from the Market Research. Marketing has to explain the application areas of the truck to Development. Together, they have to make a translation of the demands from the market into technical specifications.

Marketing and Development had intensive oral communication with each other. Furthermore, they communicated with each other through two documents. The first document was the Program of Wishes. This report contained the requirements from the market that had been gained through market research. The second document was the Program Description Book. This document contained the technical specifications of the design project. Within the design team, this document was seen as the contract between Marketing and Development.

Barriers and enablers for shared understanding

Table 4.1 shows that the interface between Marketing and Development comprises of barriers on the actor- (BA), project- (BP) and company level (BC). Furthermore, this interface had enablers on the actor- (EA) and project level (EP).

The analysis of the barriers and enablers of the interface between Marketing and Development showed that the oral communication between Marketing and Development was effective (EP). The Market Researcher was the key figure in this communication process. He spoke the language of the customer and translated it into the language of the Developers within the company (EA).

The written communication in this project phase was less effective. Marketing and Development communicated in writing, using a document called the Program-Description-Book. This document contained the product specifications. The organizational structure of the Program-Description-Book caused Development to have a difficult project start (BC). For the Engineers, the structure of the document was unclear (BP). Besides, the language of the specifications and the information provided was not what the Engineers needed (BA). This caused the Engineers to make a translation and reinterpret the document. This took time and caused failures (BA). Sometimes, the specifications themselves were also wrong (BP). Moreover, there were different versions of the Program-Description-Book. This was a result of alterations in the product specifications (BP). Sometimes, Developers used the wrong version and this lead to mistakes (BP). Since it was hard to modify the Program-Description-Book, the actors did not put all of the research findings in the Program-Description-Book (BP). Therefore, it was sometimes difficult for an Engineer to know where he could gather the information necessary (BP).

The interface between the design team and the Suppliers

The design team got an order from the Top Management of the company to involve Suppliers as early as possible in the design process. The Suppliers were knowledgeable about and experienced in the automotive industry and were therefore hired. Additionally, they had been hired to increase the capacity. Therefore, the interface with the Suppliers had a prominent role in this design project. Most of the Suppliers were situated in foreign countries.

The design team had to share both the actual design process of the truck and the content of the design process with the Suppliers. Since an important Supplier made the dashboard, styling was one of the aspects they had to share. In addition to the styling of the dashboard, the construction was also important.

The actors communicated orally in the native language of the Supplier. Several actors from the company were located at the Supplier, during almost the entire Engineering phase.

CAD drawings also formed an important aspect of the communication between the design team and their Suppliers.

Barriers and enablers for shared understanding

Table 4.1 shows that the interface between Marketing and Development is comprised of barriers on the actor- (BA) and project level (BP). Furthermore, this interface had enablers on the project level (EP).

This interface comprised a number of problems concerning collaboration with Suppliers. First, the company overestimated to what extend the suppliers could contribute to their design process (BA). They expected the Suppliers to have an extensive knowledge about designing a truck, since they had experience in the automotive industry. Therefore, the company also involved them in the concept phase (EP). However, the Suppliers only had experience with making the detailed design (BA). Subsequently, the automotive industry appeared to be different from the truck industry, due to a difference in scale (BA). The series of cars produced are larger that the series of trucks. Also, the individual differences of cars are negligible compared to the trucks. These differences influenced the design decisions made (BP). The differences in frame of reference between the company people and the suppliers caused misunderstandings about what the Supplier could contribute to the project (BA). In addition, it caused a lack of shared understanding about the status of the project (BA). In addition to the problems concerning the content of the design project, organizational problems arose due to the involvement of the Suppliers. Most Suppliers came from a foreign country. Both language and distance complicated collaboration (BA). It was difficult for the project team to explain their problems to the management. The management knew the successful stories from the Japanese automotive industry. It was difficult to convince them that the Suppliers were not able to develop new concepts and the problems were serious.

The interface between the design team and the company

The company had to deliver resources to the design team. Furthermore they had to take care of the project approval by the mother organization.
(We did not gather information about what knowledge the design team and the company shared or created. We also did not gather data about the communication processes.)

Barriers and enablers for shared understanding

Table 4.1 shows that the interface between the design team and the company had barriers on the project- (BP) and company level (BC). Furthermore, this interface had enablers on the actor- (EA), project- (EP) and company level (EC).
The interface with the organization concerned two main aspects. The first aspect was the project approval and the second aspect was Human Resource Management. The Project Board had to convince the Board of Directors that the project proposed was the best option. This process took half a year

(BC). Since the design project had a fixed dead line due to regulations, this shortened the time available for the design project (BP). On the one hand, this delay provided enablers during the definition phase. The Project Board believed in their proposal. Therefore, they let the actors involved continuing what they were doing, as long as there were no investments necessary (EC). This provided an intensive knowledge transfer between the actors during the definition phase (EA). However, because of the fixed deadline, the delay also caused time stress at the end of the project (BP). Especially the Engineers had to complete their tasks half a year faster (BP). This resulted in the generation of few alternatives, which caused certain risks (BP). Furthermore, they postponed quality problems (BP). On the other hand, the shorter development time kept the project budget from greatly exceeding the limits (EP).

Concerning Human Resource Management, the multidisciplinary dedicated team worked efficiently (EC). The communication lines were short and the actors were able to solve their problems quickly (EP). The actors solved complex issues by forming study groups. In these groups, actors who regarded the problem were involved, so they were able to create shared understanding about each other's tasks and interests (EA). In addition, all actors whose tasks were traditionally in the later stages of the design process were involved earlier (EC). An example of this was the involvement of the factory workers in prototype building. The Engineers got practical tips from the workers and the workers learned how to assemble the new truck. A problem that dealt with Human Resource Management was the capacity problem of Development (EC). This caused problems during both the project start and project end because the company brought the Developers into action in other projects. This caused the most problems during the production phase, (BP). The Developers had to solve the problems for which the company made Production responsible (BC). (The production phase was not included in this study. However, the problem just mentioned occurred at the time of the interview with the Production Manager.) Since the Engineers involved in the project had no time to solve the problems, Production did not reach their targets (BP).

The interface between the Market Researcher and the market

According to the company, a vision about what the market would like in a new truck was the foundation of this design project. This vision arose from both a general vision of the Marketing Department together with the market research executed by the Market Researcher. The interface between the Market Researcher and the market consisted of the market research that the Market Researcher executed.

The customers of the automotive company provided the Market Researcher with knowledge about both the current product as well as their future demands.

The Market researcher communicated with the customers by extensively interviewing them. (We did not gather more data about this communication process.)

Barriers and enablers for shared understanding

Table 4.1 shows that the interface between the Market Researcher and the market has barriers on the actor- (BA) and project level (BP). Furthermore, this interface had enablers on the actor- (EA) and project level (EP).

At times, it was difficult for the market researcher to gather knowledge from the market, since the customers used different terminology and spoke foreign languages (BA). The customers thought about product applications and not about product attributes, as the Market Researcher did (BA). However, the Market Researcher was able to translate the market demands into product requirements (EA). He used several techniques to succeed. First, he interviewed the customers and drivers about subjects that they were knowledgeable about, instead of using a standard questionnaire (EA). Due to the amount of interviews, the Market Researcher discussed all of the aspects about which he had to gain knowledge. Furthermore, the Market Researcher let the interviewees speak in their own jargon (EA). This helped the interviewee to go into detail about the aspects that really bothered him. Initially, this hampered communication between the Market Researcher and the customer, since jargon used by the interviewee differed from the jargon of the Market Researcher (BP). Yet, the Market Researcher was able to 'translate' the jargon (EA). His extended knowledge of the truck helped him with this process because it gave him a frame of reference (EA). The Market Researcher lacked knowledge about some aspects. Therefore, he brought experts from within the company into action to execute the interviews on these aspects (EA). This helped him to acquire detailed information. A translator was asked to translate the interviews that were conducted abroad. These interviews were more superficial because a translator cannot translate all of the nuances (BA). In order to be able to capture the knowledge gathered, the Market Researcher made (short after the interview) a report of each interview (EP). (The barrier on the project level was about a diagnose tool and did not have any relationship with the other barriers or enablers.)

The interface between Software Development and the design team

The Software Development department had to implement some innovations into the new truck. They had to share these innovations with the other disciplines of the design team.

The Software Developers and the design team had to share knowledge about how the new technology had to be integrated into the design of the cabin. Furthermore, they had to share knowledge about their design processes and the procedures that they would follow.

The Software Developers communicated both orally and with the use of written communication with each other. The Program-Description-Book formed the base document for the written communication.

Barriers and enablers for shared understanding

Table 4.1 shows that the interface between Software Development and the design team is comprised of barriers on all three levels (BA, BP and BC). This interface had no enablers.

The sixth interface was about implementing a new technology, which was a new piece of software. The company lacked experience and knowledge about this new software (BC). Therefore, it was difficult to develop a strategy for implementing it on the company level (BC). This led to problems with planning and monitoring activities concerning the design and the implementation of the software within the design project (BP). Management found it difficult to estimate the development time of the software (BP). Next to this, there were problems with the control of the parts (BP). They did not fit the existing system, because they existed not physically (BP). Therefore, it was difficult to check whether a piece of software existed and what the status was (BP). Furthermore, the specifications written were not applicable to the development process of the new type of parts (BP). This made it necessary for Software Developers to translate the original specifications (BA). At times, they also missed the information needed to write their specifications (BP). Finally, there was a lack of shared understanding between the Developers of the new technology and the other actors of the project team because of the use of different jargon (BA).

The remainder category

Finally, there was the remainder category. The next part explains the most important topics of the remainder category. First, there were a few barriers concerning changes in the project. Sometimes, actors did not communicate all of the changes to the actors involved, or changes led to the creation of parts the workers could not assemble. Second, in order to improve collaboration, the actors worked with a mockup and they used the layout drawing to have an overview of the whole cabin. It was sometimes hard for the Engineers to follow this drawing. Third, within the project, the actors worked too long with the prototype parts. This created misunderstandings about the status of the project. This problem became bigger when they passed Quality-validation, during which a large number of parts did not reach their definitive status.

Although we were able to identify the relationship between the barriers and enablers of Case 1, we cannot say much about the collaborative mechanisms within the interfaces. This is caused by the fact that we did not gain much knowledge about the other two building blocks of collaborative design. This is a shortcoming of the retrospective nature of this case study.
As a result, we could only partly answer the last research question. We would need a second empirical study to gain more knowledge about the collaborative mechanisms that occur during collaborative design.

4.6 Conclusion

The goal of this empirical study was dual. First we wanted to test if the learning history method was suitable for the purpose of this study. Second, we aimed for gaining an initial insight into the factors which influence the creation of shared understanding in a collaborative design project and their mutual relationship. In this section, we will reflect on these purposes. We will end this chapter with implications for the design of the second empirical study.

The results of Case 1 demonstrated that the research method used was suitable for our purpose. The jointly told tales that we constructed from the interviews showed us the collaborative process that the actors followed and our interpretations. We could also distill barriers and enablers from the jointly told tales of all key figures interviewed. Since the jointly told tales were constructed chronologically, it was also possible to see coherence between the

different subjects of the stories. This helped us to see relationships between barriers and enablers. The results also showed that the barriers and enablers of the key figures were directly related to their own tasks. This meant that the data was first hand, which was an expression of reliability. The internal validity of this case study was accomplished by maintaining the chain of evidence. This was realized by the presentation method that we had chosen. We presented our data together with our interpretations as jointly told tales with the accompanying categorizations.
In order to check whether our interpretations were valid, we checked these with all of the key figures.

Related to the content, this study provided us with knowledge about the influencing factors for the creation of shared understanding. We categorized the barriers and enablers in two ways:

- according to the project phase of the design project
- according to their organizational level

We coded all barriers and enablers in a multi-coder setting. This process showed us that in order to code the barriers and enablers one must have knowledge about the content of the case being studied. Otherwise, a coder could have missed the context of a barrier or enabler and may have interpreted the barriers and enablers incorrectly. The inter-rater reliability score of the coding process of the barriers and enablers on the three organizational levels demonstrated that the definitions of the three levels were sufficient.

The categorization of the barriers and enablers according to the project phase showed that the content of the barriers and enablers were closely related to the nature of the project phase in which they occurred. The combination with the categorization of the barriers and enablers on the organizational levels showed that the creation of shared understanding was most difficult in the concept phase. In the concept phase, most of the barriers occurred on the actor level. Barriers on the project level increased during the design project.

This was partly due to the fact that problems with creating shared understanding usually manifest later in the design process. However, it was also because project management became more important in the engineering and volume validation phase. In these phases, efficiency was more important than in the earlier phases of the design process. In the earlier phases of the design process, product definition and finding creative solutions were more important. Barriers on the company level occurred at the beginning and at the end of the design project, since in these phases there was the most interaction with the company.
The categorization on the three organizational levels also showed that actors with a management task had more barriers on the company- and project level, while actors with an engineering task had more barriers and enablers on the actor level.

The last activity of data analysis was the clustering of the barriers and enablers. This resulted in five clusters that all represented a type of interface. The five interfaces found were:

1. The interface between Marketing and Development
2. The interface between the Project team and the Suppliers
3. The interface between Project Team and Organization
4. The interface between the Market Researcher and the market
5. The interface between the Software Development and the design team

We found barriers and enablers on more than one organizational level within each cluster. This demonstrates that there is a relationship between the barrier and enablers. Although we could describe the relationships between the barriers and enablers, we could not say much about the collaborative mechanisms. This is because we miss knowledge of the other two building blocks of collaborative design:

- knowledge creation and integration between actors from different disci-

plines and functions
- the communication processes between the actors about both the design content and the design process

In conclusion, we can say that Case 1 provided insight into the barriers and enablers for the creation of shared understanding. It functioned as an exploration of the most important issues concerning creating shared understanding between actors in a multidisciplinary design team. We had detailed interviews with actors about their collaborative processes. From these interviews, we were able to distill barriers and enablers for the creation of shared understanding. Additionally, the results of Case 1 demonstrated that it is possible to categorize the barriers and enablers according to the projects phase and their organizational level. It was also possible to cluster the barriers and enablers.

Case 1 has been executed retrospectively for the actors involved. This has made us dependent on the actors' choice of the issues that he wanted to discuss about. Furthermore, it has not been possible to describe the collaborative mechanisms of Case 1 in enough detail. The retrospective nature of the case did not allow gaining knowledge about the actual course of the collaboration process. Based on these two aspects, we have decided to conduct a real time case study. This real time case study will enrich our knowledge about collaborative design processes again. By observing a design team, a researcher is able to select the issues that are most important to discuss. Additionally, observing a design team allows him to gain insight in the collaborative mechanisms that occur during a design project. The next chapter describes the real time case study.

AN EXPLORATIVE OBSERVATIONAL STUDY 5

Introduction 5.1

This chapter will describe the second empirical study of this thesis. It will build on Case 1, which we described in the previous chapter. Chapter 4 showed that in order to gain knowledge about the collaborative mechanisms within a case, we needed to observe actors in action during a real-time design project. It was not possible to gain data from the entire design project. Since both literature and Case 1 taught us that in the concept phase sharing and creating knowledge about the design content was most difficult, we chose the concept phase.

In this second empirical study we have investigated (as in Case 1) whether we were able to distill barriers and enablers from the data gathered. The second goal of this study was to gain more insight into the factors that influence the creation of shared understanding in a collaborative design project and their mutual relationship. (The empirical study presented here is called Case 2. Parts of this study were published earlier in Kleinsmann, *et al.* 2005a and 2005b. Some parts of this chapter are taken from these publications.)

Case 2 was about a design team that was responsible for developing the tunnel technical installations of a new Dutch high speed train trajectory.

The design project was a system engineering project. Collaboration was important in this design project, since the actors had to develop an integrated system that consisted of different subsystems. In order to design these subsystems, Engineers with different backgrounds were involved. Due to the integration of the subsystems and the scale of the design project, the tasks of the Engineers involved were highly dependent upon one another. This made creating shared understanding a critical factor of this design project.
During the case study, we were present in the company for a few days a week. We had a desk in the office of one of the departments. During the data gathering period, we observed meetings, interviewed actors and read documents about the design project. (for a detailed description of Case 2 see section 5.3.)

Section 5.4 shows the research method developed for Case 2. It first shows the method for observing the collaboration processes in a design team in order to gain the noticeable results of Case 2 (see section 5.4.1). The observations formed the input for the interviews. Section 5.4.1 describes how the interview questions were distilled from the notes made during the observations. Section 5.4.1 also shows the interview strategy that was followed. Section 5.4.2 describes the data processing phase. It describes the procedure that was used for distilling the barriers and enablers from the interviews. The third part of the research method concerns data analysis. The procedure that we followed for coding the data of Case 2 is shown in section 5.4.3. In the last part of section 5.4 we will describe how we dealt with reliability and validity issues (see section 5.4.4).
Section 5.5 will describe the answers to these research questions. Chapter 5 ends with a conclusion about the main findings of Case 2 (see section 5.6). This chapter will continue with the research questions of Case 2.

Research questions of Case 2 5.2

During the execution of Case 2, we tried to find an answer to the main research questions set in Chapter 2. These research questions were:

1. *What factors influence the creation of shared understanding during collaborative design processes in the industry?*
2. *What collaborative mechanisms influence the creation of shared understanding during collaborative design processes in the industry?*

Case 1 showed that barriers and enablers exist on different organizational levels. In Case 2, we investigated if Case 2 contains similar types of barriers and enablers as Case 1. The accompanying research question is:

What are the barriers and enablers on the three organizational levels?

By making a cross case comparison, we were able to compare the types of barriers and enablers found in Case 1 and Case 2. The results of this cross-case comparison are described in Chapter 6.

As in Case 1, we also investigated whether the barriers and enablers of Case 2 were interrelated and what types of clusters originated. Yet, the second research question of Case 2 is:

What clusters originate if the barriers and enablers are grouped together by content?

In Chapter 6, we will also make a cross case comparison between the types of interfaces found in Case 1 and Case 2.

In Case 1, we found answers to all of the research questions, except one. Since we had no knowledge about how actors create- and integrate knowledge, as well as their communication, we were not able to describe the collaborative mechanisms in detail. Therefore, we did not find a proper answer to the following research question:

What are the collaboration patterns within the clusters of barriers and enablers?

By observing a design team in action, we were finally able to find an answer to this last research question.

5.3 Description of Case 2

Case 2 was about a product design team that was responsible for the development of the tunnel technical installations of the Dutch high speed train trajectory that connects Amsterdam to Paris. The goal of the design project was to ensure that the travel between Amsterdam and Rotterdam would only take 35 minutes and that Paris could be reached in about 3 hours. The principal for this project was the Ministry of Transport, Public Works and Water Management.

In order to accomplish the design project, many companies were involved. The product design team of Case 2 was part of a consortium that was assigned responsibility for the superstructure of the route and the future maintenance of the infrastructure. Other players in the consortium were a Maintenance company, a Project Management company and a Civil Contractor.

Since all tunnel installations had to function together (in the case of an accident), collaboration was an important factor in this development project. The tunnel technical installations consisted of eleven technical subsystems. These systems were developed by actors from different (engineering) disciplines, which made this design project interesting to observe. At the time of the research project, the design project was in its concept phase. This means that the specifications for the subsystems were ready and the actors started developing the concepts of their subsystems.

At the time of this case study, the actors were making the conceptual designs of the different subsystems. Some subsystems only finished the conceptual design, while other sub teams only started because they needed the input of the other subsystems.

The product design team of Case 2 was organized as a collaborative team hierarchy, from which structure originated from the new product's architecture (Gerwin and Moffat, 1997). Table 5.1 shows the structure of the design team.

Level	Name design team	Design task
1	Consortium	Development of the superstructure of the high speed train trajectory
2	Core team for the tunnel technical installations	Integration of the tunnel technical installations with other systems of the superstructure
3	System Engineering team	Integration of the designs of the subsystems
4	Subsystems	Design of a subsystem

Table 5.1 The collaborative team hierarchy of Case 2

The team hierarchy consisted of four levels. In Case 2, we focused on level 2, 3 and 4. Level 1 was outside the direct scope of the Case 2. Level 1 was the consortium that was responsible for the superstructure, from which the tunnel technical installations were a part.

The second level was the core team that was responsible for the integration of the tunnel technical installations with other systems of the superstructure. The core team consisted of the Project Leaders of the subsystems and a Quality Engineer, a Project Leader of V&V (Validation and Verification), a Project Leader of RAMS (Reliability, Availability, Maintainability and Safety), an Occupational Health & Safety Engineer and a Procurement Engineer. The core team also planned and monitored all activities needed for developing the tunnel technical installations.

Level 3 was the system engineering team. This team had to integrate the designs of the subsystems of the tunnel technical installations. The system

engineering team consisted of the Project Leaders of the design teams of the subsystems, together with two System Engineers. The system engineering team integrated the eleven subsystems to create a whole.
On the fourth level, there were the engineering teams that developed a technical subsystem. The product design project studied consisted of eleven of these teams, which were rather homogeneous in nature.

The design project of Case 2 was a rather unique project for the actors involved. The first new factor was thinking in *Life Cycle Cost*. The design team was responsible for developing and building the superstructure, as well as maintaining it for 25 years. This called for a new way of developing. In other projects it was wisest to develop the new system with the lowest amount of effort, while still satisfying the customer. Sometimes, it was even tactical to develop a product with high maintenance costs because the company could also earn money by selling extra parts and providing man-hours for maintenance. However, in this project, the actors would cut their own finger doing that. This was due to two reasons. The first reason was obvious. The Consortium had to maintain their systems, so every maintenance activity required spending money. The second reason was that the customer pays the Consortium for the availability of the system. So, if the system would fail often then less money could be earned. In order to avoid loosing a lot of money, the design team put a lot of effort in making the availability of the system as high as possible.
The second factor that was different was the type of *development assignment* that came from the government. The assignment was broadly defined and included many uncertain factors. The actors involved in Case 2 normally executed concrete design projects with a very clear starting point. In this design project they had to find out for themselves which aspects were important. Additionally, they had to translate the broad and vague requirements (given by the government) into requirements that were exactly applicable to their design task. They also had to translate them so that they could

be tested.
The third difference for the actors involved in Case 2 was the so called *paper tiger*. In addition to the tunnel technical installations, the design team had to deliver a *safety case* to the customer. This safety case contained the evidence that they met all requirements dictated by the government. In order to be able to do this all requirements needed to be tested in a proper way. The actors also had to document all steps taken in the design process. The result was a large amount of documents which were difficult to control and formalize in a way that the documents were applicable for both Engineers and (external) auditors.
On top of all the paperwork, the design team had to prove that their system functions were reliable. Improving the reliability decreased the availability (from which the Consortium received the money), which caused an interesting tension between availability and safety.

This section provided an overview about the content of the design project as well as the organization of the design team. We also provided information about the kind of actors involved in the design project. Finally, we showed what the interesting and new aspects of Case 2 were (from the viewpoint of the actors involved). We will now continue this chapter with the research method that we followed in this case study.

Research method 5.4

Case 1 showed that it was possible to detect factors that influenced the creation of shared understanding by interviewing actors (about the creation of shared understanding during collaborative design projects). However, Case 1 showed that it was not possible to get a proper view of the collaborative mechanisms that take place during the actual collaboration process. Therefore, we decided upon a real time case study in which we observed design teams in action.

In this section, we will describe the research method that we followed in this case study. The research method followed is in this case study is largely based on the learning history process that we described in Chapter 3. This section describes how we will execute the activities that are described in the squares of Figure 5.1 in order to come to the results that are shown in the diamonds.

This section exists of four parts. The first three parts represent the three

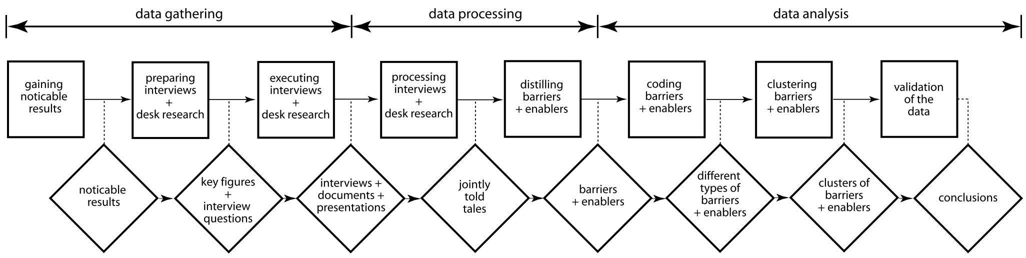


Figure 5.1
The learning
history process

phases of the research method; data gathering, data processing and data analysis. The last part of this section is about reliability and validity of the method followed. The remainder of this section describes the phases of the learning history process in detail.

5.4.1 Data gathering:

The data gathering phase consists of three activities:

- gaining noticeable results
- preparing the interviews and desk research
- executing the interviews and desk research

This section describes how we executed these activities in Case 2.

Gaining noticeable results

The first activity of data gathering was the observation of actors in meetings in which they communicated about the design they were making.

Patton (1990, p. 216) distinguishes five dimensions describing possible approaches for executing observations. Figure 5.2 shows the five dimensions and the choices made within Case 2. The first dimension is whether the researcher is a full participant or an onlooker. Since we did not want to influence the collaborative design process, we observed the design team as an onlooker. During the meetings that we observed, the actors acted as they normal did. We were not involved during the meeting.

Patton's second dimension focuses on the extend to which the observations are overture for the actors.

