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An explorative study of knowledge transfer processes in new product development in the automotive industry

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Abstract

This research builds on three projects that aim to investigate how knowledge transfer takes place in new product development in the automotive industry. The study seeks to picture how product development teams frame and shape new product knowledge, how they interpret such knowledge, and how they apply knowledge to the product development process.

From that perspective, product development activities can be seen as transactions that are integrated into an overall system of identifying, assessing, collecting and combining knowledge.

Results of my research so far reveal that there are many factors that affect the successful management of knowledge transfer in new product development projects. Based on my first two projects, using the case study approach, it is evident that for successful knowledge transfer to occur, there is a need to distinguish between design knowledge that is embedded in the tacit knowledge domain and that embedded in the or explicit design knowledge domain.

The results of project three, using a survey questionnaire approach, provide a powerful demonstration, that knowledge integration, combination and creation in product development need intensive interaction and collaboration.

The enormous importance of interaction and collaboration to integrate and combine knowledge has its origin in the nature of design knowledge. For example engineers produced in the survey a 82 % rate of agreement with the statement that they use mainly knowledge that comes from their past work experience as product developers, in order to solve complex design tasks. The underlying assumption of this finding is, that engineers are therefore mostly forced to transfer tacit design knowledge to solve complex design tasks.

The research showed that a remarkable under-performance exists in knowledge identification and knowledge articulation in new product development in the automotive industry. In vehicle development, non-routine tasks are highly complex. This requires team members to have an understanding of the complete product system architecture.

To create such an understanding, engineers need to identify and articulate knowledge. These activities can be seen as a pre-knowledge creation. The result is a shared product *knowledge base, which makes it possible for people engaged in the vehicle development process to use different kinds of knowledge to capture and link new technologies into innovative products. This may require a cultural shift by vehicle manufacturers in terms of how they steer and allocate resources to future vehicle development programmes.*

Building on four years engagement with knowledge transfer research, I conclude that organisations in the automotive sector still rely on methods and processes that were successful in the past and strictly directed at exploiting tangible assets. To integrate pre-knowledge creation, as a new found discipline in product development projects creates an enormous potential to integrate and combine knowledge in an efficient way for future product development projects.

Acknowledgements

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As a result of the research activities, my wife Claudia and my son Niklas were watching me many weekends and holidays in patience and silence while this study was produced. Additional they were always motivating me to get through this challenging time of my life. Therefore, I thank Claudia and Niklas very much and I look forward to spent with them weekends and holidays without any work.

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Abbreviations and Notation

Assessing knowledge	Is similar to identifying knowledge. The main distinction is that it manipulates knowledge resources already existing in the organisation. An engineer describing this practice used the phrase “matching the existing expertise to requested requirements”.
Barriers of knowledge of transfer	The term summarises the major inhibitors of knowledge transfer, identified in the research. Knowledge transfer is negative influenced by the perception of engineers if knowledge sticks in functional departments. Additional unawareness of valuable knowledge and the difficulty to articulate design relevant knowledge are perceived as barriers to transfer and share knowledge in the product development teams.
CAD	Computer aided engineering
CAM	Computer aided manufacturing
CAS	Computer aided styling
CAx	Generic term for various computer aided techniques, e.g. CAD, CAM, CAS
Capability	Kogut and Zander (1992) use the term capabilities to describe organisational processes by which firms synthesise and acquire knowledge resources, and generate new applications from those resources. This definition of capabilities is similar to the definitions given by other authors. For example, capabilities are the drivers behind the creation, evolution, and recombination of other resources into new sources of competitive advantage (Henderson and Cockburn, 1994; Teece, Pisano and Shuen, 1997; Eisenhardt and Martin 2000).

Capabilities to improve product development	Is the process of combining new technologies with existing technologies to generate new applications for tangible products. See also (figure P2.13, figure P2.14, figure P2.16 and table P2.16).
Collecting knowledge	Collecting knowledge is the activity of selecting and categorising from existing knowledge. Senders need to “give them [receivers] the expertise they need, not everything you possess”.
Combining knowledge	Combining knowledge is a course of action to structure knowledge and express it a way that is appropriate to receiver needs. In other words, “to tailor the selected solution to knowledge transfer requirements”.
Concrete design task *versus* abstract design task in the theoretical framework figure 15	This term identifies the degree of improvement potential in product development over knowledge transfer, shown in (figure 15). If you achieve a common understanding over socialisation and diffusion, abstract design tasks are transformed into concrete design tasks. As a result of socialisation and diffusion engineers create a common understanding, about the design tasks to solve, which helps to increase the capabilities to improve product development.
Core process of knowledge transfer, {I-A-C-C}	This procedure {I} identify, {A} assess, {C} collect and {C} combine knowledge, is a course of actions to structure knowledge and express it a way that it is appropriate to receiver needs. Externalisation takes place if knowledge is from the tacit domain is transformed into explicit domain. It is described as the core process of knowledge transfer in research project two (figure 19). The major constraint of this systematic approach is to break down complex knowledge requirements, because not all knowledge existing in the tacit domain is capable of being codified, or in some cases the effort to codify is too high and therefore there is no prospect of value creation.