All participants were aware of our presence, so the observations were overture to everyone. The third dimension is the explanation of the purpose of our observations. We told all actors that we were looking at their collaboration and communication processes. We did that so that actors would not become suspicious about what we were writing down during their meetings. This would have disturbed their collaboration process. Therefore, the actors involved knew the purpose of the research project.

The forth dimension is about the number of observations. We observed 12 meetings of 1-4 hours. During the meeting, we made notes about the conversations of the actors when they discussed a technical subject. We also copied the drawings that they made during the meeting. In addition to the observations, we also read documents belonging to a certain meeting or a subject discussed and we looked through some presentations about the project. These actions combined are multiple observations.

The last aspect is the focus of the project. As stated in Chapter 3, we chose for a holistic approach which is a broad focus.

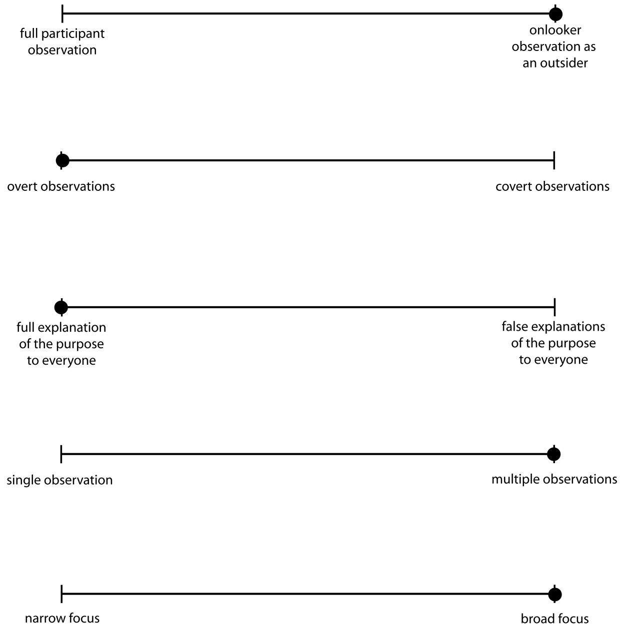


Figure 5.2 The choices for the five dimensions of variations in approaches to observations (based on Patton, 1990, p. 217, Figure 6.1)

At the start of the observations, it was important to get to know the setting and the structure of the design project (Patton, 1990, p. 219). This was difficult due to a number of reasons. First, the language the actors used was difficult to understand. During the first meeting observed, we had the strange experience that the actors communicated in our native language, yet we did not understand their conversations. This was because they used abbreviations, jargon and metaphors for communicating with each other. In order to solve this problem, we asked the meaning of the abbreviations and verified what they meant with their jargon. We also read some of their documents and looked at the different types of drawings they made. Finally, we were able to understand them.

Second, it was hard to unravel the formal interaction patterns between the actors and their mutual dependencies were unclear to us. The project team was large and contained eleven technical sub teams, a system engineering team and a core team (for the organization of the project team, see Table 5.1). In order to verify in which meetings the actors discussed the most technical subjects, we observed different types of meetings. We were also present at a two-day workshop that they held with the whole core team. This workshop was a good opportunity to get acquainted with the actors involved and to get an idea about their mutual relationships. This period of getting to know the setting and the structure was used as a start-up phase. The data collected during this phase were not part of the results of the case study.

Based on the knowledge gathered during the start-up phase, we decided to follow three types of meetings during the actual observation period:
The first meeting chosen was the Progress Meeting of the core team, which was a weekly meeting. The core team represented all disciplines involved in the product design project. The Progress meeting had a strict agenda including the following items: Comments on Minutes of the last meeting, Actions, Management Announcements, Accommodation and IT related items, Progress of the work packages, Risks and Miscellaneous. During the Progress Meetings many subjects were discussed, (e.g. financial-, technical- and political issues). Since the research project concentrated on communication about the design content, notes were made of the technical issues or issues which directly influenced collaboration and communication about the design content. In the Progress Meetings, technical issues were named and controlled (so that each core team member knew what happened and how much progress there was), but were discussed in more detail during the System Engineering Meeting, which followed directly after the Progress Meeting.
The System Engineering Meeting was the second meeting observed. During these meetings, the Project Leaders of the different subsystems and the System Engineers discussed the integration of the technical systems. The chairperson of the meeting was the System Engineer, who was the address

point of the tunnel installation to the outside world. The System Engineering Meeting had an ad hoc agenda, drawn up during the week and during the Progress Meeting earlier that day.

The third kind of meetings observed were Interface meetings between the subsystem Control and the other technical subsystems. The reason for choosing these meetings was that the control system (designed by Control) was responsible for the regulation and the control of all other subsystems. Therefore, Control needed to communicate intensively with the other subsystems about how the subsystems functioned together. The participants involved in these meetings were usually the Engineers of Control and an Engineer of the other subsystem. The Control department drew up the agenda before the meeting. The subjects discussed changed with time.

During the meetings, we made field notes of the actors' conversations. We chose to take notes on a notepad because it is quick, provides flexibility and the opportunity to copy drawings.

We were able to use a desk in the Control department during the period that we were observing the design team. This gave us the opportunity to be present in the company longer than the actual meetings. This provided us with insight into the daily business and we were able to observe some ad hoc meetings. This helped us to gain knowledge about the noticeable results in the project. During the observations, we were present in the company for two to three days a week. We wrote the field notes of the meetings and other remarkable occurrences down in a logbook.

During the meetings, the actors communicated about different subjects. In order to gain noticeable results, it was important to be able to capture this design communication. We needed to be able to detect whether or not the actors had shared understanding about the subjects discussed. Therefore, we made notes of the design communication of the actors. Since we were not able to capture all design communication literally, we did not have protocols of the design communication. Example 1 in Box 5.1 shows a part of the notes taken during an interface meeting between the Engineers of Control and Escape Doors. These notes contain the most important issues that were discussed. The sentences are not the literal sentences that an actor used, but they contain the content of what was said. The original notes were translated from Dutch to English. Another remark is that the actors communicated to each other in Dutch, but their documents were written in English.

Box 5.1 Example 1: Notes about a conversation during a meeting between Escape Doors and Control about explaining a matrix

Fb locked	Fb closed	Fb opened	S	I	M1 tube	M2 tube
0	0	0	F		F	
0	0	1	F		F	
0	1	0	D			
0	1	1	F			
1	0	0	D			
1	0	1	D			
1	1	0	N			
1	1	1	D			

Figure 5.3 The matrix being discussed

Engineer Escape Doors: I do not understand your matrix.

…

Engineer Escape Doors: What does Fb mean?

Engineer Control 2: That means feed back.

…

Engineer Control 2: This matrix functions as an example. You have to make it definitive.

Engineer Escape Doors: 3 zero's, is that an incident?

Continuation Box 5.1 Example 1: Notes about a conversation during a meeting between Escape Doors and Control about explaining a matrix

Engineer Control 2: In that case, no trains drive anymore.

Engineer Escape Doors: Exactly!

…

Engineer Escape Doors: 001 is an incident, because nobody can go into the tunnel. 010 is a disturbance, no trains stop, this is a failure.

Engineer Control 1: What is failure?

Engineer Control 2: A disturbance

Engineer Escape Doors: No, according to RAMS, a disturbance….

Engineer Control 2: Different terminology. This is a translation problem between English and Dutch. If there is a failure a Maintenance man will appear.

Engineer Escape Doors: No then everything fails.

Engineer Control 2: What is the English word for disturbance?

…

Engineer Control 1: Look at the scheme of Engineer Control 4. When does a system fail?

Engineer Escape Doors: If it does not open and if he does not come back after use.

Engineer Control 1: There are three stages for availability: Normal, Degraded and Fault. A system is degraded if one out of two or several redundant systems abandoned, but that there is no danger. Maintenance is needed.

Engineer Control 2: In the case of a disturbance, you need to know if you have to stop the train traffic.

Engineer Control 1: In the case of three doors, you have a Fault status. In the case of one door, you cannot come further than Degraded, so we have to add a column to the matrix.

Engineer Control 2: The Matrix is for one door

Engineer Control 1: A door fails or not?

Engineer Control 3: There is a third: degrade

→ Later in the discussion it appeared that the system could fail if one door failed. This is if 000 occurs. So, the doors and the group of doors can fail. If a group fails, the train will stop.

Engineer Control 2: We need a table per subsystem.

Engineer Control 1: Degraded what is that?

Engineer Control 2: RAMS

Engineer Escape Doors: You go too far!

Engineer Control 1: The operator determines.

Engineer Escape Doors: If so, you can delete the table, because the door always closes. The table shows what can go wrong. There is a sign or no sign. It works or it does not work. Signal or not, but then three times. There are three items: lock, switch and switch.

Engineer Control 2: It is the combinations that are interesting.

Engineer Escape Doors: You give a signal if there is disturbance, not a failure.

Engineer Control 3: If we do not determine it…

Engineer Control 1: Normal, degraded and False need to be clear for us

Engineer Escape Doors: You need a lamp that turns on. What you do with it…

Engineer Control 1: Wait a minute! We get another column.

Engineer Control 3: Can you determine this for each door?

Engineer Escape Doors: Yes, for each door and cumulative (3 doors)

Engineer Control 1: Then the table makes sense.

Engineer Control 2: Yes, but not for the Normal, Degraded, False signal of disturbance.

Engineer Control 1: Then we look if we could indicate this for each door

→ the first 2 are Fault, the third is degraded (In the Matrix)

Engineer Control 2: Safe train

Engineer Escape Doors: That is not a condition.

Engineer Control 2: In the case of Maintenance unlocked.

Engineer Escape Doors: In the tunnel, train…

Engineer Control 2: We need to make a table of all situations

Engineer Control 1 and Engineer Control 3: Tables. Now normal train

Engineer Control 2: My idea (?)

Engineer Control 1: S, I, M (Safe train, Incident Mitigation and Maintenance)

Continuation Box 5.1 Example 1: Notes about a conversation during a meeting between Escape Doors and Control about explaining a matrix

Continuation Box 5.1 Example 1: Notes about a conversation during a meeting between Escape Doors and Control about explaining a matrix

Engineer Control 1 speaking to EDE: We are searching… Engineer Control 4 also looked at it. The status of the subsystems…
Engineer Control 3: Maintenance should be subdivided into 1 and 2 tubes. → This gives another column.

→ Engineer Control 2 and Engineer Escape Doors have a disagreement about when the middle wall between the tubes is Fault. Engineer Control 3 reacts: Engineer Control 2 you talk 'software language' and Engineer Escape Doors talks 'hardware language'.
Engineer Control 1: We have to look at the subsystem and not to the Control system
Engineer Control 3: The problem is that it is redundant. 2 signals.
Engineer Escape Doors: We trained to fill in the matrix. You can finish it. We can do it with the four of us, but this does not go fast enough.

Analyzing these notes, we can state that one of the Engineers of Control showed his idea about the different stages in which an escape door could exist. He did this by showing a matrix that represents his ideas. The Engineer of Escape Doors tried to understand the matrix by asking questions about the columns of the matrix. The Engineers of Control explained the columns of the matrix to him.

The second piece of the conversation is about terminology. All Engineers have different names for the stages in which the escape doors could exist. This is partly due to the fact that the actors use both the Dutch and the English languages, which causes translation difficulties and mistakes. Furthermore, within the system there is a distinction made between one escape door and the systems escape doors (that consists of three escape doors). These two levels of detail also caused communication problems. As a result of these two aspects, the Engineers could not develop a shared understanding about the stages in which an escape door can exist. The actors also discussed the matrix made. It appeared that the matrix drawn up before the meeting was not complete.

By filling in the matrix, the actors tried to reach shared understanding about when the system escape doors are: ´Normal, Degraded or False´. However, this action was not guided because the Engineer of Escape Door and the Engineer of Control 1 and 2 had different basic assumptions. The Engineer of Escape Door thought about 'the system escape doors' and the Engineers of Control about 'the control of the system escape doors'. At the end of the conversation, there was no shared understanding about the stages in which an escape door can exist. The Engineer Escape Doors asked the Engineers of Control to develop a new matrix.

All notes taken during the meetings were analyzed in the same way as in Example 1 in Box 5.1. In order to practice how to detect the noticeable results of Case 2, we used the video tapes of the Delft Workshop teams (Cross, *et al*, 1996). This provided us with a good way to learn about observing a design team in action, since we could verify our interpretations with the data of Valkenburg (2000). (Valkenburg also observed the process of creating shared understanding.)

We can conclude that both our knowledge about Industrial Design Engineering and the training with the video tapes of the Delft Workshop teams enabled us to understand the content of the design communication of the actors of Case 2.

Preparing the interviews and desk research

The noticeable results formed the input for the interview questions. In this case study, we followed two interview strategies. First, we asked the actors detailed questions about what happened during the meeting. We asked questions such as:

"*What did person X say about the coding concept*?", and "*How did you react to* *that and why did you do that?*" These types of interview questions did not lead to interviews that were as useful as they could have been. Sometimes it was because the subject evolved further, but most of the time it was because the actors could not remember what exactly had happened during the meeting. Therefore, we chose a different strategy. We asked the actors about their opinion about a particular aspect. As a result, the content of the conversation became more important than how it was discussed during the meeting. During the second strategy, we asked questions such as: "*What do you think about the coding concept*?" Example 1 in Box 5.2 shows the interview questions that we asked the Engineers about their conversation as shown earlier in Box 5.1.

Box 5.2 Example 1: Some interview questions of the meeting between Escape Doors and Control

Interview Quesions

1. What does the matrix of the different stages of the escape doors look like?
2. What is the difference between a failure and a disturbance?
3. When does an escape door fail?
4. What do the terms Normal, Degraded and Fault mean?
5. What items of the escape doors are important for Control?
6. What are the possible stages of these items?
7. When does the Fault situation occur?

First, there was a question about the matrix. This question was asked, in order to see if the actors could repeat the frame that had been constructed about the matrix during the meeting. The matrix drawn also functioned as a guide for the following questions. The second question was about terminology. We asked them to show us the difference between a failure and a disturbance. The other remaining questions concerned the stages in which an escape door or the system escape doors could exist and the accompanying terminology.

At the end of every interview, we asked the actors if more remarkable things happened during the week and if the actor had something more to say about the collaboration and communication aspects. We did this to be sure that we had captured all of the important aspects concerning collaborative design.
In addition to the interviews, we also did desk research. Documents like minutes of meeting, presentations, project description documents, design philosophy documents were read in order to verify the reliability of both the observations and the interviews. The results of this desk research were written down in the Logbook that was made during the observational period.

The choice of the actors to be interviewed was dependent on two criteria. First, we concentrated on the technical aspects. Therefore, we only interviewed the actors involved about technical issues. Second, the actors chosen were highly involved in the meeting. If an actor was involved in more than one meeting, we asked questions about all meetings in which he was involved. Every interview was executed with more than one actor in order to improve the internal validity of the interviews. Due to time constraints of the actors, the interviews took place one or two days after the meetings.
In the six weeks of actual fieldwork, the 12 meetings of 1-4 hours that were observed and the 22 interviews were done with 18 actors. (Some actors were interviewed more than once, since they were key figures in more that one meeting.) In addition, informal talks with all of the actors were held. Notes were made in a Logbook during these informal talks.

Data processing 5.4.2

From the interviews, we detected the barriers and enablers for the creation of shared understanding, just as we had done in Case 1. In addition, we also clustered the barriers and enablers. This section describes how these activities were executed.

First, from the interviews barriers and enablers were detected from the interviews. We did this by listening to the interviews and interpreting them. Furthermore, the Logbook was analyzed to distill the barriers and enablers. Example 1 in Box 5.3 shows the interpretations made from three interview questions with Control Engineer 3 about the meeting between Control and Escape Doors. It is about some of the interview questions from Example 1 in Box 5.2.

Box 5.3
Example 1: The transcription of part of the interview with an Engineer of Control about the meeting between Escape Doors and Control

Interview Question 1:
What does the matrix of the different stages of the escape doors look like?

Engineer Control 3:
I think this is difficult because ehh, ... It is... Ehmm... I think Escape Doors do not know themselves how it is. Yes, because he said if they cannot open or close if they have to, they fail. However, there are some specifications to his statement, which they did not take into account. As I see it… For us it is also not clear of course. That is the reason for these discussions. For us it is about… I think, for us it is more important than for Escape Doors… But... this (pointing at the matrix of Figure 5.3). This is a matrix for one door. Somewhere in the specifications of Escape Doors, there is a specification that says that an Escape Door only fails if three doors do not function. Not function as they are supposed to. That can be good from their point of view, but what if one single door is open during normal operations? Or shows that a door is open, which might not be the truth… In that case a train is not allowed to move, because there is a door that is open. This could mean that there are people walking in the tunnel. But, in that case, the systems fail as one door fails. So, that is how you deal with it. And failure for the system is three doors… But… I do not know how to deal with it. It can be for one door. So, this should be solved.

Interpretation:

The Engineers did not take all specifications into account while making the analyses of the failure of an Escape Door. It is not clear which aspects they need to take into account. The result is that they did not know when an escape door fails.

Barrier:

The specifications that the Engineers need to take into account in order to determine the stages of an escape door are not clear to the engineers.

Interview Question 2:

What is the difference between a failure and a disturbance?

Engineer Control 3:

Yes, I wish I knew. I thought I knew. But there seem to be, many differences between the CMI's (A CMI is a document that contains information about the functioning of a subsystem). If there is a disturbance they call it Dutch 'disturbance' and in English 'failure'. But it seems that on the system level, the term 'failure' has a different meaning. 'Failure' on this level means that a complete system fails. So, for example entire Drainage, entire Ventilation, entire… Then they speak of a 'failure'. While in the CMI's it is a typical. So, one pump, or one van. Then they also speak of 'failure'. I belief there are misunderstandings about this aspect. There should be different names for these two things. I think it will cause confusion of tongues if we continue this. With the term 'failure'…, because one speaks on the subsystem level and the others on one level lower. I think this will cause confusion of tongues. And that will cause problems. Or a challenge, it is the way you see it.

Interpretation:

There are two problems with the term failure. The first is the translation from English to Dutch and vice versa. The second is the level of detail the actors are communicating.

Continuation Box 5.3 Example 1: The transcription of part of the interview with an Engineer of Control about the meeting between Escape Doors and Control

Continuation Box 5.3 Example 1: The transcription of part of the interview with an Engineer of Control about the meeting between Escape Doors and Control

Barriers:

- The mixed use of English and Dutch caused misunderstandings about the terminology used when the Engineers communicate about a failure of a system.
- The term 'failure' has different meanings, dependent on the level of detail the Engineers communicate about.

Interview Question 3:

When does an Escape Door fail?

Engineer Control 3:

Ehhmm… According to the CMI (A CMI is a document that contains information about the functioning of a subsystem) of Escape Doors, it fails if a door does not open if it has to open or not closes if it has to close. Closing is not yet a 'failure', because the door closes because of its own weight. However if, for example, a toolbox is hampering the door from closing or if there is a wooden block in the door gap… And the door should close, but does not close… That is according to Escape Doors a 'failure'. However, for us, it is a 'failure' if we get conflicting signals. If the signal of the door is at the same time 'I am open' and 'I am closed'. That is impossible. For us, this could be a 'failure'. But that is not that a door really fails, but the signal of the door fails. It is where you are speaking of. Do you mean the door itself or the signaling?

Interpretation:

For Escape Doors the term failure means that the door does not open if it has to open or does not close if it has to close. However, for control a failure means conflicting signals. This caused misunderstandings.

Barrier:

The Engineers lack a proper definition of the failure of an escape door because the term failure has different meanings for the different subsystems.

Analyzing the answers of the Engineer of Control one can see that the actors qualify their communication processes. We interpreted the answers given by the actors and formulated barriers and enablers on the basis of these answers. About the question about the matrix, the Control Engineer explained that it was difficult to determine the stages of the escape doors. He provided us with information of why this was difficult. It was because the specifications that belong to this item were not clear. From this statement, we formulated the barrier: *The specifications that the Engineers need to take into account in order to determine the stages of an escape door are not clear to the engineers.*
The answer to the second interview question shows that the actors lacked shared understanding about the terms 'failure' and 'disturbance'. The Engineer Control showed this had two causes. The first was the mixed use of English and Dutch in the design project. The second were the different levels of detail about which the actors communicate. These two reasons formed two barriers. By answering the third interview question, the Engineer of Control showed that for each subsystem the term 'failure' has a different meaning. This also formed a barrier because the Engineers lack a proper definition of the failure of an escape door, since the term failure has different meanings for the different subsystems.

We remark that not every interview question led to a barrier or an enabler. Sometimes, the actors did not mention any influencing factors for the creation of shared understanding in their answer to our interview question. We did not ask actors explicitly to mention these factors, since we did not want to influence their stories. We only focused on the factors that the actors found to be of interest.

Data analysis 5.4.3

In order to gain a better understanding of the types of barriers and enablers found, we coded the barriers and enablers according to the organizational level to which they belonged. We coded the barriers and enablers using the same coding scheme as in Case 1. Since this coding scheme was validated, only one researcher coded the barriers and enablers.

Example 1 in Box 5.4 shows two of the barriers derived in Example 1 in Box 5.3.

Box 5.4
Example 1:
Coding of the barriers found

Coding of the barriers found:

Barrier	Organi-zational level	Interface	Actor	Week
The specifications that the Engineers need to take into account in order to determime the stages of an escape door are not clear to the Engineers.	A	Interface between Control and Escape Doors	Engineer Control 3	11
The Engineers lack a proper definition of the failure of an escape door because the term failure has different meanings for the different sub-systems.	A	Interface between Control and Escape Doors	Engineer Control 3	11

The first barrier is a barrier on the actor level, since the actors lacked certain knowledge. The second barrier shows that the management did not provide a proper definition of the failure of a subsystem. This is a problem of an organizational nature and, therefore, a barrier on the company level. In addition to their organizational level, the barriers and enablers were also coded in a more qualitative way. The barriers and enablers were clustered according to their content, which resulted in interfaces that contain collaborative mechanisms. The clustering was conducted in two steps. First, the barriers and enablers were clustered per week. Second, the clusters of the different weeks were grouped again. During the clustering, the barriers and enablers of the different actors interviewed were combined and a story about issues about their collaboration process originated. The barriers and enablers that we could not group were put is a remainder category. Within a group, we analyzed what the relationship was between the barriers and enablers. In addition, we described both what knowledge actors shared and created and the communication processes they used. This provided insight into the collaboration mechanisms within the interface. Section 5.5.2 shows the results of this clustering. The barriers of Example 1 in Box 5.4 both belonged to the theme *the interface between Control and Escape Doors* because they hampered the creation of shared understanding between the subsystems Escape Doors and Control.

The validity and reliability of the research method followed 5.4.4

This section shows how we dealt with validity and reliability issues in Case 2. In order to triangulate, we used different data gathering methods. We used both observations and interviews to gain the barriers and enablers of Case 2. The observations led to interviews that were closely related to the actual collaborative processes of the actors. By interviewing the actors about these processes, we could verify if the interpretations made from the observations were valid. More importantly we could then use the interviews to capture the perception of an actor about that particular aspect. It was the actors' perception of his process of the creation of shared understanding that led to the barriers and enablers of Case 2. In addition to the observations and interviews, data was also collected from project documentation, including presentations, minutes of meetings and design documents. This triangulation of methods directly provided us with a triangulation of sources. We analyzed notes, taped interviews, reports, PowerPoint presentations, etc.

In addition to these common modes of triangulation, we also improved the validity of the data by presenting the data analysis to the respondents during two workshops. The barriers and enablers found were presented in the first workshop. This workshop provided insight into the importance of the barrier and enablers found. It also gave feed back about the quality of the interpretation of the data. No major changes were made after this validation check. In the second workshop, we showed the interfaces that originated from the data. In addition, we also provided the actors with implications in order to improve their collaborative design project. The actors were positively surprised by the power of the research project. They thought it reflected their collaboration process well and that it provided them insight into their own processes. Also, the implications given were applicable to their daily practice. The results of the second workshop showed that these interpretations were also valid.

For creating a reliable case study, Yin advises creating case study databases (Yin, 1994). In this study, we made different types of data bases.
An important data base during data collection and data analyses was the Logbook. Example 2 in Box 5.5 shows a piece of the Logbook about one week.

Box 5.5 Example 2 Logbook about one week

Logbook about one week:

Monday

- Analyzed interview Engineer Control 3 about the interface meeting between Fire Fighting and Control
- Analyzed interview Engineer Control 1 about the interface meeting between Fire Fighting and Control
- Attended an interface meeting between Escape Doors and Control

Continuation Box 5.5 Example 2 Logbook about one week

Remarks interface meeting between Escape Doors and Control

- Good example of confusion of tongues and mixture of terminologies.
- Responsibilities of both Escape Doors and Control are also unclear.

Tuesday

- Attended Progress Meeting Core team
- Attended the System Engineering Meeting
- Interviewed Engineer Control 2 about the Interface meeting between Escape Doors and Control
- Interviewed Engineer Control 3 about the Interface meeting between Escape Doors and Control
- Interviewed Engineer Control 1 about the Interface meeting between Escape Doors and Control
- Interviewed the Project Leader of Control and Engineer Control 1 about general things

Remarks Progress Meeting

- Under-layers: The drawings that have to be made will be directly tuned with the drawing engineers, from now on. The mediators filtered the information, which caused mistakes.
- The Project leader made a planning for all subsystems together
- The Project leader and the system engineer contacted Maintenance about how to deal with the documents of Control.
- There will be an internal audit.

General remark

The Project Leader of Control complained about the lack of contact between Control and the other subsystems. The other subsystems claim no contact is needed. The Project Leader of Control said he did not understand it because before the movement he was involved in everything. He said: "*Either I miss many things now, or I lost time before the movement.*"

Continuation Box 5.5 Example 2 Logbook about one week

Remarks System Engineering Meeting

The coding concept is again a topic of discussion. Control will design a coding concept and it will be presented to the other subsystems in the system engineering meeting in two weeks. According to the Project Leader of all Mechanical Systems, new actors in the project have troubles with the coding concept.

Some Quotes (not literally)

- Engineer Lighting: There are many engineers from outside. They use things they used earlier. This cannot. They have to follow the 'law'.
- Project Leader of Control: The coding concept is like a dialect. If you know it, it is very easy.

The problem with the coding concept is caused by the fact that the system needs to be maintained. For Maintenance, it is important to know where the broken object is and how it is constructed. A good coding concept can support this. The Project Leader of Control, the Lead Engineer of Lighting and the Design Data Manager have experience with this and they see the urge. The Project Leader of Heating, HVAC (Heating, Ventilation and Air Conditioning) and Mechanical Systems have to use the coding concept but do not see the urge and usability.

Wednesday

- Interviewed the Project Leader of Control about the Progress Meeting, the System Engineering Meeting and about general issues.
- Attended an interface meeting between Control and Non-Traction Power.

Remark interface meeting between Control and Non-Traction Power

The meeting was effective analyze for enablers!

Documents of the week:

- Minutes of the Interface meeting between Escape Doors and Control

- Interface document Escape doors en Control
- Minutes Progress Meeting
- Recorded interview Engineer Control 2 about Interface meeting between Escape Doors and Control
- Analyses interview Engineer Control 2
- Recorded interview Engineer Control 2 about Interface meeting between Escape Doors and Control
- Recorded interview Engineer Control 3 about Interface meeting Escape Doors and Control
- Analyses interview Engineer Control 3
- Recorded interview Engineer Control 1 about Interface meeting Escape Doors and Control
- Analyses Interview Engineer Control 1 about Interface meeting Escape Doors and Control
- Recorded interview Engineer Control 1 and Project Leader Control about general issues
- Analyses interview Engineer Control 1 and Project Leader Control about general issues
- Recorded interview Project Leader Control
- Analyses interview Project Leader Control
- Analyses meeting between Control and Non-Traction Power

Continuation Box 5.5 Example 2 Logbook about one week

The example shows that we were present in the company on Monday, Tuesday and Wednesday. For each day, it shows the activities executed and remarks about issues that acted as reminders during data analyses. At the end of every week, a list of documents was made up. The Logbook was a good tool for getting a quick overview about what happened during a week and it also provided a good overview of the meetings followed.

In order to get a quick overview of all documents produced during data collection, a mind map of all of the documents was made. The advantage of the mind map, as apposed to a text document, was that all documents produced were presented compactly on one page, without loosing the structure. Figure 5.4 shows this mind map. The mind map is organized per week, just as the Logbook was. Every week, the documents that were produced and gathered were organized according to their subject. The documents were linked to the mind map with a hyperlink. This made it easy to find and open the documents needed.

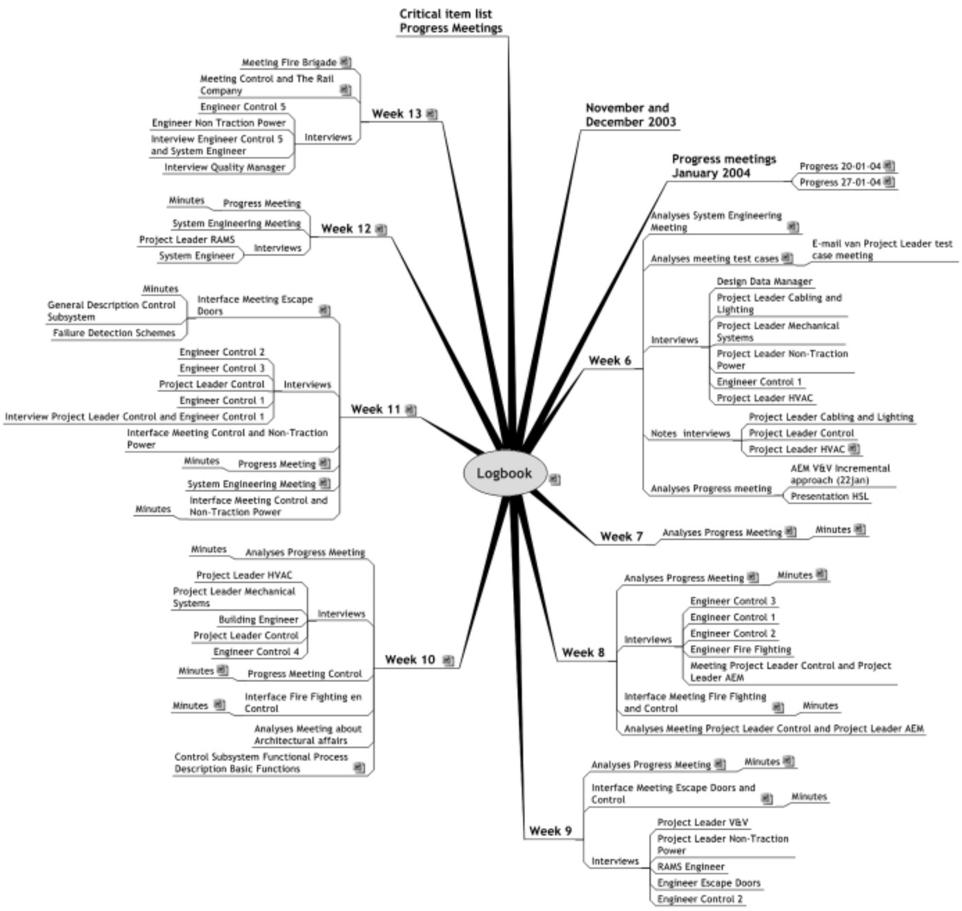


Figure 5.4 The Mindmap of the documents produced during data collection

During data analyses, we used the computer program QMAX DA for structuring the coding process of the barriers and enablers. We had a list with all barriers and enablers that we all coded according to:

- the actor to whom the barrier or enabler belongs
- the week in which the interview was conducted
- the theme to which it belonged
- the organizational level of the barrier or enabler

The computer program QMAX DA made it possible to isolate the barriers and enablers that belong to a certain category or a combination of categories. The QMAX DA file of Case 2 can be used as a reliability check for the coding of the barriers and enablers.

In conclusion, we can say that the validity of the data is guaranteed by using the multiple sources of evidence and by making the evidence transparent. The internal validity of the data is guaranteed by using several triangulation methods and the feedback of the respondents. The external validity of this case study cannot be tested within one case study. However, in Chapter 6 there will be a check on the external validity of the case study. This will be done by making a cross case comparison between Case 1 and Case 2.

Results 5.5

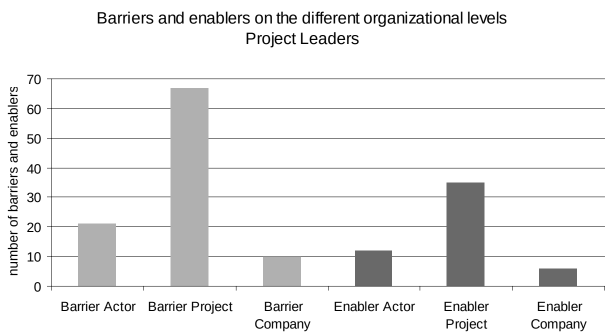
This section will report the results of Case 2. First, there will be a section about the coding of the barriers and enablers on the different organizational levels (see section 5.5.1). In section 5.5.2, the barriers and enablers are clustered according to their content. This resulted in ten different interfaces. Within these interfaces collaborative mechanisms occurred. This will also be shown in section 5.5.2.

5.5.1 Barriers and enablers according to their organizational level

In this section, we will describe the results of Case 2. From the data, we detected 155 barriers and 74 enablers. The barriers and enablers are divided normally among the actors interviewed.

The barriers and enablers were categorized according to the three organizational levels: the actor-, project- and company level. We found 50 barriers on the actor level, 93 on the project level and 12 on the company level. We also found 25 enablers on the actor level, 44 on the project level and 5 on the company level*. The relatively large number of barriers and enablers on the project level can be explained by the fact that most of our interviews were conducted with the Project Leaders of the technical subsystems. They have project management tasks within the project, which resulted in barriers and enablers on the project level. The Project Leaders were interviewed often because they had the most interaction with team members from other subsystems. The barriers and enablers on the company level can be explained by the fact that the team members were dedicated to the project and that the project was rather independent of developments within the company. The Figures 5.5 and 5.6, show that the Project Leaders of the sub systems have more barriers and enablers on the project level than the Engineers.

Figure 5.5 Barriers and enablers of the Project Leaders



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* *In this section we use graphs in order to explain patterns that we found in our data. We are aware of the fact that the definite numbers are not telling how often a certain aspect occurs. However, they do say something about the differences and similarities between aspects that we found in this study.*

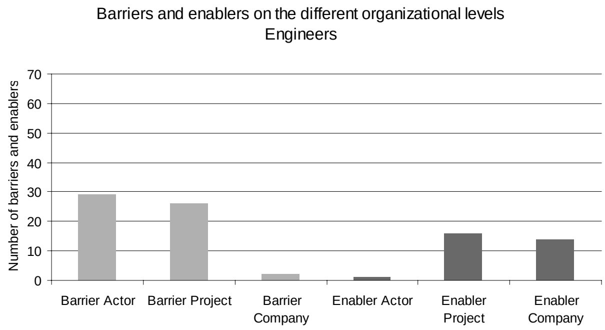


Figure 5.6 Barriers and enablers of the Engineers

Table 5.2 shows examples of barriers and enablers on the three organizational levels.

Level	Barrier	Enabler
Company	The move of the Control department to another building decreased the amount of communication between Control and the rest of the development team.	There was a system engineering group established on the consortium level of the design project.
	Maintenance did not have the capacity to think conceptually.	There was a distinction made between political/ and technical management.
Project	As a result of the cancellation of the system engineering meeting, the Project Leaders of the subsystems did not know from each other what they were doing.	Decisions related to the content of the subsystems were put In the Minutes of the System Engineering Meeting.
	The interface between the subsystems Control, Lighting and Fire Fighting was not clear.	The interface meetings between Control and the other subsystems provided Control with the information needed.

Table 5.2 Examples of barriers and enablers on the three organizational levels

Continuation Table 5.2 Examples of barriers and enablers on the three organizational levels

Level	Barrier	Enabler
Actor	The system engineer lost the feeling of being connected with the technical subsystems, due to the amount of management tasks he had.	A RAMS Engineer translated the jargon of the subsystems into their own jargon.
	Control used another definition for the failure of an Escape Door than Escape Doors did	An Engineer of Control designed the coding concept, since he was able to take the requirements of all subsystems into account

During this research project, the office building of the project team became too small. The Management decided Control had to move to another building. This caused a barrier on the company level because this organizational change hampered the content related communication between Control and the other subsystems.

The lack of ability of Maintenance to think conceptually is also considered a barrier on the company level. It is a Human Resource Management issue because they hired actors with knowledge that did not fit the type of knowledge needed.

The establishment of a system engineering group on the consortium level of the design project is an organizational change that enabled the integration of the different subsystems. The Management also chose for a distinction between political- and technical Management. This is a decision on the organizational level that enables content related communication because it is not disturbed by financial issues.

During the research project the System Engineering Meeting was often cancelled. This disturbed the information flow between the Project Leaders of the different subsystems, which formed a barrier on the project level.

For the Engineers, it was not clear what the interface was between the subsystems Control, Lighting and Fire Fighting. This formed a barrier on the project level because it caused tuning problems between the actors. It was not clear to the Engineers who had to do which aspects of the complete task.

The fact that the design decisions of the subsystems were put in the Minutes of Meeting is an enabler on the project level, since the decisions became explicit and visible for all of the actors involved.

The interface meetings between Control and the other subsystems made the actors of the different subsystems communicate with each other. This created an information flow between them. Therefore, it is an enabler on the project level.

During the observation period, the System Engineer received more management tasks. This was at the cost of his system engineering task. This made him lose the touch with his system engineering task, which was a barrier on the actor level.

The actors from Control and Escape Doors each used a different definition for the failure of an escape door during an interface meeting. This hampered the creation of shared understanding between them for a large part of the meeting. Therefore, this is a barrier on the actor level.

The actors from the different subsystems spoke different jargon, which often hampered the creation of shared understanding. However, a RAMS Engineer was able to translate the jargon of the subsystems into their own jargon. This enabled the creation of shared understanding and formed an enabler on the actor level.

During the project, there were problems with the coding of the drawings. The system engineering team decided that an Engineer of Control had to make a coding concept because he was able to take the requirements of all disciplines into account. Therefore, this is an enabler on the actor level.

The interfaces 5.5.2

The next step of the data analysis was the clustering of the barriers and enablers according to their content. This has resulted in ten interfaces and a small remainder category (which consists of only 5 barriers and enablers). All interfaces consist of both barriers and enablers on more than one organizational level. This shows that there are relationships between the barriers and enablers. In the remainder of this section, we will analyze the collaborative processes within each interface. For each interface, we will describe:

- what knowledge the actors shared and created
- the communication process between the actors
- the relationship between the barriers and enablers

By doing this, we have described the collaborative mechanisms of Case 2.

The interface between the design team and the Civil Contractor

The first interface was the interface with the Civil Contractor. The Civil Contractor built the buildings in which the equipment of the design team was housed. A problem with this interface is that the buildings had already been built, without taking into account for what type of equipment they should be suitable. The interface between the design team and the Civil Contractor was a complex interface with many actors involved. An Architect designed the buildings. He got his order direct from the customer and was asked to design only the outside of these buildings. At that time, the customer did not know the exact purpose of the buildings. The Civil Contractor built the buildings that the Architect designed. However, the buildings were not completely suitable for the subsystems developed by the design team. Therefore, the design team and the Civil Contractor had to make a design for adjustments to the buildings. The design team and the Civil Contractor shared knowledge about:

- The licenses for the buildings
- The design of the subsystems
- The design of the buildings

Together they created knowledge about:

- The necessary adjustment of the buildings

- The design of the division of the buildings

Since the design team did not have much experience with collaboration processes with Civil Contractors, they hired a Building Engineer to help them with the interface. The Building Engineer functioned as a boundary spanner. She mapped the most important bottlenecks that the design team faced concerning the buildings. After that, she translated this information into the language of the Civil Contractor.

The communication with the Civil Contractor was formally organized. Most communication went via a partner in the Consortium who was responsible for Project Management. However, as the design project continued, there was communication between Engineers in the design team and Engineers of the Civil Contractor who had to make the interface documents. One important kind of interface document was the civil underlayers. These were drawings that showed the design of the buildings in a way that allowed the Engineers of the design team to see how their equipment would fit into the buildings (or what adjustments to the buildings were necessary in order to let the equipment fit into the buildings). Furthermore, they used the drawings to determine where they could position the equipment. Figure 5.7 shows an example a drawing that was made during a meeting.

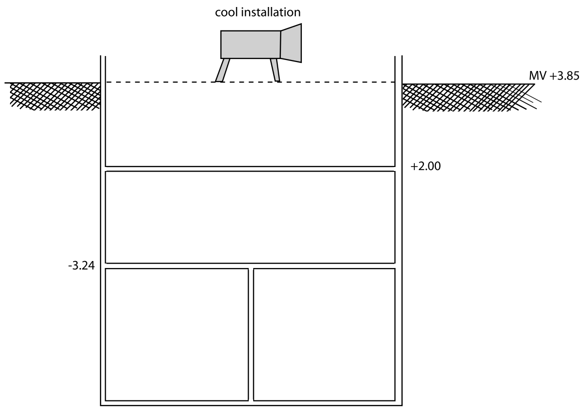


Figure 5.7
A drawing of a cross-section of a building made during a meeting

The drawing of Figure 5.7 shows a cross-section of a building upon which the design team had to place a cool installation. They used this drawing to get an overview of the levels of the building in relation to the ground level (= MV in the drawing).

Barriers and enablers for creating shared understanding

This section describes which barriers and enablers belong to the collaboration process between the Civil Contractor and the design team. The collaboration mechanism consists of barriers on the project- (BP) and actor level (BA). The enablers are on the company- (EC), project- (EP) and actor level (EA).

Most of the barriers of this collaboration process came from the fact that the buildings needed to be revised. The buildings were not completely sufficient for the equipment of the design team and some adoptions to the buildings were necessary. As a consequence, the equipment developed did not completely fit into the buildings and, as a result, expensive changes needed to be made (BP). Therefore, the trajectory of getting permits partly needed to be repeated (BP). In addition, the division of the buildings was not yet designed, which cost time (BP). The Engineers of the design team lacked experience with the division of the buildings. Therefore, they could not estimate the impact of some changes. For example, Non Traction Power did not know how complex it would be to place the emergency diesels in the buildings (BA). The aspects mentioned hampered collaboration with the Civil Contractor.

In order to solve this problem, the design team hired a Building Engineer who had experience with collaborating with Civil Contractors (EC). In the beginning, the collaboration process with this Building Engineer went not fluently, because the Building Engineer communicated on a different level than the actors from the design team (BA). However, after a while, the interface between the Building Engineer and the Project Leader HVAC became efficient. This resulted in a good collaboration between the Building

Engineer and the design team (EP). The Building Engineer was able to map the most important bottlenecks with the interface with the Civil Contractor (EA). Furthermore, the Building Engineer wrote a builders estimate. This was a translation of the specifications for the division of the building of the design team, into the jargon of the Civil Contractor (EA). This enabled the communication with the Civil Contractor.

A second aspect of the interface with the Civil Contractor was that the Engineers needed to get the civil underlayers from the Civil Contractor. The Management underestimated this aspect earlier on in the design project. As a result, the Civil Contractor did not finish these drawings on time (BP). Furthermore, this was a time consuming process of getting the proper civil underlayers from the Civil Engineers (BP). In addition, the Engineers from the Civil Contractor who had to make the drawing were inexperienced with making this kind of drawing (BA). In order to enable the interface with the Civil Contractor, the Management decided that the Engineers of the design team could help the Engineers of the Civil Contractor by providing them with the information necessary (EP). This stimulated the information transfer between them.

The interface between the design team and Maintenance

The second interface was the interface with Maintenance. The Maintenance organization was part of the Consortium, since the systems that the Engineers of the design team were designing needed to be maintained for 25 years. A good maintainability of the subsystems was important for two reasons. First, it could reduce the costs for Maintenance. Second, a subsystem that could be easily maintained would have a high availability, which was also an important factor in this design project.

Both Control and Non Traction Power involved Maintenance in their design process. They let them review the designs of their subsystems. However, the

Maintenance organization was not used to being involved in the conceptual stage of a design project. Normally, they would only check if the systems meet their requirements once they were finished. This resulted in the fact that the involvement of the Maintenance organization was only procedural. Yet Development needed content related knowledge in order to be able to make engineering decisions favourable from a Maintenance point of view. The Engineers of the design team were also not used designing while keeping in mind the maintainability of the system they are designing. In earlier design projects it was sometimes tactical to develop a system with high maintenance cost, since the company could earn money from selling extra parts and man-hours for maintenance.

The communication between the design team and Maintenance was formally organized. Most communication went through documents that Maintenance had to review and vice versa. Examples of their written communication were the design documents of both Control and Non Traction Power.
During this research project, one meeting between Control and Maintenance was observed. The actors communicated about the location of the control rooms and the information that would be presented to the Engineers working in the control rooms during the meeting. The Engineers of Control also made drawings on the whiteboard in order to explain their viewpoints to Maintenance. The Figures 5.8 and 5.9 show two of these drawings. Figure 5.7 shows the functional relation between the control panel of Maintenance and the control panel of Control. This drawing also shows the location of the Control system and the monitoring system of Maintenance (the OCC). The proposal of Control is to move both the Maintenance control room, as well as the control room of Control, to one location; the OTN.

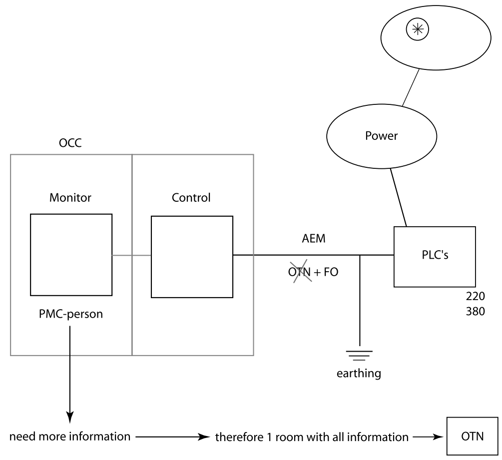


Figure 5.8
Drawing of the monitoring system of Maintenance
in relation to the Control system

Figure 5.9 shows a geographical position of the control panel that Control proposed to Maintenance. The two big squares represent two buildings. One is on the north side of a tunnel and one is on the south side of a tunnel. Control proposed to Maintenance the idea of putting the control room in the building on the north side.

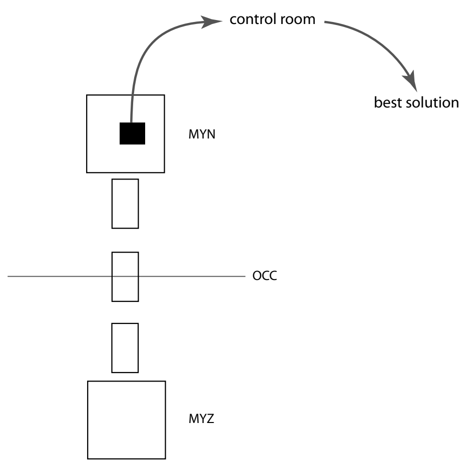


Figure 5.9
Drawing of the geographical position of the control room in the buildings of Maintenance

Barriers and enablers for creating shared understanding

The interface between the design team and Maintenance had barriers on the company- (BC), project- (BP) and actor level (BA). In addition, there were enablers on the project level (EP). Both Control and Non Traction Power involved Maintenance in their design process (EP). However, this enabling factor created barriers on different levels. The Maintenance organization was formally organized. They only wanted to collaborate on a formal base, which hampered collaboration (BC). Also, Maintenance had a lack of capacity to do all of the paperwork. This made it difficult for both Control and Non Traction Power to arrange appointments with Maintenance (BP). Besides, Control asked them to give their opinion about the division of the buildings that Control had proposed. However, the comments Maintenance gave to Control were not about the design, but about the status of the documents and about the lacking documents. This was because Maintenance was not used to being involved in a conceptual stage of a design project (BC). The Engineers of Maintenance were not able to think conceptually (BA).

It took Control much more time to make it clear to Maintenance that they needed the knowledge of Maintenance (BP). In addition, Non Traction Power had to wait for one year to get their documents reviewed, which also hampered the design process of Non Traction Power (BP).

As a result of the attitude of Maintenance, the actors of the design team did no longer sought involvement with Maintenance (BP).

The interface between Control and Fire Fighting

The third interface was the interface between Control and Fire Fighting. The collaboration process between Control and Fire Fighting was a collaboration process between the electronically oriented Engineers of Control and the mechanical oriented Engineers of Fire Fighting. It was an internal interface, since both were part of the design team. The Engineers in this collaboration process did share knowledge about:

- The design of the Fire Fighting system
- The parts of the Fire Fighting system that Control needed to control
- The design process of Control
- The documentation of the interface

Furthermore, together they created knowledge about:

- The interaction between the control system and the fire fighting system
- The information of the fire fighting system that should be shown on the control panel

The actors had oral- and written communication with each other. There were two types of oral communication: formal and informal. We only took formal communication into account, since this was the only type of communication that we could structurally observe. Formal oral communication was organized in meetings. Among other things, the Engineers use documents for structuring the meetings and to mark their progress. Drawings were used to make certain aspects clearer. They used different types of drawings. Control, for example, used the scheme of Figure 5.10 to explain their design process to Fire Fighting.

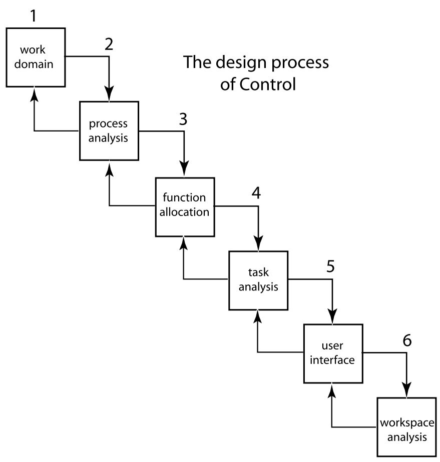


Figure 5.10
A drawing that Control made during a meeting in order to explain their development process

During a meeting the Engineers of Control and Fire Fighting made the drawing of Figure 5.11 on a whiteboard, in an attempt to make the functionalities of the Fire Fighting system clear to each other. While making the drawing, they had a discussion about whether they needed a pump or a valve between a pump and the detection unit.

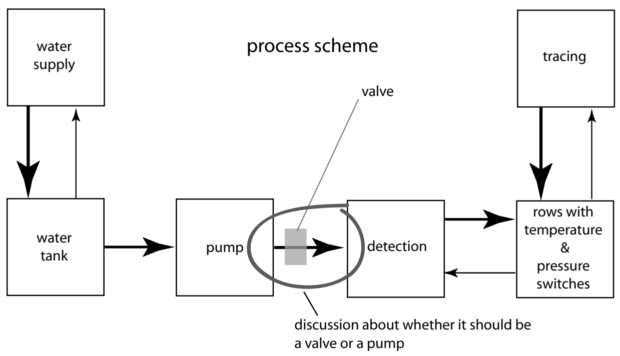


Figure 5.11 A schematic representation of the functionalities of the fire fighting system

Furthermore, in order to communicate they also made different types of formal drawings. The Figures 5.12 and 5.13 show two of these formal drawings. Figure 5.12 is a drawing that is called a CMI. A CMI provides a systematic overview of the control of the signals of a subsystem. The drawing of Figure 5.12 is a CMI for a pump. (CMI's are software oriented.)
Figure 5.13 is a formal drawing that is called a P&ID. By making a P&ID, the Engineers can show flow diagrams between different parts of their equipment. Figure 5.9 is a P&ID about the drainage system in a tunnel along the route. (P&ID's are hardware oriented.)

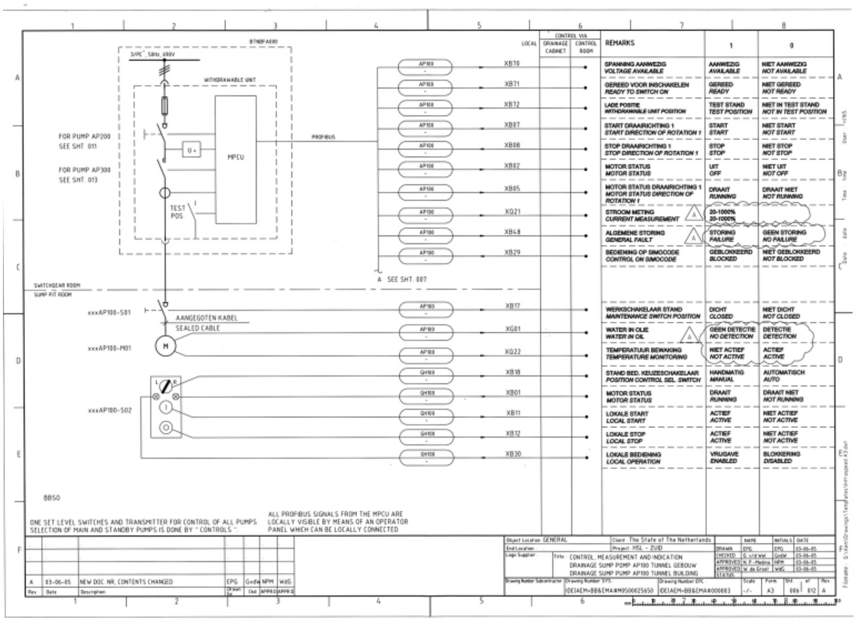


Figure 5.12
An example of a CMI of the subsystem drainage

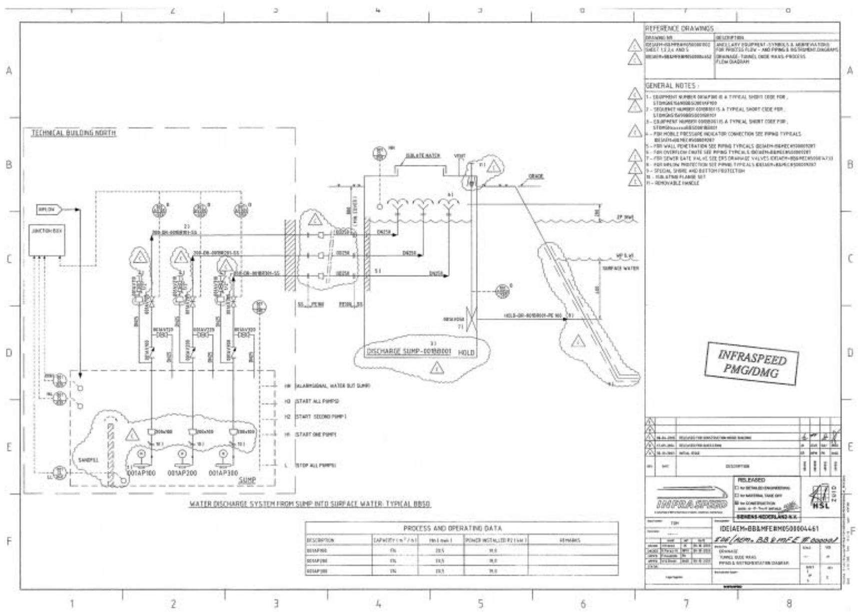


Figure 5.13
An example of a P&ID of the subsystem drainage

Barriers and enablers for creating shared understanding

The interface between Fire Fighting and Control caused barriers on the company- (BC), the project- (BP) and the actor level (BA) and enablers on the project- (EP) and the actor (EA) level. Control moved to another building, which decreased the communication with the other subsystems (BC). Therefore, Control organized formal interface meetings (EP). One of these meetings was with Fire Fighting. At the start of the first meeting, Control explicated to Fire Fighting the design process they would follow. They used the whiteboard to show a schematic overview of their process, which is shown in Figure 5.10. This provided Fire Fighting with some understanding of the interface with Control (EP). Despite this, the actors had a passive attitude towards each other because the Engineers of both subsystems were not willing to think further than the scope of their own task (BC). The Engineers of Control did not want to be involved in the design of the fire fighting system and the Engineers of Fire Fighting did not want to make concrete appointments about what they should deliver to Control. Fire Fighting thought the meetings were too frequent. However, Control needed the information of Fire Fighting. Therefore they were satisfied with the frequency. The attitude of both parties was partly caused by the fact that the Management in the core team did not communicate the appointments made about the interface between the two parties (PB). In addition, the Project Leader of Mechanical Systems slowed down the information exchange between his Engineers and the Engineers of Control. This was because he wanted to control the information flow (BP). These aspects caused the Engineers of Escape Doors to define their scope too narrowly (BP). In addition, it was not clear to the Engineers who was responsible for which aspects of the design project (BA).

Another issue was that, the scope of Fire Fighting had changed during the design project (BP). This made the Interface between Control and Fire Fighting unclear. In addition, there was also a change in the design that had an impact on Non Traction Power. However, this design change was not communicated to Non Traction Power (BP).

There were also some issues with the written communication between Control and Fire Fighting. For example, Control put the Minutes of the first interface meeting in a database, which was not directly accessible for Fire Fighting (BP). Therefore, the Engineers of Fire Fighting could not read the Minutes. The Engineers of Fire Fighting complained about the knowledge of Control about their subsystem. However, Control did not get the Fire Fighting Design Document. This would have provided Control with much more information about the fire fighting system. The Fire Fighting Design Document was given to Control after the first interface meeting, which decreased the efficiency of the meeting (BP). Furthermore, it was not clear what kinds of documents the Engineers of Fire Fighting should have made for Control. The Project Leader Mechanical Systems, who was responsible for Fire Fighting, did not tell his Engineers what types of documents they had to make. For example, the Project Leader Mechanical Systems did not explain to his engineers the importance of the CMI's (BP). Therefore, Fire Fighting made the wrong documents (PB).

There were also some enabling aspects that concerned the written communication. For example, Control Engineer 3 was responsible for the technical drawings of the Fire Fighting system at the start of the design project. This helped him to understand the design of the Fire Fighting system (EA). Besides, during the design project, the Project Leader Mechanical Systems made an Engineer, who was used working with this type of documents, responsible for the interface documents (EA).

During the meetings, the Minutes of the last meeting, helped the actors to structure the meeting (EP). The Engineers also used whiteboards to explain themselves, which directly enabled the creation of shared understanding between them (EA) (see Figure 5.11). The result of these enablers was that the Engineers of Fire Fighting saw both the value of the meeting (EA) as well as the value of the documents they have to deliver to Control (EA).

The interface between the design team and the sub team of RAMS

The fourth interface concerned the interface between the design team and the sub team of RAMS (Reliability, Availability, Maintainability and Safety). The safety of the systems designed played an important role in this design project. This caused an interesting tension between the availability and the safety of the system developed. For these reasons, the RAMS process was an important part of this design project. The Management of the core team decided to form a separate RAMS team that had to support the different subsystems with their RAMS process. The Engineers of the subsystems needed help from the RAMS team in order to make their subsystems meet the RAMS requirements. Therefore, the RAMS team needed to gain knowledge about the designs of the different subsystems from the Engineers of the subsystems.

A task of the RAMS team was to make estimations about the probability that a subsystem could fail. They did that by first determining the chance that a part or a subassembly might fail. By multiplying failure chances of the parts or subassemblies, they were able to calculate the chance that a subsystem may fail. The RAMS Engineers derive the assumption for the chance that a part might fail from RAMS handbooks. The Engineers of RAMS showed their calculations to the other Engineers by making Fault Trees. Figure 5.14, shows an example of a Fault Tree for the chance of a failure in the service system. Each box in the tree represents a part of a subassembly. The parts are put on the lowest level in the Fault Tree. The higher the box is on the Fault Tree, the more complex the subassembly.. A subsystem is on the highest level of the Fault Tree. The Engineers of the subsystems reviewed the fault trees.

Another task of the RAMS team was to help the Engineers of the subsystems to reach a certain safety level (A low chance that a subsystem might fail). In order to be able to do that they had to know the design of the system, as well as the way the system was situated in the tunnel. Therefore, the Engineers of the subsystems discussed their designs with RAMS. They used drawings like Figure 5.15 to make certain aspects more clearer to one another.

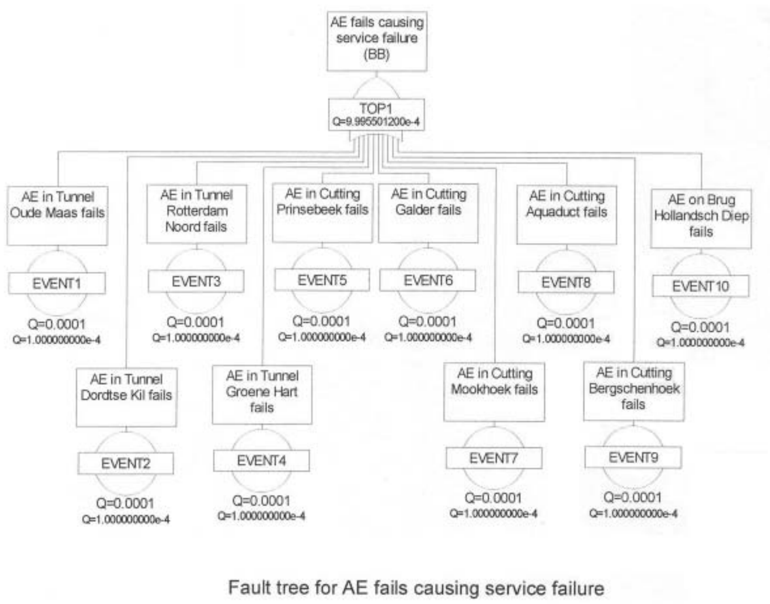


Figure 5.14

A fault tree that shows the chance that a service failure might occur.

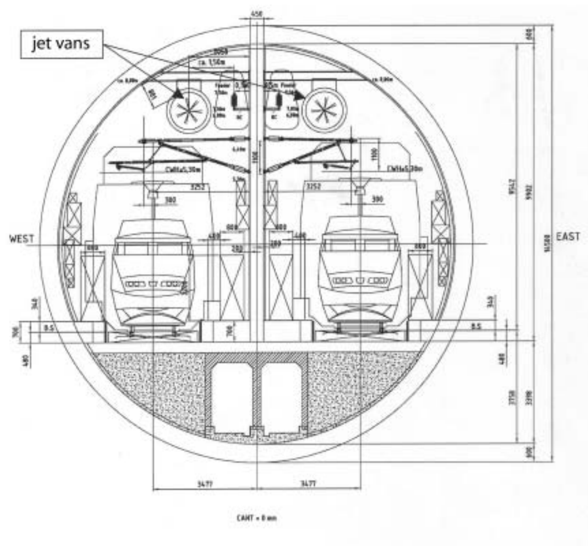


Figure 5.15

A section of a tunnel, which shows the placement of the jet vans.

In addition to schemes and drawings, most communication between the design team and the sub team of RAMS went through documents or informal oral communication.

Barriers and enablers for creating shared understanding

The interface between the design team and RAMS caused barriers on the company- (BC), project- (BP) and actor level (BA) and enablers on the company- (EC), project- (EP) and actor level (EA).

The interface between the RAMS team and the Engineers of the subsystems was difficult. According to the Project Leader of RAMS, the Engineers of the subsystems saw RAMS as a difficult task that caused extra work (BA). It was hard for the RAMS team to convince the Engineers of the subsystems of the importance of the RAMS requirements (BA). Another problem was that RAMS was not invited in the System Engineering Meetings of the Project Leaders of the subsystems. This hampered the contact between them (BP). Appointments between the Engineers of RAMS and the Engineers of the subsystems were often made orally. They were not put down on paper (BP). This made the appointments between RAMS and the design team unclear. In addition, appointments could not be traced (BP). The RAMS team sometimes did not use the formal communication patterns. Therefore, documents that were not suitable for the Engineers of the subsystems originated. An example of such a document is the *Assumption list*. The name of the document was awkwardly chosen (BA). Many engineers had a piece of paper on their wall with the text: "*Assumptions, mother of all fuck ups!*" This made it obvious that the Engineers did not take the list seriously. Furthermore, the other Engineers did not know if this Assumption List was the same as a type of document called ICF, which they sometimes used (BA). This also caused misunderstandings.

There were some capacity problems in the RAMS team. The RAMS team was rather inexperienced, so they hired another external engineer to support the RAMS process (EC). On paper, this external Engineer was not the Project Leader of the RAMS team. This role was allocated to an internal Engineer. However, during the design project it was not clear who had the lead. Therefore, it was not clear to the Engineers of the subsystems who they should approach (BP).

Later in the design project, they hired another Engineer (EC). However, this Engineer could not be properly instructed (BC) because his desk was in the Control department, instead of in the RAMS department.
Another effect of the inexperienced RAMS team was the fact that the terminology in the RAMS handbooks was also not clear to some of the RAMS Engineers (BA). The strength of the RAMS Engineers was that they were able to translate the jargon of the Engineers of the subsystems into their own jargon, which enabled the communication between them (EA).

The interface between the Project Leaders of the subsystems

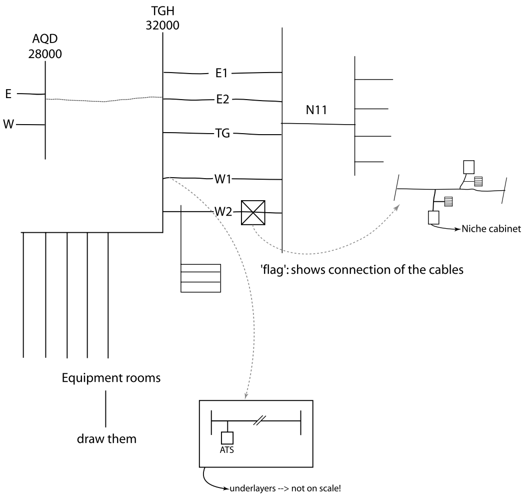
The fifth interface concerned the interface between the Project Leaders of the subsystems. The Project Leaders of the subsystems were responsible for the integration of their subsystems. Therefore, they had to be sure that they tuned their dependencies with each other. There was a System Engineer who was responsible for structuring the integration process between the subsystems.

The Project Leaders of the subsystems and the System Engineer shared detailed knowledge about the design of the subsystems with each other. They created knowledge about the dependencies between their subsystems. They also created knowledge about the most optimal design solutions seen from the viewpoint of the whole system.

The Project Leaders of the subsystems normally had a System Engineering meeting every week. However, during the observation period this meeting was often cancelled, due to the busy schedule of the System Engineer. During the week the Project Leaders organized meetings between two or more subsystems in order to discuss their mutual dependencies, both on a process- and on a content level.
During the System Engineering meeting there were discussions about both

the design process to follow and about design issues concerning the content. If the Project Leaders had a discussion about the content of the design of the subsystems, they often used the whiteboard to make a drawing of the aspects that were being discussed. Figure 5.16 is an example of such a drawing. This drawing was made during a discussion about the installation design. They had a discussion about the placement of the cables and the connection of the cables.

Figure 5.16 Drawing, made on a white board, of the installation design



Barriers and enablers for creating shared understanding

The interface between the Project Leaders of the subsystems caused barriers on the project- (BP) and actor level (BA) and enablers on the project level (EP).

Within the system engineering meeting the Project Leaders of the different subsystems communicated about issues concerning the integration of the subsystems. The System Engineering Meeting was cancelled because the System Engineer was not available to chair the meeting (BP). As a result, there were no meetings planned between two or more subsystems to go into detail about certain aspects (BP). Therefore, the Project Leaders do not know

from each other which tasks they were executing (BA).
According to the Project Leaders of the technical subsystems, the System Engineering Meeting itself was not so efficient because it was not guided strictly (BP). Furthermore, the way the Project Leaders communicated with one another was sometimes tiring because the actors try to overrule each other (BP). The system engineering meeting had an ad hoc agenda. This enabled the Project Leaders to discuss the most urgent and important aspects (EP). This agenda was sent to the Project Leaders together with the Meeting request (EP).

The interface between Control and Escape Doors

The sixth interface concerned the interface between Control and Escape Doors. The collaboration process between Control and Escape Doors was comparable to the interface with Fire Fighting. It was also a collaboration process between the electronically oriented Engineers of Control and the mechanically oriented Engineers of Escape Doors.

The Engineers in this collaboration process did share knowledge about:

- The design of the system Escape Doors
- The way Control has to control the escape doors
- The design process of Control
- The documentation of the interface

Furthermore, together they created knowledge about:

- The interaction between the control system and the system escape doors

The Engineers of Control and Escape Doors had oral- and written communication with each other. There were two types of oral communication: formal and informal. We only took formal communication into account, since this was the only type of communication that we could structurally observe. Formal oral communication was organized into meetings. Among other things, the Engineers used documents for structuring the meetings and to mark their progress. Drawings were used to make certain aspects clearer. They used different types of drawings. Control, for example, used the scheme of Figure 5.10 to explain their design process.

The interface between Control and Escape Doors evolved tightly and only consisted of barriers on all three levels (BC, BP, and BA). The main subject that the Engineers had to discuss was the stages in which an escape door could exist. Since there were no clear definitions for the failure of the system escape doors (BC), it was for both disciplines unclear what caused the failure of the escape doors. Without clear definitions, the Engineers were unable to have a proper discussion about how Control needed to control the system escape doors (BA). It resulted in a confusion of tongs about terminology and the jargon used by the Engineers (BA).
Another problem in this interface was that the Project Leader Mechanical Systems had too many tasks (BP). The Project Leader Mechanical Systems hampered the information transfer between his Engineers and Control (BP). Besides, his Engineers did not properly know their task (BA). For the Engineers, it was also not clear who was responsible for which aspects of the design process (BA). For example, the Engineer of Escape Doors thought RAMS was responsible for a certain document, which he had to deliver to Control him-self. This made the Engineer of Escape Doors think that the RAMS team was too late with their information and that he was not able to deliver his information to Control (BP). Also, the importance of some documents was not properly communicated to the Engineer of Escape Doors (BA). These misunderstandings led to the fact that the Engineer of Escape Doors had a too narrow scope of his own task (BA). Since the Engineer of Escape Doors did not want to think and communicate about aspects outside of this scope, the misunderstandings had an impact on the interface with Control.

The interface between the design team and sub team of V&V

The seventh interface was the interface between the design team and the sub team of V&V (Verification and Validation). The V&V process was an important process in this design project, since the customer demanded that all requirements could be traced and tested on each level in the design project.

In order to meet the strong V&V requirements, the Project Leader V&V developed a V&V plan, which consisted of four procedures:

- the apportionment of the requirements (The customer developed requirements on a general level, which were translated into technical requirements for each subsystem. The division of these technical requirements is called apportionment.)
- the traceability of the requirements on each level
- the ability to test the requirements and to prove that they are tested
- the changes of the requirements

The Project Leader V&V had to share these four procedures with the Engineers of the subsystems. They had to create experience in how to deal with these procedures.

In the concept phase, the most important aspect was the design of the tests used to prove that a subsystem met its requirements. Also, the planning of the execution of the tests was one of the aspects.

In the beginning of the design process, the V&V manager gave a presentation for the Engineers in order to inform them of how to follow the V&V procedures. (This was before the research project started.) In the concept phase, the communication between the Project Leader V&V and the Engineers of the subsystems was mostly through documents. In order to structure the V&V process, the Project Leader V&V developed templates, which the Engineers could use for reporting their V&V procedures. Furthermore, the Project Leaders of the subsystems had oral communication with the Project

Leader V&V during the progress meeting. In these meetings, they discussed the problems concerning the V&V procedures.

Barriers and enablers for creating shared understanding

The interface between the design team and the sub team V&V caused barriers on the project- (BP) and actor level (BA) and enablers on the project level (EP).

When developing the V&V procedures, the Project Leader V&V did not involve the Project Leaders of the subsystems, who had to execute the procedures (BP). As a result, the Engineers did not know exactly what the Project Leader V&V expected from them and how they had to execute the V&V procedures (BA). Therefore, the Engineers faced V&V as a difficult administrative task (BA).

It cost the Project Leader V&V a lot of time to help the Engineers executing the V&V procedures (BP). It was difficult for the Project Leader V&V to explain to the Engineers what he wanted because he had a strategic approach. The Engineers, on the other hand, had a pragmatic approach. These two approaches did not quite match (BA). The Engineers saw the necessity of the V&V process (EP). For facilitating the V&V procedures for the Engineers, the Project Leader V&V developed templates, which the Engineers could use to document their actions (EP).

In addition, there were also problems with the traceability of the requirements. From reviews executed by technical experts, it appeared that the requirements cannot always be traced in the documentation (BP). Besides, the authors of the documents did not show if they took the comments of the reviewer into account (BP).

The Project Leader V&V could not always verify if the requirements had actually been reviewed (BP). In order to test the requirements, the Project Leader V&V designed a framework for making a connection between the requirements and the test plan (EP). However, it was not possible to complete the framework with the existing project documentation (BP). It was also not possible to make it plausible that the tests could be properly executed. Furthermore, there was a problem with the planning of the tests. The planning that the subsystems handled did not completely fit the planning of the Consortium (BP).

For Non Traction Power, the V&V procedures came too late. They had to make decisions about V&V before the V&V procedures were ready (BP). These decisions did not fit the V&V procedures that had been developed by the Project Leader V&V (BP). Therefore, they had to adjust their documents and they had to work on the traceability of the requirements. The Project Leader V&V also developed a procedure for changing the requirements, yet engineers did not always follow the procedure suitably. Therefore, not all design changes were traceable (BP).

On the consortium level, the apportionment of the requirements was not done properly. Therefore it had to be redone. This influenced the design of the subsystems that were almost ready (BP).

The interface between the design team and their Suppliers

The eighth interface is the interface between the design team and their Suppliers. The process of choosing the Suppliers was called procurement. Procurement was structured by payment milestones in this design project. These are milestones on which certain pieces of equipment needed to be delivered. The payment milestones were agreed with the bankers who financed this project. The bankers thought the payment milestones were needed to guarantee progress of development. However, these payment milestones are not necessary optimal from a development point of view.

Another aspect in the interface with the Suppliers was that a Supplier who was chosen was also responsible for the 25 years of Maintenance. In addition, a Supplier had to reach the quality standards that accompanied to this design project. These two aspects made a good relationship with the Supplier important.

In this research project, we were not able to follow the communication between the suppliers and the design team. However, from their comments about this interface we were able to reconstruct the communication structures and topics.

In the contact with the Suppliers, the discussion about financial- and technical issues had two separated trajectories. We focused only on the technical aspects.
The Suppliers and the design team shared knowledge about the context of the design project. The design team showed the organizational structure to the Supplier in the first meeting. In addition, the design team showed the design of the particular subsystem for which the Supplier had to design a part. Both aspects gave the Supplier information about his role in the whole design project. He was also aware of the quality standards he had to reach.
A Supplier presented an offer for the order he applied for to the design team. Furthermore, he had to show that he was able to meet the high quality standards required. Both the Quality Engineer and the Project Leader V&V had intensive contact with the Suppliers in order to help them with both the Quality procedures and with the V&V process.

Together with the Engineers of the subsystems the Suppliers had to create knowledge about how the part that needed to be designed would fit into the whole subsystem and how it would interact with other subsystems. Also, the planning of the delivery of the system designed was important becasue there were mutual interdependencies (both technically and financially).

Barriers and enablers for creating shared understanding

The interface with the Suppliers consists of barriers on the project- (BP) and actor level an enablers on the project- (EP) and actor level (EA).

Due to the payment milestones, some equipment was bought earlier in the process than was optimal for development. In addition, the development of the subsystems was not done on time and the payment milestones were fixed. As a result, less time for procurement remained (BP). However, the short time for Procurement appeared to be efficient because the Suppliers were chosen quickly (EP).

The fact that the financial- and technical aspects were separated allowed the core team to make a balanced choice for a Supplier (EP). In this project, a Supplier is seen as a partner. In addition to the direct task of the Supplier, the design team also explained the context of the entire design project to the Supplier (EA).

The Suppliers also had to meet the requirements concerning the project documentation that the customer demanded. Therefore, it was important that the Quality Engineer supported the Suppliers with this process. There were some problems concerning this issue. First, the contact between the Supplier and the Quality Engineer was hampered because the Quality Engineer was not allowed to contact the Supplier directly (BP). The Management had changed the procedure (EP). A second barrier was that some Suppliers worked with different norms than the norms that were described in the General Requirement Specification document (BP). If a Supplier worked with another norm, then there was no pass/fail criteria set for this norm. This made it impossible to test the design of the Supplier properly (BP).

The interface between the design team and the Fire Brigade

The ninth interface was the interface between the design team and the fire Brigade. The Inspectors of the Fire Brigade had to approve the equipment of Fire Fighting, Fire Alarm, Control and Non Traction Power. Therefore, the Engineers were dependent on the Fire Brigade's requirements. The Fire Brigade was separated into four districts with (on some aspects) their own ideas and requirements.

In this research project, we followed one meeting between one of the four Fire Brigades together with the Project Leader of HVAC and Non Traction Power. Most of the representatives from the Fire Brigade did not have a technical background.

During the meeting, the actors mostly communicated about procedural aspects. They agreed that the Fire Brigade had to make one program of wishes and demands. Furthermore, they discussed the different scenarios in the case of an accident. The emphasis in this discussion was about responsibilities. Another item was the question whether all of the signals needed to be controlled computationally or by hand during an emergency. In addition to these items, the Project Leader of Non Traction Power showed the Fire Brigade how the emergency diesels functioned.

The communication with the Fire Brigade was formally organized via a partner in the Consortium. This partner was responsible for Project Management. Incidentally, there were meetings planned between the Fire Brigade and the design team. They also used documents to communicate with each other (the precise content of these documents was outside the scope of this case study).

Barriers and enablers for creating shared understanding

The interface with the Fire Brigade consists of barriers on the company- (BC) and actor level (BA) and an enabler on the actor level (EA). First, the partner in the Consortium who is responsible for the interface with the Fire Brigade did not have knowledge related to the design of the subsystems (BC). In addition, the fact that the Fire Brigade consisted of four districts made it difficult to get a clear view of what the requirements were and how to meet the requirements posed. Sometimes, the requirements of the separated groups of the Fire Brigade even conflicted (BA).

Furthermore, the Fire Brigade sent actors to the meetings with no technical background (BA). This hampered communication about the technical subsystems. The Engineers of the design team sometimes had technical solutions for aspects that the Fire Brigade wanted to solve procedurally (BA). In order to solve these problems, the Project Leaders of the subsystems translated their technical requirements into requirements on a level that the Fire Brigade could evaluate (EA).

Remarks about the interface between the Engineers of the design team

The tenth interface was a more general description of the communication processes between the Engineers in the design team. It was not about a specific knowledge sharing or creation process. Both the barriers and enablers in the communication processes (the oral- and the written communication) are described next.

Barriers and enablers for creating shared understanding

The oral communication between the actors had barriers on the company- (BC), project- (BP) and actor level (BA) and enablers on the project- (EP) and actor level (EA). Within the team there was an informal atmosphere, which resulted in a lot of informal communication (EA). The disadvantage of this informal atmosphere was that the Engineers created a passive attitude towards each other concerning the formal information transfer between them (BA). As a result, the Engineers of the subsystems functioned as five separated islands (BC).

Furthermore, the team that we observed expanded quickly during the observation period, which resulted in actors that did not know all of the other actors involved (BP). In addition, it was hard for the new Engineers to know what other actors were doing and who to approach to gathering the information necessary (BP). There was also no formal circuit developed that could provide clarity about who was to execute which task and what kinds of documents the Engineers had to make (BP). The Management tried to enable the information transfer by organizing General Progress Meetings with the whole project team (EP). During these meetings, the progress of the entire design project was on the agenda and the new actors were introduced. In the General Progress Meetings there were also general presentations about the subsystems held by the Engineers of the subsystems. This provides the Engineers with insight into each other's systems (EA).

The information transfer between the Project Leaders of the subsystems and their own Engineers did not occur smoothly. Many Engineers did not know what was expected from them in this stage of the project. They also did not know what their responsibilities were towards Engineers from other subsystems (BA). The subsystems Control and Non Traction Power solved the problem of the information transfer between the Project Leader and the Engineers. They both developed a kind of dual leadership between the Project Leader and the Lead Engineer. This formed an enabler on the project level (EA).

The written communication caused barriers on the project- (BP) and actor level (BA). There were two quality issues. The first was the fact that the documents were not always revised properly (BP). The second was that the documents passed the Quality Engineer minimum two times (BP). Both aspects caused iterations and hampered the progress. This was partly caused by the level of English of the Engineers, which was not sufficient in the beginning of the project (BA).

A second aspect concerning the documents was that there were technical drawings made by the designs of the subsystems. These drawings were coded. Since there were many Engineers with many different backgrounds in this design project, there was a danger that the Engineers would interpret the coding concept differently than the original purpose. The consequence would then be that Maintenance would have to learn several coding concepts. To avoid this, Control developed the concept, since they were able to evaluate the demands of the other subsystems concerning the coding concept (EA). However, in spite of this, there were barriers on the project and actor level. Non Traction Power had difficulties with the coding concept. For one thing, they had to code their drawings before the coding concept was ready (BP). Furthermore, Non Traction Power had comments on the coding concept. They thought that it did not contain all of the information (BP). Non Traction Power also thought that the coding concept was hard to read because it was too long (BA). In addition, they were not used to working with the type of coding concept Control had developed (BA).

This section showed a detailed description of the collaborative design processes of the actors. For each of the interfaces, we could describe the three building blocks of collaborative design:

- knowledge creation and integration between actors from different disciplines and functions
- communication between the actors about both the design content and the design process
- the creation of shared understanding about both the design content and the design process

By showing the barriers and enablers for creating shared understanding we showed the factors that influenced the quality of the collaboration process. More importantly, we showed how these factors influenced the quality of the collaborative design process.

5.6 Conclusion

The aim of this study was to gain a deeper insight into the factors that influence the creation of shared understanding in a collaborative design project and their mutual relationship. In order to gain this knowledge, we formulated three research questions. These questions were:

- *What are the barriers and enablers on the three organizational levels?*
- *What clusters originate if the barriers and enablers are grouped together by content?*
- *What are the collaboration patterns within the clusters of barriers and enablers?*

In Case 2, we found barriers and enablers on all three levels. We found most barriers and enablers on the project level. Section 5.5.1 provided us with some examples of the barriers and enablers found. This provided us with insight into the nature of the barriers and enablers of Case 2. In Chapter 6, we will go into more detail on this aspect. It was remarkable that most barriers and enablers occurred on the project level. For the team observed, communication about tuning between the processes of the different departments seemed to be more important than tuning about the design content. More importantly, the management of the team observed advised against communication about the design content in the meetings. This could be the reason why we found so many barriers and enablers on the project level. We also did not find many barriers on the company level, since there was not much interaction with the company itself during this design project.

The second categorization was the clustering of the barriers and enablers according to their content. This resulted in ten clusters, which each represented a type of interface. The interfaces found are:

1. The interface between the Project Leaders of the subsystems
2. The interface between the Engineers of the design team
3. The interface between Control and Escape Doors
4. The interface between Control and Fire Fighting
5. The interface between the design team and the sub team of RAMS
6. The Interface between the design team and sub team of V&V

7. The interface between the design team and Maintenance
8. The interface between the design team and the Civil Contractor
9. The interface between the design team and their Suppliers
10. The interface between the design team and the Fire Brigade

Within all ten interfaces we found barriers and enablers on more than one organizational level. This demonstrates that there is a relationship between the barrier and enablers.

The real-time set up of Case 2 provided us with knowledge about the barriers and enablers for the creation of shared understanding. Additionally, it also provided us with knowledge about both:

- the knowledge creation and -integration process of the actors
- their communication processes

Therefore, we were able to describe the collaborative mechanisms within each interface. These collaborative mechanisms are reported in section 5.5.2. The description of these collaborative mechanisms forms the answer to the third research question of this empirical study.

In this case study we also tested if we could make the learning history method applicable for a real time case study. In order to do this, we developed a method for observing a collaborating design team. We used our knowledge as Industrial Design Engineers for capturing the most important aspects of the design communication between the actors. By analyzing the notes we made, we were able to distill interview questions that dealt with aspects that concerned the creation of shared understanding about the design content between the actors. After each meeting, we interviewed the actors that were most involved during the relevant aspects of the meetings. From these interviews, we distilled the barriers and enablers for the creation of shared understanding.

All barriers and enablers could be coded according to the organizational level they belong to. We also clustered the barriers and enablers according to their content. The coherent stories of the actors, combined with the observations (executed by a researcher) enabled the finding of the relationships between the barriers and enablers. In order to guarantee the internal validity of Case 2, we checked the interpretations that we made with the actors involved. The results of Case 2 showed that the research method used was suitable for the purpose of the second empirical study.

In conclusion we can say that, through Case 2, we were able to answer the research questions set in this chapter. In order to generalize the findings of Case 1 and Case 2, we will report a cross case comparison in Chapter 6. In this chapter we will compare the nature of the barriers and enablers found, as well as the types of interfaces that we found. In order to evaluate the collaborative mechanisms that we found, we will compare the brief knowledge of the collaborative mechanisms of Case 1 with the extensive knowledge of Case 2.

A CROSS-CASE COMPARISON 6

Introduction 6.1

Chapter 4 and Chapter 5 described two case studies. In both cases we investigated what the barriers and enablers are for the creation of shared understanding between actors from different disciplines. Furthermore, we investigated the mutual relationship between the barriers and enablers.

We found in both Case 1 and Case 2 an extensive amount of barriers and enablers. The results of Case 1 showed that the barriers and enablers in the different phases of the design process differed from each other. As other studies also confirmed, the concept phase turned out to be the most difficult phase for the creation of shared understanding about the design content.

The results of Case 1 demonstrate that barriers and enablers exist on three different levels, dependent on the level of analysis. The first level is the actor level. Factors on this level are directly related to two actors creating shared understanding. The second level is the project level. Factors within this level deal with aspects that are related to the management of the design project. The third level is the company level. Factors on the company level deal with organizational factors that are specific to the company. This categorization shows that actors with an engineering task have the most barriers on

the actor level, while actors with a management task have the most barriers on the project- and company level. The results of Case 2 also confirm these findings.
The clustering (according to their content) of the barriers and enablers of Case 1 demonstrated that the barriers and enablers on the different organizational levels were interrelated. Five different interfaces between actors involved in the design project originated. There was also a remainder category. Within an interface, barriers and enablers on different organizational levels existed. Finally, Case 1 provided some insight into the mutual relationships between the barriers and enablers, yet we needed a real time case to get a more extensive insight. Therefore, we decided to do a second empirical study that was executed in real time (Case 2).
In Case 2, we observed a design team in the concept phase. Similar to Case 1, Case 2 included barriers and enablers on the three organizational levels. By clustering the barriers and enablers, we found ten different interfaces between the actors involved. All interfaces consisted of barriers and enablers on different organizational levels. Case 2 also provided us with knowledge about the knowledge creation and -integration process, as well as the communication processes of the actors. Therefore, we could describe the collaborative mechanisms within these interfaces.

This chapter describes a cross case comparison between Case 1 and 2. The content of the two cases will be compared in section 6.2. This shows that, concerning their content, there is a proper base for comparing them because they both meet the criteria set in Chapter 3.
In section 6.3, we will compare the nature of the barriers and enablers that we found. First, we will compare the distribution of the barriers and enablers among the three organizational levels. Then, we will determine the factors that influenced the creation of shared understanding in the two cases. By doing so we will answer the first research question set in Chapter 3, which reads:

> *What factors influence the creation of shared understanding during collaborative design processes in the industry, according to the actors involved?*

Section 6.4 evaluates the different types of interfaces found and it goes into more detail about collaborative mechanisms in the different types of interfaces found. By doing this we can answer the second research question. This question reads as:

> *What collaborative mechanisms influence the creation of shared understanding during collaborative design processes in the industry?*

This section continues with the cross case comparison of the content of the two design projects.

Cross-case comparison between two collaborative projects 6.2

In Chapter 3, we set up the criteria for a design project for the empirical study. In order to investigate if there is a proper basis for comparing Case 1 and Case 2, this section will evaluate if the two cases meet these criteria. The criteria concern:

- The type of product
- The functionalities of the product
- The relationships between the functionalities
- The involvement of the actors to the design project
- The disciplines of the actors
- The type of task an actor has

Both Case 1 and Case 2 comprised design projects of high-tech complex products. Both came from established companies who executed product design projects on a daily basis.

The design project of Case 1 was about the midlife update of an existing truck. The truck developed was a mass produced product. Within the product line there were many varieties, which resulted in different types of the same product. Case 2 concerned a system design project of the tunnel technical installations of the Dutch high speed train. The system as a whole could be seen as a one-of product. However, within the system there were many subsystems that were reoccurring along the route. These subsystems were often mass produced products that were made applicable to the subsystem. In both design projects, the main parts of the product were mass produced product parts. These parts were integrated in a way that a (one-off) product originated. This makes the two cases comparable.

Other aspects were the different functionalities that the product comprised and their mutual relationships. The focus of Case 1 was on the development of the cabin. The cabin was a clear defined part of the truck in which functionalities were highly integrated. Both technical- and human aspects were important during the design of the cabin. In addition, both mechanics and electronics played an important role. Also within Case 2, the dependency between the different sub systems is extensive. In the case of an accident the different tunnel installations have to function together. Since the tunnel technical installations consist of both mechanical and electronic subsystems, the system also consisted of different functionalities.

The last aspect of comparison concerning the content of the design projects, were the innovative aspects within the design project. Within Case 1, there was a technological innovation that concerned software. Case 2 contained several innovative aspects on the process level that dealt with the RAMS process (Reliability, Availability, Maintainability and Safety) and the V&V process (Validation and Verification). Accordingly, both design projects contained innovative aspects. However, the type of innovation was different.

The actors involved in the design projects of both Case 1 and Case 2 were all fully committed to the design project. Both project teams also consisted of actors from different disciplines. Within Case 1, actors from Marketing, Development and Production were involved. From origin, all actors involved had a technical background (so also from Marketing). In Case 2, only actors with an engineering background were involved. The technical background of these engineers varied from Mechanical Engineer to Electrical Engineer to Building Engineer.

Both cases involved actors with management tasks and tasks related to the content of the design project. In Case 1, the Project Leaders, the Production Manager, the Software Developer and the Mechanical Engineer all had management tasks on different levels. The Program-Description-Book-maker, the Market Researcher and the Ergonomist had tasks related to the content of the design project. In Case 2, we involved the Project Leaders of the subsystems, the System Engineer and the Project Leaders of the project team. They each had a management task. Furthermore, we involved Engineers with tasks related to the content of the design project on different levels. Some tasks concerned the integration of different subsystems, but there were also actors working on a small part of a subsystem.

Case 1 and Case 2 differ in respect to the fact that Case 1 is a retrospective case study and Case 2 is a real time case study. Additionally, Case 1 comprehends the entire design project, whereas Case 2 only comprehends the concept phase. We can even though say that, in spite of these differences, the two cases are comparable on the base of their content. Since both cases have met the requirements set, there is a proper basis for a cross case comparison. Just the type of innovation within the two design projects is different. In section 6.4, we will analyze if there are differences in the creation of shared understanding about a new technology or a new process. In the next section, we will make a cross case comparison of the types of barriers and enablers that we found in the two cases.

The factors that influence the creation of shared understanding 6.3

In this section, we will analyze the nature of the barriers and enablers that were found. We will first compare the amount of barriers and enablers on the three organizational levels between the two empirical studies. Then, we will determine what the nature of the barriers and enablers is within the three organizational levels. This analysis will lead to the answer of the first research question.

6.3.1 Comparing the barriers and enablers on the organizational levels

This section is about the distribution of the barriers and enablers on the three organizational levels. In Case 1, the amount of barriers on the actor level is higher than the amount of barriers on the project level. This is opposite in Case 2. The explanation we give for this difference is that communication about the design content is seen (by the design research community) as the most difficult kind of communication when trying to reach shared understanding. Olsen *et al.* (1992) did a study about the kinds of communication in development projects that showed that 20% of the design meeting is about planning and monitoring of the development process, 30% is about progress and 40% is about the design content. Their study shows that communication about the design content is the most substantial component of all communication. Therefore, we interviewed the actors mainly about the communication about the design content in Case 1. This makes it not remarkable that we found most barriers and enablers on the actor level. From a psychological point of view it can be said that actors forget planning- and progress issues and that they often remember issues concerning the design content more easily. In Case 2, we could not (and did not want to) influence the content of the interviews. We interviewed the actors about the content of their meetings shortly after the meetings were held. In this design project, communication about tuning between the processes of the different departments seemed to be more important than tuning about the design content. Stronger yet, the management of the core team advised against communication about the design content in meetings. Therefore, more communication was on the project level. As a result, we found more barriers and enablers on this level.

Both Case 1 and Case 2 show a small number of barriers and enablers on the company level. This is not remarkable, since our focus was on design teams that were fully committed to the design project. Therefore, we did not observe much interaction with the company. Due to the project approval and some human resource management issues, Case 1 had more barriers and enablers than Case 2. In Case 2 these issues did not play a prominent role.

Comparing the types of barriers and enablers of the two cases 6.3.2

In this section, we will compare the barriers and enablers of the two cases to one another. In order to be able to compare them, we abstracted the barriers and enablers. As proposed by Miles and Huberman (1994, p. 256), we did this by scanning all barriers and enablers to see which factors were underlying. For example, the barrier: *The Engineers of Escape Doors did not know they were responsible for the CMI's* belongs to the factor: *The empathy of the actors about the interest of a task.* Miles and Huberman call this process factoring. The outcomes of this process are factors. Barriers and enablers that belonged to the same factor have been clustered. We have made clusters within each of the three organizational levels (actor-, project- and company level). All barriers and enablers can be abstracted. There is no remainder category.
Not all factors occurred equally in Case 1 and Case 2. Some categories contained only a few barriers or enablers. Therefore, we made a shift between the factors that we have taken into account for analyzing and the factors that we have not taken into account. We took only the factors into account that contained enough barriers and enablers that we were able to generalize them (to some extend). Furthermore, we only took into account categories that occurred in both cases.

We found twelve different factors that influence the creation of shared understanding on the actor level. All factors represent a quality of an actor that is needed to create shared understanding about the design content and the design process. Table 6.1 shows the ranking of occurrence of the factors within Case 1 and Case 2. In this table, the order of the factors in the first column is the ranking of Case 1. The ranking of Case 2 is expressed by the numbers in the third column.

Table 6.1
The ranking of the occurrence of the factors on the actor level

Factors actor level	Ranking Case 1	Ranking Case 2
The ability of actors to make a transformation of knowledge	1	2
The applicable experience of an actor	2	3
The empathy of the actors about the interest of a task	3	3
The view of an actor on the design task	4	5
The equality of the language used between the actors	5	1
The skills of actors to process knowledge	5	4
The applicable knowledge of an actor	6	3
Knowledge about the task to be performed	6	4
The view of an actor on the process to follow	6	5
The view of an actor on the knowledge to be shared	7	4
Prospect of actors on the task of the others	7	5
The ability of actors to make use of different communication methods	7	5

In this section, we will consider only four factors, since these are filled significantly. These four factors are:

- The ability of actors to make a transformation of knowledge
- The equality of the language used between the actors
- The applicable experience of an actor
- The empathy of the actors about the interest of a task

The first factor on the actor level is *the ability of an actor to make a transformation of knowledge*. This factor occurs more frequently in Case 1 than in Case 2. It concerns the knowledge exchange between two different disciplines. Since actors of different disciplines use different knowledge, a transformation of knowledge is always needed. The actors need to transform both the content of the knowledge and the representation of the knowledge. In both cases, the barriers within this factor deal with the translation of a product specification into knowledge that Engineers can use during their design tasks. In Case 1, there are enablers concerning this factor. The enablers deal with the transformation of knowledge gathered from the market into product specifications.

The second factor on the actor level is *the equality in language used between the actors*. Although Case 2 has a higher percentage of barriers and enablers in this factor than Case 1, the types of barriers and enablers are the same. The major issues concerning the equality in language are:

- the different jargon that the actors use (both in words as well as in drawings)
- the different native languages that the actors use

The third factor on the actor level is *the applicable experience of the actors*. In both Case 1 and Case 2, actors use their experience during their current design task. This influences their actions. Case 1 had a higher percentage of barriers and enablers within this factor than Case 2. The enablers of the two cases within this factor deal with the experience that actors have with the regular tasks within the design project. They use their experience from earlier projects to do their current design task. The barriers deal with the innovative aspects of the design project because the actors lack experience with these aspects. In both cases, the companies tried to make use of the experience of external actors (like Suppliers) in order to gather knowledge about the innovative aspects in the design project. This only partially solves the problem because these external actors had no past experiences with the design of the specific product. Therefore, it was hard for the company to create shared understanding with these actors about the regular- and the specific aspects of the design project.

The fourth factor on the actor level is t*he empathy of actors about the interest of a task*. This factor deals with the understanding of the content and interest of one's task. In addition, it is about to what extend an actor is able to interrelate his tasks to other (interrelated) tasks. Although the percentage in which this factor occurs differs in the two cases, the barriers and enablers within this factor are comparable. The barriers within this factor deal with:

- Actors do not fulfill a task that is required because they are not aware of the interest of the task or they underestimate a task or,
- Actors perform a task and do not inform other actors, since they do not know that the information is important for the other actor.

In Case 1 there is an enabler that prevents these two situations: If an actor knows the context of his task, he has more empathy for other tasks just outside the direct scope of his own task.

Eight factors originated on the project level. The factors on this level concern project management factors like time, money en quality. Additionally, we have found factors that concerned the efficiency of the design project. Table 6.2 shows the ranking of occurrence of the factors within Case 1 and Case 2. In this table, the order of the factors in the first column is the ranking of Case 1. The ranking of Case 2 is expressed by the numbers in the third column.

Table 6.2 The ranking of the occurrence of the factors on the project level

Factors on the project level	Ranking Case 1	Ranking Case 2
The efficiency of information processing	1	1
The quality of project documentation	2	2
The rigor of the project planning	2	4
The controllability of product quality	2	5
The division of labor	3	3
The degrees of freedom within the design task	3	7
The controllability of project budget	4	7
The controllability of design changes	5	6

On the project level, there were five factors concerning the creation of shared understanding to be considered. These factors are:

- The efficiency of information processing
- The quality of project documentation
- The division of labor
- The rigor of the project planning
- The controllability of product quality

The first factor is *the efficiency of information processing*. In Case 2, more barriers and enablers are found concerning this aspect than in Case 1. This is because it is better to observe the efficiency of information processing than to ask an actor about it retrospectively. Despite that, in Case 1 there are barriers and enablers concerning the efficiency of information processing. There are some problems on this aspect that concern the information exchange between the design team and their Suppliers. Within the project team, the information processing is efficient. This is due to the multidisciplinary team that functioned well. Additionally, the thorough definition phase of the project enabled the efficiency of the whole design project.

Within Case 2, the most important barriers concerning the efficiency of information processing are:

- the information arrives too late for the receiver, so he can not continue his task
- the status of the document is not known by the receiver
- the status of the documents are not sufficient
- the information is put in a database that the receiver can not open
- the information is not put in a database
- the information flow is disturbed because an actor has no time to process it
- it is unclear what information is needed
- there are iterations due to mistakes
- there are too few meetings for processing information
- in meetings sometimes not the most important issues are discussed

- appointments are made orally and can not be found on paper

Enablers concerning the efficiency of information processing are:

- the early involvement of another sub team
- the active approach of one sub team towards another sub team
- the efficient data management system
- the active use of the Minutes of Meeting

By analyzing the factor of the efficiency of information processing, it is clear that the difference in level of detail makes it hard to make a meaningful comparison between the two empirical studies.

The second factor on the project level is *the quality of project documentation*. In Case 2, the quality of the project documentation is almost as important as the design of the system itself. Therefore, it is not remarkable that there are more barriers and enablers related to this factor than in Case 1. However, the aspects found are comparable. Problems with the quality of the documents are caused by:

- ongoing changes in the documents
- incomplete documents
- new appointments about how to set up the document
- for the actors it is unclear how to deal with certain documents
- the interest of a particular document is unclear for the maker
- different versions of the same document
- unclear structure of the document

Despite some quality problems, most of the documents made provide applicable information for the receiver. In addition, the Engineers actively use the documents, such as Minutes of Meeting and action lists, in order to structure the complexity of the design project.

The third factor on the project level is *the division of labor*. The design project of Case 1 has had a lack of manpower at the beginning of the design project. This is due to another design project that was not finished. Furthermore, the company did not have enough manpower to do all activities themselves. As a solution, they involved Suppliers in the design process.

One problem within Case 2 is the changing of the scope of the sub teams and the accompanying changing interfaces between the sub teams. Another aspect concerning the division of labor was that some actors that had too much work during the project and therefore focused too much on one aspect of their task.

By analyzing these aspects and by comparing them to Case 1, we can say that the barriers and enablers found in Case 2 are more operational in nature than the aspects found in Case 1. This difference was caused by the retrospective nature of Case 1 and the fact that Case 2 was executed real time. This makes a comparison difficult.

The fourth factor on the project level is *the rigor of project planning*. In both cases this factors occurred about equal. Both design projects had a tight schedule. In Case 1 this was because of the time to market and in Case 2 due to the payment milestones that were fixed. The tight project planning has led to efficient decision making in both cases.

The fifth factor on the project level is *the controllability of product quality*. In both cases they have a formal process of checking the product quality. In Case 1, there have been some problems with the quality of the parts and the controllability of the parts. Also, the testing of software has been difficult because the usual validation procedures are developed for hardware. In Case 2, the barriers and enablers are related to the procedures to control product quality. Since at the time of the study there were not yet any parts, there is nothing we can say about the quality of the parts.

Four factors originated on the company level. They all comprised a different aspect concerning the organization of a design project within a company. Table 6.3 shows the ranking of occurrence of the factors within Case 1 and Case 2. In this table, the order of the factors in the first column is the ranking of Case 1. The ranking of Case 2 is expressed by the numbers in the third column.

Table 6.3
The ranking of the occurrence of the factors on the company level

Factors on the project level	Ranking Case 1	Ranking Case 2
The organization of resources	1	1
The organization of the design team	2	3
The allocation of tasks and responsibilities	3	2
The availability specialized knowledge within the company	4	4

On the company level there are three of the factors that occur frequently enough to be analyzed. Therefore, we took these of the factors into account in this analysis. These three factors are:

- The organization of resources
- The allocation of tasks and responsibilities
- The organization of the design team

The first of the factor was *the organization of resources*. This occurs more frequently in Case 1 than in Case 2. In Case 1 the organization of resources has been difficult in the beginning and in the end of the design project. At the start of the project the resources needed to be allocated to the project. At the end of the design project, there have been also some issues concerning the organization of resources, because many Engineers went to new design projects. In Case 2, we have not observed many aspects that concerned the organization of resources. An explanation for this is that we only observed the concept phase and not the beginning and the end of a design project. It was during these phases that the organization of resources was important in Case 1.

The second of the factor of importance on the company level was *the allocation of tasks and responsibilities.* This of the factor occurs more often in Case 2 study than in Case 1. The Engineers were not willing to be involved in aspects outside the scope of their own task, in Case 2. They only wanted to be involved in a particular task when this was formally arranged. This is partly due to the complexity of the design project. The actors of the design team had to make the tunnel technical installations. This is a complex system all on its own. However, it is just a small piece of the design of the whole high speed train trajectory. Therefore, there exist many interdependencies on different levels inside and outside the project team and outside the company. For the Engineers it was difficult to foresee the consequence of getting involved in a task outside their direct scope. The necessary paperwork of this design project also intensifies this. Furthermore, the group that had to integrate the subsystems has not functioned properly. They have not been able to define the interfaces between two sub groups clearly. Therefore, the Engineers of the subsystems have not actively been involved in integrating aspects that were just outside the scope of their own task into their design. Another explanation of why the integration was hampered was that in other design projects their company usually gets paid extra for doing work outside of the scope of their assignment. In Case 1, these aspects have not been issues of discussion. There are three possible explanations for this. First, we interviewed the actors retrospectively. Actors usually do not talk about these things if the problems are solved. Another explanation is that the project team was more used to collaborating with each other. They have done a similar design project before. The last explanation is that the company of Case 1 had a formal product creation process which describes the dependencies between the actors. This makes these dependencies clear from the very beginning. The project team of Case 2 study defined the dependencies during the design project at the start of a project phase.

The third of the factor on the company level was *the organization of the design team*. In Case 1, the organization of the project team was well organized. They had a multidisciplinary team from the beginning of the design project in which the important disciplines were involved from the project start until the end of the design process. All disciplines gave their input during the whole design project. This has not been so well organized in Case 2. An explanation for this is that the Engineers have never been involved in all of the phases of an integrated design project. Normally they only do a part of the trajectory.

Therefore, they are not used to giving their input in other stages and disciplines of the project. The Maintenance organization was the best example of this. They have never before been involved in the concept phase of a design project.

In this section, we reflected upon the type of factors that influenced the creation of shared understanding. We found of the factors that contain barriers and enablers for the creation of shared understanding on each of the organizational levels. By doing this we have answered the following research question:

What factors influence the creation of shared understanding during colla-borative design processes in the industry, according to the actors involved?

In the next section, we will investigate the relationships between the barriers and enablers.

6.4 The relationship between the barriers and enablers

The results of Chapters 4 and 5 show that the barriers and enablers on the three organizational levels are interrelated. The results also show that interrelations between the barriers and enablers can be attributed to interfaces between (groups of) actors from different disciplines. In Case 1, we found five interfaces and we found ten in Case 2. All interfaces consist of barriers and enablers on more than one organizational level. In this section we will compare the interfaces found in the two cases. In this section, we will also answer the second research question of this study which reads:

What collaborative mechanisms influence the creation of shared understanding during collaborative design processes in the industry?

The types of interfaces of Case 1 and Case 2 6.4.1

In this section, we will categorize the interfaces that we found in order to analyze certain types of collaborative mechanisms within the types of interfaces. We will use the boundary spanning literature as a stepping stone for the definition of the types of interfaces.

In the literature about boundary spanning, authors make a distinction between internal- and external communication (see for example Katz and Tushman (1981), Ancona and Caldwell (1992) and Sonnenwald (1996)). Internal communication is within the design team and external communication is outside the design team. According to the literature on boundary spanning, both types of interfaces have different interaction patterns. Looking at the interfaces of Case 1 and Case 2 that concerned external communication, a distinction between two levels of detail can be made. There are interfaces with their own organization and there are interfaces with the outside world. Also, within the internal interfaces we need to make a distinction between two types of interfaces. Since Hoegl *et al.* (2003) found that task innovativeness influences the quality of the teamwork, we would like to make a distinction between interfaces related to a regular task and interfaces that concern an innovative task. Based on the preceding, the four types of interfaces of the two cases are:

1. The interface with the outside world
2. The interface between the design team and the organization
3. The interfaces within the design team that deal with regular aspects within the design project
4. The interfaces within the design team that deal with innovative aspects within the design project

Table 6.4 shows the interfaces found that are clustered according to the four different types of interfaces. Both case studies have interfaces with barriers and enablers in all four types of interfaces.

Table 6.4 the different types of interfaces in Case 1 and Case 2

Type of interface	Case 1	Case 2
The interface with the outside world	The interface between the Market Researcher and the market The interface between the design team and their Suppliers.	The interface between the design team and the Fire Brigade. The collaboration process between the design team and the Civil Contractor. The interface between the design team and their Suppliers.
The interface between the design team and the organization.	The interface between the design team and the organization	The collaboration processes between the design team and Maintenance.
The interfaces within the design team that deal with the innovative aspects within the design project.	The interface between Software Development and the design team	The interface between the design team and the sub team of RAMS. The Interface between the design team and sub team of V&V.
The interfaces within the design team that deal with regular aspects within the design project.	The interface between Marketing and Development	Interface between the Project Leaders of the subsystems. The interface between the Engineers of the design team. The collaboration process between Control and Escape Doors. The collaboration process between Control and Fire Fighting.

In section 6.4.2, we will analyze and compare the four different types of interfaces that exist within the two empirical studies.

Analysis of the collaborative mechanisms within each type of interface 6.4.2

In this section, we will first compare the kind of knowledge the actors have to share. Second, we will analyze the communication methods they use to share the knowledge. Finally, we will analyze the kind of barriers and enablers that exist within the interfaces and their mutual relationship.

The interface with the outside world

In interfaces with the outside world there is sometimes a formal relationship between the design team and the other party. At other times, the design team needs to gain knowledge of the parties in the outside world because these parties are the future customers/users of the product. In all situations, the relationship in the interface can best be described as a relationship between a customer and a supplier. Sometimes, the design team has the role of the supplier and sometimes they have the role of customer. This section will describe these two kinds of roles.

The design team in the supplier role

It is often the case that if the design team has the supplier role, then the customer does not see any benefits for collaboration and he is not willing to cooperate. However, the design team needs the customer because, in the end, they have the power to reject the new product if it does not fit their needs. Therefore, both companies of Case 1 and Case 2 needed methods for gaining knowledge about both product use and the requirements set by their customers.

In Case 1, the Market Researcher had to approach the future customers. The Market Researcher showed that a combination of an active approach with customers and the skills to speak the language of the customer enables the creation of shared understanding in this type of interface. What also enabled the creation of shared understanding was the clear view that the Market Researcher had about the knowledge he had to gain from their customers.

The communication structure between the Market Researcher and the market was formalized, since the Market researcher had to plan his visits to the customers. However, the Market Researcher approached the market pragmatically. He interviewed the customers about topics they were knowledgeable. Furthermore, the Market Researcher interviewed the customer (often in their own professional environment) at a moment when the customer had time to talk to him.

In Case 2, the situation was more complex and did not go as smoothly. Since there was a business-to-business relationship between the design team and the Fire Brigade (who had the customer role), the actual users were known at the time of the design project. However, the Fire Brigade was not willing to provide the design team with information about their user requirements. They only wanted to provide information when there was a formal contract between them. Additionally, the criteria that the Fire Brigade set were sometimes contradicting. Both the highly formalized communication structure and the indistinctness about what types of knowledge the actors had to share hampered the creation of shared understanding between the design team and the Fire Brigade.

Other research (in consumer industry) shows that it is difficult to involve consumers early in the design process because they are not able to express what kind of products they may want in the future (see e.g. (Von Hippel, 1978), (Dougherty, 1990)). Other researchers have tried to find methods to overcome these problems. Sleeswijk *et al.* (2005), for example, developed a tool for sharing insights from user studies with designers. According to Sleeswijk *et al.*, a tool for communicating t market information to designers should meet three qualities. The tool should:

- enhance empathy
- provide inspiration
- support engagement

The first evaluation studies of the tool show that this participatory character of the tool developed provides designers with a deeper understanding and a more intensive use of insights from user studies.

In industry, Market Researchers use creativity techniques like brainstorming, brain drawing and storyboard making as a way of involving future users into the development process. An early involvement of the customer in an advisory role (using the techniques mentioned) will have a positive affect on product quality.

The design team in the customer role

In both of the design projects of Case 1 and Case 2 the Suppliers involvement was high. The Suppliers executed a substantial part of the entire design project in both cases.

In Case 1, there were some problems in this interface. The Suppliers had different mental models of the development processes than the design team of Case 1. The actors on both sides of the interface did not have shared understanding about which tasks they had to do and what the outcomes of the development processes should be. This resulted in a lack of shared understanding between them that caused unnecessary iterative loops. The Suppliers were also not able to do all of the tasks that they had to do, which caused a non-optimal work share between members of the design team. Another problem was that the Suppliers were located in other countries, which complicated the decisiveness. The foreign language spoken by the suppliers also complicated the communication. According to the company people, a part of the solution for these problems was choosing for a long-term relationship with a Supplier. If there would be a long term relationship between the Supplier and the design team, then they both could put more effort into the relationship. Both companies could take time to become acquainted with each other's processes and expertise. After some design projects, they would know what to expect from each other.

The structure of the design project of Case 2 forced the design team to create a long-term relationship with a Supplier. (In addition to the design of a part of the tunnel technical installations, the Suppliers were also responsible for

25 years of Maintenance.) As a result, the selection procedure was carefully executed. The Project Managers of the subsystems carefully explained a possible Supplier the context of his design task and the design process that was to follow. As a result the Supplier got a clear view of his own assignment and the interrelation with other aspects of the entire design project.

The interface between the design team and the organization

In Case 2, the interface between the design team and the organization comprised the interface with Maintenance. The design team needed the input from Maintenance because the Consortium would be responsible for both the development and the maintenance of the project for 25 years. However, this interface was not organized properly. The Maintenance Company did not have the knowledge to be involved in the early stages of the design project. They also missed the capacity to do the work.

The communication structure between the design team and Maintenance was highly formalized. For both Maintenance and the design team, it was unclear what knowledge they had to create and share with each other. They only shared procedural knowledge, while they needed to share knowledge concerning the content of the design of the subsystems.

The involvement of Maintenance is comparable with the involvement of Production in the design process of Case 1. Both concern (for efficiency reasons) the involvement of a discipline earlier in the process than they have to do their actual jobs. In Case 1, this worked efficiently. The communication lines with Production were short and the actors were able to solve their problems quickly by forming study groups for solving complex issues. In these groups, all actors who regarded the problem were involved. Therefore, they were able to create shared understanding about each other's tasks and interests.

An engineering law states that during a development project, 80% of the decisions are made during the first 20% of the project time (80/20 rule). This shows the importance of involving Maintenance and Production (with respect to the content) in the early stages of the project. That is the best time for them to give advice about important decisions. Involving Maintenance and Production in a later stage will only solve cosmetic problems. We know that the interface between Development and Maintenance or Development and Production causes difficulties, because the actors of these disciplines have different approaches and mental models (Smulders, 2004 and 2006). In order to create shared understanding between these disciplines, the actors should pay a lot of attention to what kind of information they actually need (problem definition). Also, the format of information exchange between the two disciplines should be made explicit and applicable for both. Finally, there should be a clear planning, in which the actors visualize the main activities and dependencies.

The interfaces within the design team that deal with regular aspects

We found similarities in the type of knowledge that the actors have to share with each other, by analyzing the interfaces that belong to this type of interface. In both Case 1 and Case 2, actors needed detailed knowledge from the content of each other's design (tasks). In Case 1, Marketing had to share the results of the Market Research with Development. The actors had to make a transformation of the knowledge gathered during the market research into specifications that the Engineers could use as a starting point for their design task. This was a form of knowledge creation that required input from both Marketing and Development. In Case 2, the Engineers of the different subsystems had to share extensive knowledge about the designs of the subsystems. The actors had to create knowledge about the interaction between their subsystems, as well as the process to be followed.

In an interface within the design team, the interdependencies between the design tasks of the actors are high. The design tasks of the two groups involved are highly integrated. Therefore, extensive communication between the actors is needed. In both Case 1 and Case 2, a formal communication structure was set up to enable integration. We know from Case 2 that the actors communicate in meetings with each other on a regular basis, but they also have informal communication. During these meetings, they discuss how they can make optimal design solutions concerning the design task as a whole. In addition to the oral communication, the actors together make sketches about their designs. They intensively discuss these sketches.

The written communication infrastructure is in both design projects highly formalized. In Case 1, the actors see the main interface document between Marketing and Development as a contract. In Case 2, the written communication is so formalized that actors think of documents as deliverables. In both cases the design teams had a lack of shared understanding about content related aspects on a conceptual level. However, since this interface deals with regular aspects within the design project, there are always actors in the design team (or within the organization) who deal with a comparable situation. The effective use of these past experiences will enable this type of interface. Furthermore, it is important to have a strong System Engineering group with product-architectural knowledge (Gerwin and Moffat, 1997). This System Engineering group has to make all of the interfaces clear. They also need to integrate knowledge on different levels of the project. The System Engineering group should be able to think conceptually. Yet, they must also be able to understand (detailed) information from the different technical subsystems in order to be able to make a good decision. The System Engineering group should also have the power to make all decisions concerning the integration of the technical subsystems.

The interfaces within the design team that deal with innovative aspects

The interfaces that deal with the innovative aspects within the design team concern the sharing- and creation of knowledge and the communication between the actors are comparable with the interfaces on the regular aspects of the design project.

However, since it concerns an innovative task, the actors face both technical uncertainty and a lack of information about how to perform the task (Ancona and Caldwell, 1990). These uncertainties influence the collaborative mechanisms between the actors. Therefore, this interface is different from the previous interface. The type of innovation that took place in Case 1 and Case 2 are different. In Case 1, the innovative aspect concerns a technical innovation. In Case 2, there are two process innovations. Therefore, before we look at the cross case comparison, the collaborative mechanisms of both cases will first be reviewed separately.

In Case 1, the innovative aspect concerned the implementation of new technology; a piece of software. The Software Developers and the design team shared knowledge about the integration of the software in the design of the cabin and about their design processes and procedures to be followed. Since the actors had no experience with this new technology, it was difficult to develop a strategy for its implementation. This led to planning and monitoring problems. Furthermore, there was a lack of shared understanding between the Software Developers and the other actors of the project team because the Software Developers used different jargon than the other actors.

The innovative aspects of Case 2 concerned the implementation of new processes. The Engineers responsible for the new processes and the Engineers of the subsystems had to share knowledge about the new processes and about the design of the subsystems. The engineer responsible did not involve the Engineers of the subsystems (who were in charge of executing procedures) when the new processes were developed. As a result, the Engineers did not know exactly what was expected from them and how they had to execute the new quality procedures. Therefore, executing the procedures took a long time. Additionally, the different approaches of the Engineers of the new processes versus the other Engineers caused problems. Finally, it was difficult for all Engineers to monitor the progress and the quality of the execution of the new processes.

Looking at the implementation of a new technology and the implementation of new processes, the issues concerning the creation of shared understanding appeared to be the same. In both cases, the actors could not rely on past experiences, which hampered the actors in making the necessary transformation of knowledge. Since it was not clear what kinds of knowledge the actors needed from each other and where the information was stored, this caused difficulties in planning and monitoring the project. Furthermore, it hampered the information processing between the actors.

This finding is in line with the innovation theory which says that every abrupt change causes difficulties and asks a lot of effort from the actors involved. Solutions can be found by explicitly making the new procedure an integral part of the development process (Buijs and Valkenburg, 2005). This takes time because new interfaces must be made clear. Actors should also be trained about the new process in a way they are able to interact with the specialists.

This section compared the interfaces that we found in Case 1 and in Case 2 with respect to their content. It was possible to compare the cases, on each of the four types of interfaces. By comparing the cases, we could determine in which case the collaborative mechanism worked most properly. This provided us with some implications for enabling collaborative mechanisms and we could show why certain mechanisms hampered the collaboration processes of the actors. The knowledge generated in this section can be used as a first step towards the improvement of collaborative design projects.

6.5 Conclusion

This chapter described a cross case comparison of Case 1 and Case 2. We compared the two cases on the base of their content. Since both cases met the requirements that we set in Chapter 3, we concluded their similarities in content form a proper base for a cross case comparison.

In order to answer the two main research questions of this thesis, we compared the two cases in two different ways. First, we compared the nature of the barriers and enablers that we found. In order to be able to do this, we abstracted the barriers and enablers. The abstracted barriers and enablers formed the factors that influenced the creation of shared understanding. The following factors occurred most in both cases:

On the actor level:

- The ability of actors to make a transformation of knowledge
- The equality of the language used between the actors
- The applicable experience of an actor
- The empathy of the actors about the interest of a task

On the project level:

- The efficiency of information processing
- The quality of project documentation
- The division of labor
- The rigor of the project planning
- The controllability of product quality

On the company level:

- The organization of resources
- The allocation of tasks and responsibilities
- The organization of the design team

The (analyses of) the content of these factors form the answer the first main research question of this thesis, which reads:

What factors influence the creation of shared understanding during collaborative design processes in the industry, according to the actors involved?

Second, we evaluated the different types of interfaces found. We could distinguish the following four types of interfaces:

- The interface with the outside world.
- The interface between the design team and the organization
- The interfaces within the design team that deal with regular aspects within the design project.
- The interfaces within the design team that deal with innovative aspects

within the design project.

All interfaces found in both Case 1 and Case 2 could be categorized in one of these four types of interfaces. We analyzed the collaborative mechanisms in the four types of interfaces. In this way, the second research question could be answered. This question is:

What collaborative mechanisms influence the creation of shared understanding during collaborative design processes in the industry?

In this chapter we answered the main research questions of this thesis. In Chapter 7, we will evaluate the research method followed. Furthermore, we will elaborate on the findings of this thesis.

UNDERSTANDING COLLABORATIVE DESIGN 7

Introduction 7.1

We started this thesis by showing that Project Managers of design projects face collaboration problems in their daily practice. Both researchers and practitioners do not put much effort into developing the collaborative aspects of product design on a structural basis. Therefore, we decided upon a study to create a better understanding of collaborative design. We defined collaborative design as:

Collaborative design is the process in which actors from different disciplines share their knowledge about both the design process and the design content. They do that in order to create shared understanding on both aspects, to be able to integrate and explore their knowledge and to achieve the larger common objective: the new product to be designed. (See section 2.2.4)

This definition of collaborative design shows that the main aspects in the collaboration process are:

- knowledge creation and -integration between actors from different disciplines

- communication between the actors about both the design content and the design process
- the creation of shared understanding about the subjects communicated

Knowledge creation and integration are the goal of the collaborative design process. If actors are not able to create and integrate knowledge, then they will not be able to design a new product. The actors involved in the design project share and create knowledge through design communication. The actors communicate orally and through the use of textual documents. Additionally, drawings and prototypes play an important role in supporting content related design communication. The quality of the design communication depends on the process of creating shared understanding. Therefore, it is necessary to create insight into the process of creating shared understanding between actors involved in a collaborative design project.

Since literature does not provide knowledge about the factors that influence the creation of shared understanding between the actors in a collaborative design project, we did two empirical studies about these factors. The factors can either hamper or stimulate the creation of shared understanding. We called the hampering factors barriers and the positively influencing factors enablers. The first empirical study (Case 1) was executed in an automotive company. In this study, we explored, the collaborative processes between actors involved in a design process. We interviewed actors retrospectively about their design processes and their collaboration with other disciplines.
The second empirical study (Case 2) elaborated upon Case 1. The second study was about a design project of tunnel technical installations for the Dutch high speed train trajectory. In this study, we observed the collaborative design processes of the actors involved. Afterwards we interviewed them about their collaborative design process. In both empirical studies, we used the learning history method for both data gathering and data processing. In Chapter 6, we compared the two case studies. Chapter 6 described both the main factors that influence the creation of shared understanding in

collaborative design projects and their underlying collaborative mechanisms.

In this chapter we will evaluate the aim of this study. This aim is: *gaining a better understanding of collaborative processes of actors from different disciplines during the product design process in industry.*

The chapter starts with an evaluation of the research method chosen in order to gain a better understanding of collaborative design. This method is based on the learning history method. We have used the learning history method in Case 1 in a different way than in Case 2. The main difference between the first and the second empirical study is that the first case has been retrospective for the actors involved and the second case has been conducted during the design project. It is interesting how this methodological difference influenced the results of the case study. We will compare the results found within the cases from a methodological point of view in Section 7.2.

Section 7.3 comprises the implications that we have made, based on the results of this thesis. This thesis serves four different types of audiences: practitioners in new product design projects in general, participants of the two cases, students and other researchers. Therefore, there are implications made for these four audiences. This chapter ends with the main conclusions of this thesis (section 7.4).

Reflection on the research method followed 7.2

In this section, we will compare the research methods followed in Case 1 and Case 2. Figure 7.1 shows the research steps taken in both case studies. The squares represent the research steps taken. In order to be able to get the results needed (that are represented by the diamonds in Figure 7.1), we have developed procedures that fit each case under study. They are the same for both Case 1 and Case 2. The research process of both case studies consisted of three phases: data gathering, data processing and data analyses. In this section, we will reflect on how we executed these phases in the two studies.

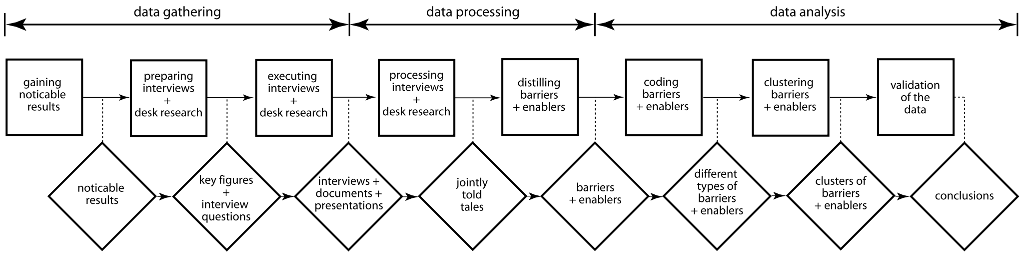


Figure 7.1
The research steps
taken for both
case studies

7.2.1 Data gathering

The data gathering phase consists of three steps:

- gaining noticeable results,
- preparing the interviews and desk research
- execution of the interviews and desk research

In Case 1, we did the data gathering phase retrospectively (after the design project had been completed) and in Case 2 was conducted real-time (during the design project). This, of course, has had consequences for the execution of the research steps in this phase.

The first step was focused on gaining the noticeable results of the design projects. Since the design project of Case 1 had already finished, we interviewed the two Project Leaders for gaining the noticeable results. This was effective for two reasons. The first reason was that it was fast. The second reason, however, is more important. Interviewing the Project Leaders about the noticeable results of the design project helped to give structure to the extensive amount of information available; it helped to create a focus. This focus was needed at the time of Case 1, since we did not have much experience with data gathering about collaborative aspects in a design project in practice. In Case 2, we already had that experience and we gained the noticeable results by observing the design team during the meetings. We made notes of the design communications of the actors involved and analyzed these notes. This provided us with a number of noticeable results from each meeting. Simultaneously, we got both insight into the knowledge creation- and integration processes of the actors, as well as in their (design) communication process.

The two different approaches for gaining noticeable results led to results on different levels of detail. The noticeable results of Case 1 were on a more abstract level than in Case 2. This had consequences for the execution of the interviews. We will show these consequences at a later stage.

In conclusion we can say that observations are only valuable if you have a clear view of what needs to be observed. If you have a focus, than gaining noticeable results from your own observations is preferable. Since observations provide an extra triangulation step, they will lead to more reliable results. A researcher is not dependent on the noticeable results that the Project Leaders want to share. Furthermore, it allows the researcher to get a better grip on the interest of a noticeable result because the researcher also has knowledge about how the other collaborative aspects evolved during the design project.

The second step was preparing the interviews and desk research. The selection of the actors to be interviewed was important during the second step. In Case 1, we discussed with the Project Leaders which actors were most involved during the noticeable results. On the basis of this discussion, we selected seven key figures to be interviewed. In Case 2, we selected (on the base of our observations) the actors who were most involved during the noticeable results of a particular meeting for interviewing.

Of course, the method for selecting the key figures was dependent on the way in which we approached the cases. Both methods for the selection of the key figures were efficient for each particular case. In general if a researcher is capable of selecting the key figures, then this is preferable. However, this is only the case if the researcher has enough knowledge about the involvement of the different key figures during the noticeable results of a case.

The structure of the interview was also determined in this research step. In Case 1, we followed a guided interview approach (Patton, 1990, p. 288). The interview guide contained three subjects on which we interviewed the key figures:

- the tasks of the key figure
- explanation of the design process that a key figure follows
- how the key figure experiences his collaboration and communication processes

In Case 2, we used a more structured interview approach. From the analysis of the observations, we made a structured interview checklist about the noticeable results of a meeting.

The third step was executing the interviews and desk research. Since the noticeable results of Case 1 were rather abstract, we did extensive interviews about the three subjects mentioned. The main part of the interviews was about the experience of a key figure concerning his collaboration and communication process. The strategy that followed resulted in extensive (and rich) interviews of about three hours each. In addition to the interviews, desk research was conducted. We asked the key figures to show us the most important project documentation and presentations they provided during the design project. This desk research provided a deeper understanding of the design project. Furthermore, it helped verifying the opinion of the key figures. As stated before, in Case 2 we interviewed the actors in a more structured way. We interviewed the actors according to an interview checklist that we had made on the basis of our observations. This strategy led to condensed interviews that provided rich information. In addition to the interviews, we also did desk research by reading project documentation, project presentations, emails and minutes of meeting.

The combination of observing a design team and interviewing them about their conversation is a valuable method for data gathering. The observations of the meetings helped us to interview the actors of Case 2 in a structured way, without loosing the holistic character of the case study. Since each interview was condensed, this way of interviewing was found to be efficient.

Data Processing 7.2.2

The data processing phase existed of two steps which are shown is Figure 7.1. The first step was the processing of the interviews and the desk research. We made transcripts from the interviews of Case 1. Since the interviews were extensive and open, not all parts of the interviews were useful. Therefore, we made a selection of the relevant parts and put these parts in a chronological order (according to the product creation process of the company). The result was a story of an actor about his collaborative design process that focused on how he created shared understanding with other actors in the design team. Two researchers analyzed these stories and created jointly told tales by combining the interview parts with their analysis. The desk research was used in Case 1 to gain more depth knowledge of the case study. They were not part of the jointly told tales of the key figures.

Since we used a structured checklist for executing the interviews of Case 2, these were structured and condensed. By answering the questions of the interview (in a chronological order) the actor creates already a structured story. As a result, we decided to process the interviews of Case 2 by listening to the tapes made during the interviews. This was possible because, we knew, from Case 1, what kinds of factors we could expect. Additional knowledge that we gathered from the desk research was put in the Logbook that we made. This Logbook was also analyzed.

The second step was the distillation of the barriers and enablers. This was done in a similar way in both cases. By reading the transcripts of Case 1 and by listening to the tapes of Case 2 (plus analyzing the Logbook), we searched for factors that influenced the creation of shared understanding between the actors. If we found a factor, we formulated clear statements about that factor. These statements formed the barriers and enablers.

7.2.3 Data analysis

Figure 7.1 shows that the data analysis phase consists of three steps:

- coding of the barriers and enablers
- clustering the barriers and enablers
- validation of the data

In Case 1, we coded the data in two different ways: according to the phase in the product creation process of the company and according to the three organizational levels (the actor-, project- and company level). For the coding according the project phase, we used the formalised structure of the product creation process of the company. A detailed description about the activities of the different phases made this possible. For the coding of the barriers and enablers on the three organizational levels, we developed definitions of each level. We coded all barriers with three researchers and enablers with two researchers. The inter-rater reliability was sufficient. From the coding of the barriers and enablers of Case 1, we learned that it was necessary have in depth knowledge of the case in order to be able to interpret and code the barriers and enablers.

In Case 2, we coded the barriers and enablers in one way: according to their organizational level. One researcher coded the barriers and enablers of Case 2. This researcher did the data gathering and analysis alone (this researcher was experienced with the coding process because she also had coded Case 1).

The second step was the clustering of the barriers and enablers according to their content. In Case 1, one researcher clustered all of the barriers and enablers. The clusters that originated received a name. A second researcher was given the names of the clusters and put each barrier and enabler into one of the clusters. In Case 2 this procedure was executed by one researcher.

The third step of data analysis was the validation of the data that we found. We verified our interpretation with the actors involved for both cases. We did that in two steps in Case 1. First, each key figure checked his Learning History in order to check if we interpreted the interviews correctly. The second step was a workshop in which we actively discussed the barriers and enablers that had been found in the different interfaces. In Case 2, we presented the results of the case study to the actors involved. Furthermore, we did two workshops to check the interpretations made with the actors involved.

This data validation step was important for the researchers, since we could check the interpretations that we had made. In addition, it was also important for the design team involved. For them it created a moment of reflection. They used it for determining the key lessons of the design project (phase). We will go into more detail on this aspect, in section 7.3.

Reflection on doing case study research 7.2.4

In this thesis, we chose to do case study research. One of the main characteristics of doing case studies is that there are no constrained methods for data collection and analysis. Therefore, we developed the Learning History method into a research method that was valid for the purpose of this thesis.

The basis of this research method is storytelling. This thesis shows that storytelling can be a valid method for doing a holistic case study. By telling their stories, the actors showed their view on the collaboration process in a holistic way. The congruency of the stories told showed the relationships between certain topics, which made it possible to relate the stories of the different actors with each other. In order to do this, it was crucial that we, as researchers, understood the content of the stories that the actors told us.

Our experience from the real time case study has thaught us that it takes time to understand the content related communication between the actors. Researchers who want to do a similar research project should take into account that this requires time. This time can also be used to let the actors become used to a researcher observing them, as well as for experimenting with the type of interview questions that could best be posed.

Actually, during data gathering in a holistic case study, a researcher needs to find a balance between the research method developed and the real life situation in which he finds himself. It is important to keep the aim of the research in mind. At the same time, a researcher should deal pragmatically with the opportunities that the case provides in order to reach the goal. This is sometimes hard, but it also makes this type of research exciting.

During data analysis, we unraveled the large amount of data that we had gathered. Transparency was significant during this phase. Of course, from a research point of view transparency was relevant. However, our experience taught us that it was important for the actors involved to know what we had done with their stories. By telling us their stories they trusted that we would interpret the data properly and that we would share this information with the right people. We took the time to share our interpretations with the actors involved. We also made it clear to them for which purposes the data would be used. This positively influenced the collaboration process between us, the researchers, and the actors involved in the collaborative design process.

The last aspect that we would like to reflect on is the fact that we combined a retrospective case and a real-time case into one research project. We used the retrospective case as a pilot for the real time case study. One can say that Case 1 provided us with guides for detecting and appointing the most interesting aspects (concerning collaboration) in the midst of the chaos of the real time project. This interaction between the two cases worked out well. This two step approach could also be suitable for other explorative research projects in practice.

7.3 Implications for using the results of this thesis

In Chapter 1, we have explained that this thesis is of interest for practitioners, students of Industrial Design Engineering (IDE) and other researchers in the field of design. We have separated the practitioners into two groups because the implications for these two groups differ. The first group is practitioners in new product design projects in general. The second group is the practitioners of the collaborative design processes of the two cases. For these four different groups, we will provide implications for improving collaborative design that is based on the findings of this thesis. During this research project we already developed some tools for improving collaborative design that are applicable for the different audiences. These are also reported in this section. This section continues with some implications for design practice.

Implications for practitioners of collaborative design projects 7.3.1

In Chapter 1, we quoted a Project Leader of Phillips who said:
"*…Dependent from their discipline, they have a feeling for each other's discipline, but the real details… It is complex to be able to know from every discipline all parts. As a Project Manager, you really have to be aware of this. That is also the reason why I need something to monitor that…*" (Project Leader, Philips, 2004).

Although there is not yet an applicable tool for monitoring collaborative design, we think that this thesis is a first step towards that direction. We can illustrate this by reanalyzing the example we gave in Chapter 1. The example is presented in Example 1 in Box 7.1.

Box 7.1
Example 1

An Electrical Engineer got an assignment to design a circuit board for a digital hand-held device. In the list of specifications, he saw the maximum amount of space he could use for the circuit board. From his experience, he knew that he was not able to put all of the components he needed in that space. The Project Leader told him that the Ergonomic came up with this specification as a result of user requirements. The Electrical Engineer asked the Ergonomic if he could change this requirement. The Ergonomic told him that this was the maximum amount of space

Contuniation
Box 7.1
Example 1

the Electrical Engineer could use. The Ergonomic explained himself with theories of movements of the human body. He also used tables with measurements of the human body and pictures about the structure of human joints. Although the Ergonomic tried to explain his point of view clearly, the Electrical Engineer did not understand. By using drawings of circuit boards and mathematical formulas, the Electrical Engineer tried to explain to the Ergonomic the impossibility of getting all the functionality into such a small space. The Ergonomic did not understand what the Electrical Engineer was talking about. They ended the discussion with the knowledge that there was a space problem. Yet, they were not able to negotiate with one another in a productive way in order to solve the problem.

A Project Leader who faces the problem as described in Box 7.1 can use the results of this thesis to recognize the underlying causes of the collaboration problem that occurs on the actor level. The main problem here is that the Ergonomic and the Electrical Engineer are both incapable of transferring their knowledge to one another. The different languages that they use intensify this problem. Since a solution for such a design problem asks for an innovative solution, we can categorize the interface between the Ergonomist and the Electrical Engineer as: an interface within the design team that deals with an innovative aspect. Looking at the collaborative mechanisms of this type of interface, a Project Leader should be aware of the fact that this design issue can lead to planning and monitoring problems. In order to manage this, a Project Leader should help the Ergonomist and the Electrical Engineer transferring their knowledge to one another. He should function as a boundary spanner between the two actors. If the transition of knowledge is made and both actors have learned some of the language of the other, then both the Ergonomist and the Electrical Engineer can together solve the design problem. Furthermore, a Project Leader should be flexible with the planning of this aspect. He should be aware that this design task may influence the critical path of the entire design project. In order to control this, a Project Leader should monitor (in detail) the progress and possible problems. Only this can make managing new aspects possible. These aspects plead for a Project Leader who has knowledge about the content of the design task. This is also in line with recommendations of Cooper (1999) and Valkenburg (2000, p. 218).

The reanalysis of Example 1 in Box 7.1 shows that a Project Leader can use the results of this thesis to manage the collaborative processes of the design team. However, this does not yet provide the Project Leader with the monitoring tool that he needs. The question is how a Project Leader can recognize and distill the collaborative mechanism within his design team. The answer to this question was given by a Project Leader of a technical subsystem of Case 2. He opted for implementing the learning history method in their design projects. He thought it would be a powerful tool for detecting collaboration problems. He suggests that an external researcher or consultant should create the learning histories of the particular design project. Although we think that this is the optimal solution, it seems that it is not the most applicable solution. We think that a Project Leader can also learn to use the learning history method during the design project. It should become a permanent aspect of his management tasks (just as the regular project management tools for planning and monitoring are).

A Project Manager should actively observe his own team during their regular meetings. He should take notes about the most important issues concerning communication about the design content. During the regular face-to-face meetings (that are now mostly about planning and monitoring issues and design problems or -changes) with the separate actors, he can use his notes as input for discussing the collaborative aspects with the actors. This form of storytelling will provide the Project Leader with knowledge about the collaborative aspects of the design process. A Project Leader should also learn to distill the barriers and enablers from these conversations. Dependent on the kind of barriers and enablers he has found, he can then decide if he needs to intervene.

7.3.2 Implications for practitioners involved in the two cases

This section is about the implications for the actors who were involved in the two case studies. The implications we offer here are more detailed than in the previous section. In this section, we will describe how we presented the implications. Additionally, we will show some examples of the implications that were given.

We organized workshops in order to give feedback to the actors involved in the cases. These workshops had two goals. First, we provided the actors involved with insight about their collaborative processes. The second goal of the workshops was to verify whether or not we had interpreted the data correctly.

For the actors of Case 1, we organized one workshop with the key figures and the project board of the collaborative design project. To provide the actors with feedback, we gave a presentation about the results of the case study. We went into detail about the amounts of barriers and enablers that each key figure had. In addition, we presented the types of barriers and enablers in each project phase. The second part of the workshop was about the interfaces found. We presented the actors with the relationships found between the barriers and enablers within each interface. For example, the interface between Software Development and the design team. We found that the company did not have enough expertise in software design. This led to barriers that concerned the planning and the monitoring of the design of software. It also led to collaboration problems between the actors involved, since they did not understand each other. Concerning software design, for example, we provided the design team with the following implications:

- determine the influence that software design has on your other design

processes
- determine how the software design process can be implemented in the standard procedures of the product creation process
- determine if the standard project management tools are applicable for software design
- hire an expert in the field of software design in cars
- actively train the other actors involved in software design (teach them the jargon and the software design process)
- take your time with implementing the software design processes in the organization

The participants of the workshop said that they were pleased both with the mirror that we presented to them and with the pragmatic tips we had given.
After the presentation of the results we asked each participant of the workshop to determine per interface which barrier was:
- most urgent
- most important
- directly could be solved by one's own

This led to a vivid discussion between the participants of the workshop about both the interfaces that we presented and the barriers and enablers within the interfaces. For the actors involved, this workshop was the first occasion where they actively discussed aspects that concern collaboration. After the workshop, the actors said that they were not aware of the barriers that the others had faced. The discussion they had during the workshop was a fist step towards setting issues about collaboration on the agenda. All participants thought that this was valuable.

In Case 2, we executed two workshops. Both workshops had a different purpose. The first workshop was comparable to the workshop with the participants of Case 1. The second workshop was different.
In this workshop we tried out an intervention with the design team of the subsystem Control. We facilitated a workshop about their collaboration

problems. (These collaboration problems mostly concerned the interfaces that they had had with the subsystem Escape Doors and Fire Fighting. In Chapter 5, we showed these problems extensively in the Boxes 5.1-5.4. These boxes contain Example 1, which we used for explaining the method for data gathering.) In this workshop:

- We mapped the innovative aspects that the actors in the Control team faced in a plenary session with the whole team of Control (see picture A in Figure 7.2). This provided the Project Leaders with an overview of the aspects that were regarded as new by team members (and therefore, were viewed as difficult).
- We let the participants individually model the context of their own design task. During the discussion about this, the actors created shared understanding of the actual context.
- We let them model their own design process and compared their individual design processes with the processes of the others (see picture B in Figure 7.2). Afterwards, the Project Leaders explained the relationship between the design process of Control and the design processes of the other sub teams. This provided shared understanding about the relationship of the design process of Control with the design process of the entire design project.
- We let them construct the organizational chart of the design project (see picture C and D in Figure 7.2). We did this in order to show them the dependencies between their sub team and the other sub teams. The method we used for doing this was to make cards of all parties who were involved. They had to organize the cards in small teams. Afterwards, the different organizational charts were actively discussed. This helped the actors to create shared understanding about the actual dependencies.
- The participants filled in a matrix (which was like the matrix of Figure 5.3) that provided shared understanding about the different stages in which the Control system could exist.

Picture A

Picture B

Picture C

Picture D

Figure 7.2 Pictures of a Workshop held with team members of Case 2 in order to improve their collaborative processes

When evaluating this workshop both the Project Leader of Control and the other actors of the Control team said that this workshop provided them with a better understanding of the issues discussed. The Project Leader became aware of the most difficult aspects of the design tasks of the individual actors. The actors in the design team better understood the context of their design task. Additionally, they also created shared understanding about the stages in which their subsystem could exist. This positive evaluation shows that an intervention like this can be used to manage collaborative design. Of course, in the future this should be further developed.

Implications for design education 7.3.3

In Chapter 1, we outlined the profile of an Industrial Design Engineer (IDE) educated at Delft University of Technology (DUT). This profile shows that an Industrial Design Engineer of DUT is educated as a generalist. He has knowledge about: engineering, management of innovation, formgiving, ergonomics and sustainability (Oppedijk van Veen *et al.*, 2001, p.20). Additionally, he has extensive knowledge about product design processes. In this thesis, we proved that this knowledge make it possible to evaluate aspects concerning collaborative design. Therefore, we think that IDE students are candidates for becoming Project Leaders of future collaborative design projects. Since we want the students of IDE to be capable in the area of managing collaborative design, we have to educate them in this area during their study. In order to be able to manage collaborative design they must learn three aspects.

- The first aspect that IDE students have to learn is how to face the problem of collaboration between disciplines. This will help them to recognize these problems in future situations. Recognizing the problem of collaboration between disciplines is difficult for IDE students. They are generalists and are, therefore, able to understand all design disciplines to certain extend. In order to train them in facing and recognizing collaborative problems between disciplines, we developed a design game that simulates the collaborative aspects of design projects. This game will be explained in the next part of this section.
- Second, this research project showed that the learning history method has been a powerful tool for evaluating design projects. The learning history method is based on story telling. In order to learn executing the learning history method, we think that students IDE should train how to use storytelling actively during their collaborative design projects. We developed also a tool for that. This tool is called VALiD (Video Assisted Learning in Design). VALiD is also explained later in this section.
- The third aspect IDE students have to learn about detecting barriers and enablers. We can train students IDE in detecting barriers and enablers by letting them executing a case study, by using the same research method as we did. The last part of this section provides an example of a master student executing a research project according to the same research method that we used for Case 2.

This section continues with the tools that we developed in order to teach IDE students the three aspects mentioned.

A tool for training IDE students in facing collaboration problems

In this section we will show two design games that simulate collaborative design. The first game is the Delta Design game developed by Bucciarelli. The second game is a design game that we developed based on the Delta Design game.

In the Delta Design game, the participants have to design a building for the Deltans, who live on the planet Deltoid Plane (Delta P). Delta P is a planet with only two dimensions. In Delta P there are other laws of nature than on Earth. The Delta Design game must be played with four participants. Each participant receives a unique team role that represents a discipline. Each discipline comes with the accompanying knowledge. The four disciplines are:

- The Architect
- The Structural Engineer
- The Thermal Engineer
- The Project Leader

The Architect has to build a building that is pleasant to live in for the inhabitants of Delta P. The Structural Engineer is responsible for the construction of the building. The Thermal Engineer is responsible for the climate of the Building. The Project Leader has to plan and monitor the design process and he has to take the costs of the building into account. In order to be able to fulfill these tasks, all participants have to learn the rules of their own discipline before the game starts.

Since all disciplines only know a part of the entire design task the four disciplines have to collaborate in order to fulfill their design task. Collaboration is hampered by the fact that the criteria of the four disciplines are contradictory on some aspects. This makes it necessary for the participants to negotiate.

Figure 7.3 shows students playing the Delta Design game. The grid on the playing board shows the two dimensions of Delta P. The triangles on the picture are the building blocks of the building. The triangles can either be red or blue. The red triangles are warm and the Deltans think that they are ugly. The blue triangles are cold and the Deltans like them. The two triangles with the dots are anchor points of the building. The Structural Engineer uses these for calculating the strength of the construction of the building.

Figure 7.3
Students are playing the Delta Design Game

Bucciarelli developed the Delta Design Game in order to show students that design is a social process of negotiating between object worlds. Since Bucciarelli is a Mechanical Engineer, he developed the Delta Design Game from a rather technical point of view. Even the task of the Architect is related to strict formulas and numbers. This forces the participants of the Delta Design Game to negotiate about numbers.
This is only a part of all design communication. We think it is the negotiation about the vague and elusive aspects of design that makes design communication between disciplines difficult to understand.
Therefore, we decided upon the design of a new game that better approaches design communication. Based on the Delta Design Game, we have developed

a new design game*. The goal of this game is to build an ideal society on an island on another planet. This society can be built with tan gram pieces in different colors. Each color represents a different material. (Yellow is stone and is meant for buildings and houses. Blue represents water and green is nature or agriculture.) This design game also has four team roles. The design team of the island is made up of four experts:

- The Energy Expert, who has to make sure that the inhabitants have enough energy. Energy must be gained by making rivers or by making a dam in a big lake. The Energy Expert need to meet hard criteria. With the use of formulas, he can exactly calculate if he met his targets.
- The Culture Expert has to guarantee that the inhabitants of the island feel comfortable. He must take care of the soft criteria of happiness. (For example, the inhabitants like recreation parks, big cities and cultivated plants.) In addition to these soft criteria he also has to take care of the total amount of inhabitants. The Culture expert has tables in which he can find the possible amount of inhabitants in certain situations.
- The Health Expert is in charge of keeping the inhabitants healthy. Clean water can keep the inhabitants healthy. Farmlands pollute the water. Therefore, the Health Expert should find a balance between farmland and water (this means a balance between the blue and green tan gram pieces). He knows the optimal proportions between the two. Another important aspect for health is the size of a city. Cities that are too large will cause illness. Therefore, the Health Expert also has to take care of the proportions between cities and nature.
- The Landscape Architect has to create a good atmosphere. He is responsible for the design of the island. Before the game starts, he must first prepare a design that is based on mood boards that are provided. There is a tension between a nice atmosphere and the number of inhabitants who can be on a certain piece of land.

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* *Four Bachelor students developed the game within the framework of a course in which they learn doing research. One of their coaches was the author of this thesis.*

As in the Delta P game the criteria that the different actors have to meet contradict with one another. In addition, in the new game the approaches of the different experts also differ. For example, the Landscape Architect makes drawings of concepts of islands, while the Energy expert calculates if he meets his criteria. This aspect is important for the simulation of design communication because (as also appeared in the literature review in Chapter 2) this is also the case in practice.
Figure 7.4 shows a design team playing the design game.

Figure 7.4 Students are playing the Design Game

The picture shows that the participants are actively discussing their design. On the table is the playing board, on which the participants are building the island with the use of the tan gram pieces in the three different colors. The drawings of the Landscape Architect are also shown in this picture.
Although we have not yet completely analyzed the differences in design communication between the Delta P Game and the new game, the first results show that the new design game better simulates design communication. This is because it captures both the technical aspects of design communication, as well as the tacit and elusive aspects. We are planning to use this game in the future as a way of confronting IDE students with the aspects of collaborative design in a multidisciplinary team.

A reflection tool for training IDE students in story telling

The second aspect, we want to teach IDE students, is that they have to learn about storytelling as a reflection tool. Storytelling is a proven method for reflection on the more subjective aspects of design (Lloyd, 2000). The active construction of stories forces the participants to actively reflect on their design process. Reflection is a prerequisite for learning by doing as proposed by Kolb (1984), which is applied in the design education program of IDE.

In the faculty of IDE there are several tools developed for enhancing reflection. One of them is VALiD which stands for: Video Assisted Learning in Design. In this section VALiD will be explained.

Lloyd, McDonell and Valkenburg executed the VALiD project (which is a research and education project) with IDE master students in their final year, (For example see: McDonnel *et al.* (2004) or Valkenburg and Hövels (2006)). The goal of VALiD was to investigate if students learned more about their design process if they, not only executed a design task, but also made a movie about their design process. During the course, the IDE students had to *do* a design exercise. This exercise was videotaped. The second step was *to look* at the video of their design process. This led to two and an half hours of videotape for each design team. From this video tape, they had to construct a ten minute story. The story constructed *tells* their opinion about the design process followed.

The results of the work of Valkenburg and Hövels show that students learn more by making and viewing a video tape about their design process than they do from the actual design process itself. The construction of the stories about their design process improved their learning process significantly.

One remarkable factor was that the students started to construct different stories of the same process (McDonnel *et al.*, 2004). One team, for example, constructed a 'positive' story in which the design process was a structured rational decision making process. In addition to this, they created a 'negative' story, which was full of misunderstandings and miscommunication. This shows that students were able to create multiple stories and that they were aware of possible storylines.

The IDE students who were involved in the VALiD project showed that they are able to create their own stories of their design processes and that they had learned from these stories.

In the future, it would be interesting to use the method, as developed in VALiD, for letting students who participate in the design game reflect upon their own design game. This would provide the students with insight into collaborative design processes in multidisciplinary teams. Additionally, we could train them in storytelling techniques so that they could use them for learning during real collaborative design projects.

Executing a case study according to the learning history method

The third and last aspect that students have to learn about is the detection of the barriers and enablers for the creation of shared understanding. In order to test if students are able to detect barriers and enablers in a design project in industry, we conveyed the research method we used in Case 2 to a master student.

The design project that he followed was comparable to Case 2. He did a case study according to the same method as we used for Case 2 and the observation period was about equal to that of Case 2. The results of this case study were comparable to Case 2. For example, the distribution of the barriers and enablers among the three organizational levels was the same. The author of this thesis coded the barriers and enablers found together with the master student. Their inter-rater reliability was 70%.

From this research project, we can conclude two things. First, other (master) students of IDE are probably able to detect barriers and enablers from real life collaborative design projects as well. Second, it showed that we are able to transfer the learning history method properly. In the future, it would be useful to let more students observe collaborative design teams in action. This would provide them with insight into collaborative design processes in industry. It could also be a good way to expand our knowledge about collaborative design.

Implications for future design research 7.3.4

In this research project, we focused on the creation of shared understanding between disciplines during collaborative design. We explored, in two extensive empirical studies, what the barriers and enablers were for the creation of shared understanding.
In Chapter 1, we stated that this study could be used in future studies on collaborative design. We meant that other research projects could expand and deepen the knowledge gained in this thesis by doing more research on collaborative design. In this section, we will describe possible future research projects that could elaborate on the results of this thesis.

Section 6.3 shows the factors that influence the creation of shared understanding that we found in Case 1 and Case 2. In future research, we could elaborate on this point. It would be captivating to investigate if the list of factors established would suffice for other cases or if there are more factors. In order to create knowledge about this, we need to do more case studies that are executed according to the learning history method as proposed in this thesis. In order to create a deeper understanding, the cases can be either retrospective or real time. Having a larger number of cases to refer to (executed according to the learning history method) would deepen our understanding of the factors. This would also create more insight about the importance of certain factors.
It would also be interesting to focus on one important factor. Our results show that the transition of knowledge is the factor on the actor level that occurred most often. Therefore, gaining more knowledge about what actors from different disciplines need to know from each other's disciplines in order to collaborate effectively could be another line of research. Within a design team, there must be a balance between enough specialists' knowledge and

architectural knowledge. What we do not yet know is if this balance differs throughout the phases of the design process. Leonard-Barton and Sensiper (1998) in their study show that knowledge creation and integration exist of divergent and convergent phases. For a Project Leader in a collaborative design project it would be interesting to know how one could positively influence the transition between these phases. Should a Project Leader bring the same actors into action for both activities, or is it better to switch the actors during the different phases of collaborative design process? Another line of approach could be team play. Dougherty and Takacs (2004) state, that team play encourages heedful interrelating between actors in product design teams, since it makes their knowledge more vivid. It would be captivating to investigate if team play can also enable the transition of knowledge.

By executing more case studies it would also be interesting to look at the interfaces of the particular case. It is probable that the interfaces that we would find in other cases could also be categorized in one of the four types of interfaces that we have distinguished. By analyzing the collaborative mechanisms within these interfaces, we would provide a deeper knowledge about how the collaborative mechanisms work. By having extensive knowledge about the collaborative mechanisms within an interface, it is possible to create a series of *best practices* for collaborative design within a certain interface. These practices could help future Managers of collaborative design projects.
Within the interfaces, there is a link between barriers and enablers on different organizational levels (the actor-, project- and company level). Dougherty (1990 and 1992) and Adams *et al.* (1998) also implicated a relationship between the actors' collaboration and the context of their collaboration. Dougherty (1990) showed that there are three distinct cycles of knowledge creation:

- on the departmental level,
- on the interdepartmental level
- on the project-to-firm level

These cycles correspond with the three organizational levels that we distinguished. Since Dougherty (1990) looked at knowledge creation between departments, instead of between actors, the departmental level could probably be replaced by the actor level of this study. The interdepartmental level represents the project level. The project-to-firm level is equal to the company level of this study.

Dougherty showed that successful firms intertwined the three cycles of knowledge creation. This suggests that there is a relationship between the levels. Dougherty (1992) recommends that firms develop an organizational context that enables collective action. However, Dougherty does not provide guidelines for developing such a context. Interviews with Managers of collaborative design teams have revealed that they often struggle with the organization of their design team and the embedding in the organization. Therefore, it would be valuable to gain more knowledge about this aspect.

Research about methods and tools that can remove the barriers for the creation of shared understanding is another possible continuation of this research project. We know from other research and stories from product designers in the industry that persona's, scenario's and using metaphors are examples of powerful tools for making elusive and tacit knowledge explicit. By using these tools storytelling also plays an important role. During decision making, actors (involved in a collaboration process) can actively refer to rich stories that are offered to them.

While playing the Delta P Game of Bucciarelli, we experimented with offering the participants a rich story about the Deltans on Delta P. Since the design communication in the Delta P game was rather technical, the participants did not actively use these stories.

However, it would be interesting to test if providing a rich story for the participants of the new design game would help the participants with creating shared understanding. This is also one of the lines of research that could be pursued.

7.4 Conclusion

The aim of this study was:

gaining a better understanding of collaborative processes of actors from different disciplines during the product design process in industry.

The previous chapters showed that by providing a literature review on collaborative design, together with two empirical studies, we were able to gain a better understanding of collaborative design projects. We found factors that played a major role in the collaborative design projects of Case 1 and Case 2. Furthermore, we gained insight in the collaborative mechanisms within the four types of interfaces that we could distinguish. These results make, this thesis is a step towards understanding collaborative design projects in practice.

In this chapter, we evaluated the research method that we followed in this thesis in order to gain a better understanding of collaborative design. The main conclusions are:

- Understanding the content of the cases has been essential for executing this research project. For the coding of the data, it was necessary that a researcher had in depth knowledge about the content of the case.
- Transparency towards the actors involved is important since they will only provide rich information if they trust the researcher.
- Observing a design project is only valuable when it is clear what the collaborative aspects are that will be investigated.
- The validation of our findings with the actors involved in the cases has been an important step for checking the interpretations made.

Furthermore, we elaborated on the findings of this thesis. We provided some implications for how the four types of audiences can use the results of this thesis in order to get a better understanding of collaborative design. The main conclusions are:

- Practitioners of design projects in general can use this thesis for recognizing the underlying causes of their collaborative problems, by recognizing the factors that lay behind. In addition, they can use it for comparing the collaborative mechanisms described in this thesis with their own situation. By doing this, they will be able to manage their collaborative design project actively because they have some examples of how to deal with difficult situations.
- The findings of this thesis have functioned as an evaluation tool for the actors involved in the two case studies. We have conducted different types of workshops in order to present our main findings to the company people.
- IDE students are candidates for becoming Project Leaders of future collaborative design projects. In order to be able to manage collaborative design projects, students IDE should learn the following three aspects: First, they have to learn about the problems with collaboration between different disciplines. Second, they have to learn about using storytelling as a way for reflecting on design projects. Third, they have to learn about detecting barriers and enablers. In order to teach them these aspects some tools are developed (which are presented in section 7.3).
- For researchers, this thesis is a first step in understanding collaborative design. Future research projects can elaborate on this thesis in various ways. For example, by expanding the amount of cases, a library of best practices can be build up. Furthermore, it is also interesting to do research on tools that help removing the barriers for the creation of shared understanding between disciplines. A more abstract continuation of this thesis is also possible. For example, it would be interesting to investigate what (type of) knowledge is necessary in the different phases of the design process. Additionally, it would be captivating to investigate what organizational structure a design team should have in order to fulfill this need for knowledge.

In conclusion we can say that this thesis affords a better understanding of collaborative design in industry. It also shows that there many areas within the collaborative design process that are still uncultivated and ready to be investigated. Actually, this is in line with the basic idea behind the learning history method: *continuous learning from (someone else's) experiences.*

Hopefully, by reading this book, you are triggered to apply the things you have learned to your own setting in order to make improvements. We challenge you to share your experiences. Only with continuous learning will we finally be able to fully understand collaborative design!

SUMMARY

Fast product follow-ups and increasing customer demands have changed product design from a rather unstructured process, into a systematic activity. Nowadays, both companies and researchers have investigated the organizational aspects of integrated product design. However, attention to the collaborative aspects lags behind the structural and organizational aspects.
The aim of this study is gaining a better understanding of the collaborative processes of actors from different disciplines during the product design process in industry. We called this collaborative design. We defined collaborative design as:

Collaborative design is the process in which actors from different disciplines share their knowledge about both the design process and design content. They do that in order to create shared understanding on both aspects, to be able to integrate and explore their knowledge and to achieve the larger common objective: the new product to be designed.

This definition shows that collaborative design consists of three building blocks:

- knowledge creation and -integration between actors from different disciplines
- communication between the actors about both the design content and the design process
- the creation of shared understanding about the subjects communicated

In this thesis we have focused on the process of creating shared understanding. During empirical research, we have investigated what factors influence the creation of shared understanding between actors in collaborative design projects. Factors that support the creation of shared understanding are *enablers* and factors that hamper the creation of shared understanding are *barriers*. Additionally, we have examined the collaborative mechanisms that occur in these projects. Collaborative mechanisms describe what influence the barriers and enablers for the creation of shared understanding have on the three building blocks of collaborative design. The accompanying research questions of this thesis are:

1. *What factors influence the creation of shared understanding during collaborative design processes in the industry?*
2. *What collaborative mechanisms influence the creation of shared understanding during collaborative design processes in the industry?*

Based on these two explorative *what* questions, we have chosen for case studies as research strategy for this project. In order to execute case studies, we have used a technique called *learning histories*. The learning history method is based on a form of ethnographic story telling called *jointly told tale*. Jointly told tales make it possible to incorporate experiences of the actors with the (objective) viewpoint of the researcher. The structure of the stories make it possible to relate events to each other, which enables the detection of the collaborative mechanisms .

To answer the research questions set, we have done two case studies (Case 1 and Case 2). Case 1 was executed in an automotive company and was set up as a retrospective case study. This means that we did the case study after the design project was finished. The aim of Case 1 was gaining a first insight in the factors that influence the creation of shared understanding in a collaborative design project and their mutual relationship. Case 2 elaborates on Case 1. It was about a design project of tunnel technical installations for the Dutch high speed train trajectory. Case 2 was set up as a real time case study. The purpose of Case 2 was gaining a deeper insight in the factors that influence the creation of shared understanding in a collaborative design project and their mutual relationship. In order to answer the two research questions set, we compared the results of Case 1 and Case 2.

Influencing factors for creating shared understanding

In both cases, we have found a considerable amount of barriers and enablers. The barriers and enablers exist on three organizational levels: the actor-, project- and company level. Barriers and enablers on the actor level deal with the knowledge and experience of an actor and his perception about the content of his design task and design process. Barriers and enablers on a project level are related to project management factors. Barriers and enablers on the company level are related to organizational issues within the company. In order to be able to compare the barriers and enablers of the two cases, we have abstracted them. On each organizational level we have found factors that either hamper or stimulate the creation of shared understanding. The two most important factors on each organizational level are:

On the actor level:

- The ability of actors to make a transformation of knowledge
- The equality of the language used between the actors

On the project level:

- The efficiency of information processing
- The quality of project documentation

On the company level:

- The organization of resources
- The allocation of tasks and responsibilities

These factors that influence actors creating shared understanding form the answer to Research Question 1.

Collaborative mechanisms that influence creating shared understanding

Within each case groups of barriers and enablers are interrelated and clusters of barriers and enablers have been formed. The content of these clusters can be attributed to different types of interfaces between (groups of) actors from different disciplines. An interface exists if two groups of actors work to a large extent separately, but have a common boundary. Because of this common boundary, they must share and create knowledge with each other. The interfaces found in this study consist of barriers and enablers on more than one organizational level.

All interfaces of both cases could be classified into four types of interfaces, which all consist of different types of collaborative mechanisms. These four types of interfaces are:

The interface with the outside world

Within the interface with the outside world the design team can have two different roles. The fist role is the *supplier role*. In this role, the design team designs a product for a customer. In order to do that according to the demands of the customer, the design team has to involve the customer (in an advisory role) in the design process. The cases have shown that this can be difficult since the customer often does not see benefits for collaboration. An active approach of customers, together with the skills to speak the language of the customer will enable the creation of shared understanding in this type of interface. The second role is the *customer role*. In this role the design team contracts a part of the design task to a Supplier. The cases have shown that if the design team is in the customer role, it is often difficult for them to explain a Suppliers what they expect from them (both regarding the process and the content). A careful selection procedure of a Supplier and establishing a qualitative long-term relationship with a Supplier can enable this interface, since both parties build up experience collaborating together.

The interface between the design team and the organization

The interface between the design team and the organization concerns in Case 1 the interface between the design team and Production. In Case 2, it concerns the interface with Maintenance. Both concern (for efficiency reasons) the involvement of a discipline earlier in the process than they have to do their actual job. In the cases, both Production and Maintenance did not have the knowledge to contribute with respect to the content in the early stages of a design project, as was asked by the design team. Additionally, they miss the capacity to do the work In order to create shared understanding between these two disciplines the actors should pay much attention to what information is actually needed (= problem definition). Also the format of information exchange between the two disciplines should be made explicit and applicable for both. Finally, there should be a clear planning, in which the actors visualize the main activities and dependencies.

The interfaces within the design team that deal with regular aspects

In interfaces within the design team, actors need detailed knowledge from the content of each others design (tasks). In both cases the design teams had lack of shared understanding about content related aspects on a conceptual level. The effective use of these past experiences will enable this type of interface. Furthermore, it is important to have a strong System Engineering group with product-architectural knowledge. The System Engineering group should be able to think conceptual, but must also be able to understand (detailed) information from the different technical subsystems to be able to make a good decision. The System Engineering group should also have the power to make all decisions concerning the integration of the technical subsystems.

The interfaces within the design team that deal with innovative aspects

As in the third type of interface the actors in this interface need detailed knowledge from the content of each others design (tasks). However, as this type of interface concerns an innovative task, the actors face both technical uncertainty as well as lack of information about how to perform the task. This uncertainties influence the collaborative mechanisms between the actors, since they could not rely on past experiences. The cases have shown that this hampers the actors making the necessary transformation of knowledge. Since it is not clear what knowledge the actors need from each other and where the information is stored have caused also difficulties in planning and monitoring the project. Solutions can be found by explicitly making the new aspects integral parts of the development process. This takes time since new interfaces must be made clear. Additionally, actors should be trained about the new aspects in a way they are able to interact with the specialists.

This section provided insight in collaborative mechanisms of the two cases and forms the answer to Research Question 2.

Conclusion

The aim of this study was gaining a better understanding of the collaborative processes of actors from different disciplines during the product design process in industry. This study provided knowledge about both the influencing factors for the creation of shared understanding as well as the collaborative mechanisms that occur during a collaborative design project. This is a first step towards understanding collaborative design. This thesis also showed that there many areas within the collaborative design process that are still uncultivated, ready to be investigated. Actually this is in line with the basic idea behind the learning history method: *continuous learning from (someone else's) experiences*.

SAMENVATTING

Tegenwoordig volgen productgeneraties elkaar snel op en verlangen consumenten steeds meer van producten. Om dit bij te kunnen houden moeten bedrijven hun producten systematisch ontwikkelen. We noemen deze systematische manier van productontwikkeling *integrale productontwikkeling*. Bij integrale productontwikkeling werken bedrijven vaak met multidisciplinaire ontwerpteams.

Zowel bedrijven als onderzoekers hebben de algemene organisatorische aspecten van de integrale productontwikkeling vergaand onderzocht en methoden ontwikkeld om dit proces te optimaliseren. Echter, de aandacht voor de specifieke manier waarop mensen met elkaar moeten samenwerken is grotendeels onderbelicht gebleven. Het doel van dit proefschrift is het verkrijgen van een beter begrip van de manier waarop actoren in een ontwerpproces in de industrie met elkaar samenwerken. We noemen dit *co-design*. In dit proefschrift hebben we co-design gedefinieerd als:

Co-design is het proces waarin actoren van verschillende disciplines hun kennis delen over zowel het ontwerpproces als de inhoud daarvan. Ze doen dit om over beide aspecten gedeeld begrip te creëren. Hierdoor kunnen ze hun kennis integreren en *exploreren op een manier die het mogelijk maakt dat ze hun gemeenschappelijke doel bereiken: het ontwikkelen van het nieuwe product.*

Deze definitie van co-design laat zien dat het bestaat uit drie bouwstenen:

- kennis creatie en -integratie door actoren van verschillende disciplines
- communicatie tussen actoren over zowel het ontwerpproces en de inhoud daarvan
- het creëren van gedeeld begrip over de besproken onderwerpen.

De focus van dit proefschrift ligt op het verkrijgen van inzicht in hoe mensen in een ontwerpproject gedeeld begrip creëren over de besproken onderwerpen. In een empirisch onderzoek hebben we onderzocht welke factoren het creëren van gedeeld begrip tussen mensen in een ontwerpproject beïnvloeden. De factoren die dit proces bevorderen heten *katalysatoren* en de factoren die dit proces belemmeren heten *barrières*. Daarnaast hebben we ook gekeken naar de *samenwerkingsmechanismen* die in de ontwerpprojecten voorkomen. Samenwerkingsmechanismen beschrijven de invloed die de barrières en katalysatoren hebben op de drie bouwstenen van co-design. De onderzoeksvragen van dit proefschrift luiden:

1. *Wat zijn de factoren die het creëren van gedeeld begrip in co-design processen in de industrie beïnvloeden?*
2. *Wat zijn de samenwerkingsmechanismen die het creëren van gedeeld begrip in een co-design proces in de industrie beïnvloeden?*

Gebaseerd op deze twee exploratieve *wat* vragen, hebben we gekozen voor case studies als onderzoeksmethode. Bij de uitvoering van het case studie onderzoek, is gebruik gemaakt van de methode *learning histories*. Deze methode is gebaseerd op een etnografische vorm van verhalen vertellen; de *jointly-told-tales*. *Jointly-told-tales* maken het mogelijk om ervaringen van actoren te combineren met de (objectieve) interpretatie van de onderzoeker.

De structuur van verhalen maakt het mogelijk om afzonderlijke gebeurtenissen met elkaar te verbinden, waardoor de samenwerkingmechanismen gedetecteerd kunnen worden.

Om de onderzoeksvragen te kunnen beantwoorden zijn twee case studies gedaan (Case 1 en Case 2). De eerste case is uitgevoerd in een bedrijf dat voertuigen ontwikkeld. De case studie is opgezet als een retrospectieve case studie. Dit betekent dat de case gaat over een ontwerpproject dat al beëindigd was op het moment van onderzoek. Het doel van Case 1 was het verkrijgen van een eerste inzicht in de factoren die het creëren van gedeeld begrip beïnvloeden. Daarnaast wilden we ook inzicht krijgen in de onderliggende relaties tussen de gevonden factoren.

Case 2 bouwt voort op Case 1. In Case 2 is de ontwikkeling van de tunneltechnische installaties van de Hoge Snelheidslijn Zuid bestudeerd. Het onderzoek is uitgevoerd tijdens het ontwerpproject. Het doel van Case 2 was het verkrijgen van een diepgaander inzicht in zowel de factoren die het creëren van gedeeld begrip beïnvloeden en de onderliggende relaties.

Om de twee gestelde onderzoeksvragen te kunnen beantwoorden hebben zijn beide cases met elkaar vergeleken.

Factoren die het creëren van gedeeld begrip beïnvloeden

In beide cases zijn een aanzienlijke hoeveelheid barrières en katalysatoren gevonden. Deze kunnen worden ingedeeld op drie niveaus; het actor-, project- en organisatie niveau. Barrières en katalysatoren op het actor niveau hebben te maken met de kennis en ervaring van een actor en zijn perceptie over de inhoud van zowel de ontwerptaak als het ontwerpproces. Barrières en katalysatoren op het project niveau zijn gerelateerd aan project management factoren. Barrières en katalysatoren op het organisatie niveau hebben te maken met aspecten van organisatorische aard. Om de barrières en katalysatoren met elkaar te kunnen vergelijken zijn deze geabstraheerd. Op elk van de drie niveaus hebben we factoren gevonden, die het creëren van gedeeld begrip belemmeren of bevorderen. De twee meest voorkomende factoren op elk van de drie niveaus zijn:

Op het actor niveau

- De aanleg van actoren om een transformatie van kennis te kunnen maken
- De mate van gelijkheid in de taal die actoren gebruiken

Op het project niveau

- De efficiëntie van het verwerken van informatie
- De kwaliteit van project documentatie

Op het organisatie niveau

- De organisatie van middelen
- De verdeling van taken en verantwoordelijkheden

Deze factoren beïnvloeden het creëren van gedeeld begrip tussen actoren en vormen (samen met de analyse ervan) het antwoord op de eerste onderzoeksvraag.

Samenwerkingsmechanismen die gedeeld begrip beïnvloeden

In elke case hebben we clusters gevormd van barrières en katalysatoren die met elkaar verband houden. De inhoud van elk cluster is gerelateerd aan verschillende soorten *interfaces* tussen (groepen) actoren van verschillende disciplines. Een interface ontstaat als groepen actoren voor een groot deel onafhankelijk van elkaar werken en dat hun werk tegelijkertijd een gemeenschappelijk grensvlak kent. Dit gemeenschappelijke grensvlak zorgt ervoor dat de actoren kennis moeten delen en creëren. De interfaces die we in deze studie hebben gevonden bestaan uit barrières en katalysatoren op meer dan één van de drie gevonden niveaus. Alle interfaces die we hebben gevonden konden worden geclassificeerd naar vier soorten interfaces, die elk een ander samenwerkingsmechanisme beschrijven. Deze vier soorten interfaces zijn:

De interface met de buitenwereld

Een ontwerpteam kan twee rollen aannemen als het gaat om de interface met de buitenwereld. De eerste rol is die van *toeleverancier*. In deze rol ontwerpt het ontwerpteam een product voor een klant. Om aan de eisen van deze klant te kunnen voldoen moet het ontwerpteam de klant (in een adviesrol) betrekken in het ontwerpproces. De twee case studies hebben laten zien dat dit moeilijk is omdat de klant vaak niet het voordeel van de samenwerking ziet. Een actieve benadering van de klant samen met de vaardigheid de taal van de klant te spreken bevordert het creëren van gedeeld begrip met de klant in dit type interface.

De tweede rol die het ontwerpteam kan aannemen is de rol van *klant*. In deze rol besteedt het ontwerpteam (een deel van) de ontwerptaak uit aan een toeleverancier. De twee case studies hebben laten zien dat het voor ontwerpteams moeilijk is aan de toeleverancier uit te leggen wat ze van hen verwacht qua inhoud en qua proces. Een zorgvuldige selectie van een toeleverancier, samen met het opbouwen van een langdurige relatie met een toeleverancier, bevordert de samenwerking in deze interface omdat beide partijen ervaring opbouwen in het samenwerken met elkaar.

De interface tussen het ontwerpteam en de organisatie

De interface tussen het ontwerpteam en de organisatie is in Case 1 de interface tussen het ontwerpteam en Productie. In Case 2 is het de interface tussen het ontwerpteam en Maintenance. Beide interfaces gaan over het betrekken van een discipline in het ontwerpproces voordat deze hun eigenlijke taak moeten uitvoeren. Uit de case studies is gebleken dat zowel Productie als Maintenance niet de kennis hebben om zo vroeg in het proces een inhoudelijke bijdrage te kunnen leveren. Daarnaast missen ze ook de capaciteit om het werk te kunnen doen. Om gedeeld begrip tussen deze twee disciplines te creëren zullen de actoren veel aandacht moeten schenken aan de discussie over welke voor informatie ze van elkaar verwachten (= probleemdefinitie). Daarnaast moet de manier waarop kennis wordt gedeeld expliciet worden gemaakt voor beide partijen. Ook moet er een duidelijke planning worden gemaakt, waarin de actoren hun belangrijkste onderlinge afhankelijkheden kunnen visualiseren.

De interfaces binnen het design team die gaan over routinematige aspecten

Actoren binnen een ontwerpteam hebben gedetailleerde kennis nodig van elkaars ontwerptaak. Uit beide cases blijkt dat de actoren in dit type interface een gebrek aan gedeeld begrip hebben over inhoudsgerelateerde aspecten op conceptueel niveau. In beide cases heeft het effectieve gebruik van ervaringen uit het verleden geholpen bij het creëren van gedeeld begrip in dit type interface. Verder is belangrijk gebleken dat er een sterke System Engineering groep nodig is, die kennis heeft van de productarchitectuur. Deze System Engineering groep moet conceptueel kunnen denken. Daarnaast moet deze groep begrip hebben van de technische aspecten van de subsystemen die worden ontwikkeld. Ook moet deze System Engineering groep de bevoegdheid hebben om alle beslissingen te nemen die de integratie van de subsystemen aangaan.

De interfaces binnen het design team die gaan over innovatieve aspecten

Net als in de derde soort interface, hebben actoren in deze interface gedetailleerde kennis nodig over elkaars ontwerptaak. Omdat deze interface gaat over innovatieve taken worden de actoren geconfronteerd met onzekerheden over hun taak en het proces dat ze moeten volgen. De actoren kunnen niet terug vallen op ervaringen uit andere projecten. Dit beïnvloedt de samenwerkingsmechanismen. Beide case studies hebben laten zien dat de actoren niet in staat zijn om de benodigde transformatie van kennis te realiseren. Dit kwam mede omdat het onduidelijk was welke kennis de actoren van elkaar nodig hebben en waar deze kennis wordt opgeslagen. Een rechtstreeks gevolg hiervan zijn problemen met het plannen en monitoren van het ontwerpproject. Het probleem kan worden opgelost door de nieuwe aspecten een integraal onderdeel te maken van het ontwerpproces. Dit kost tijd, omdat de nieuwe interfaces helder moeten worden. Verder zullen de betrokken actoren zodanig getraind moeten worden dat ze in staat zijn om te kunnen samenwerken met de andere specialisten.

Deze paragraaf heeft inzicht gegeven in de samenwerkingsmechanismen en vormt het antwoord op onderzoeksvraag 2.

Conclusie

Het doel van deze studie was het creëren van een beter begrip van co-design processen in de industrie. Deze studie verschaft inzicht in de factoren die het ontstaan van gedeeld begrip tussen disciplines bevorderen dan wel belemmeren. Verder verschaft dit proefschrift inzicht in de samenwerkingsmechanismen die een rol spelen in het ontwerpproces. Dit is een eerste stap op weg naar het begrijpen van co-design.
Dit proefschrift laat ook zien dat er binnen het co-design proces gebieden zijn waarvan de kennis nog erg beperkt is. Deze gebieden zijn klaar om onderzocht te worden. Dit is geheel in lijn met de basis gedachte van het learning history proces: *continu leren van (andermans) ervaringen*.

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