Descriptive knowledge management frameworks	Descriptive frameworks identify attributes of knowledge management important for their influence on the success or failure of knowledge management initiatives (table P2.7).
Design knowledge	Design knowledge is not static. Rather it develops under dynamic conditions, due to the fact that product development is a continuous process of improvement, design trade offs and new learning loops.
Design Reviews	Are meetings at particular milestones. The product development team gives a detailed overview about the development activities, which is represented in explicit form. Drawings, several presentations are used to visualise the product development stage. As outcome of these meetings, further activities are planned and assigned to responsible product development groups.
Diffusion	Identifies the degree to which the knowledge has been communicated. A particular act of diffusion may have many potential audiences: in a product development project your audience is on a cross-functional level, owning different fields of expertise.
DMU	Digital Mock up represents the digital vehicle generated in CAx – systems.
Dynamics of knowledge transfer	The use of the term “dynamic” is intended to stress that the research undertaken from this angle recognises that the process of product development is shaped by joint action of activities that follow lines that change over time.
EDI	Electronic data interchange
EEC	European Economic Community

Effective transfer of tacit design knowledge	Successful new product development builds on the effective transfer of tacit design knowledge. Such a process would entail the use of multiple presentations, discussions, and dialogues about the knowledge across multiple teams within both the engineers owning the knowledge and engineers in need of knowledge.
Externalisation	Describes the codification of tacit knowledge, it is one way to transform tacit into explicit knowledge.
Explicit design domain	The primary characteristics of the explicit design domain are that is diffused, codified and concrete. In general explicit or codified knowledge refers to knowledge that is transferable through formal and systematic language.
Face-to-face	*Face-to-face* is defined as communication between single persons, which supports to form and generate a common understanding about the product development process.
FMVSS	Federal Motor Vehicle Safety Standards
Group expertise	Design knowledge is part of practices integrated in the product development process; it is subject to negotiation and arguments between different engineering groups and as such this expertise is to some extent combined and integrated into the product development process.
Identifying knowledge	Identifying knowledge refers to the activity of spotting, within business units, existing knowledge resources needing knowledge, and to provide that knowledge in an appropriate representation to receiver requirements.
Internalisation	Describes learning by doing, and documented knowledge can play a helpful role in this process. For example technical specifications or design guidelines are useful to support the product development process.

Knowledge conversion	A process model of knowledge creation builds on the crucial presupposition that human knowledge is created and enlarged by means of a social interaction between tacit and explicit knowledge. This interaction is called a knowledge conversion. It is further important to note that this conversion does not take place within individuals but between individuals within an organisation (Nonaka and Takeuchi, 1995).
Knowledge gap: *In relation to the knowledge transfer process*	If sender and receiver do not understand the domain specific knowledge of each other at all we can state in a simplified form that the knowledge gap is the maximum. For example if the receiver doesn't understand the knowledge provided at all, a successful application of the provided knowledge would be impossible in a new product development process. Therefore the underlying assumption is that knowledge transfer success is very limited if knowledge provided is by the receiving parties not well understood.
Knowledge transfer in new product development	Knowledge transfer takes place if the receiver is assumed to understand the provided knowledge and is able to use it for technical applications.
KM	Knowledge management
MSC / NASTRAN	Computer aided software to perform stiffness/ strength analysis on virtual components and systems
PAM / Crash	Computer aided software to perform crashworthiness analysis on virtual vehicles and vehicle systems
PDM	Product data management

Performance gap	In the research analysis is the term performance gap used, which represents, the delta between maximum agreement, which would be 100 % and achieved survey results represented in table P3.2 and figure P3.4. The identified performance gaps helps product decision makers in realising the areas in the product development process where the potential for value creation is not fully exploited.
Pre- knowledge creation	Vehicle development requires that team members have an understanding of the complete product system architecture. To create such an understanding, engineers need to identify, access and combine design relevant knowledge. This activity can be seen as a pre-knowledge creation and the result is a shared product knowledge base, which makes it possible for people engaged in the vehicle development process to use different kinds of knowledge, to capture and link new technologies into innovative products. Pre-knowledge creation expands the explicit design-domain over externalisation. If you prepare knowledge to receiver expectations, a kind of codification takes place. Additionally this codified knowledge is a resource for internalisation. This newly created knowledge is available for new applications and can become second nature. Based on past experience, engineers form new ideas, and explicit knowledge is the basis for new tacit knowledge internalisation to take place.
Prescriptive knowledge management frameworks	Prescriptive frameworks provide direction on the types of knowledge management procedures without providing specific details of how those procedures can or should be accomplished. In essence, they prescribe different ways to engage in knowledge management activities (table P2.7).

Product knowledge base	To create a sufficient knowledge base of a product, knowledge must be translated into a form that it is available for product development teams, therefore knowledge must be identified and combined. Identifying and combining knowledge means deciding what describes the product, in a manner that other functional departments can use and handle the information provided by the specialist. A result of this interaction is that knowledge elements are generated and integrated in social networks. Knowledge between different functional disciplines is combined and actively used. Practical example is shown in (figure P1.8 and figure P1.9)
SECI modes	The SECI modes consist of socialisation (S), externalisation (E), combination (C), and internalisation (I). Socialisation converts new tacit knowledge such as shared mental models, technical skills, and shared experience. Typically, it occurs from an apprenticeship rather than documents or manuals. Externalisation transfers tacit knowledge into explicit concepts. Externalisation can be seen in the process of concept creation and triggered by dialogue or collective reflection. Combination converts explicit knowledge into more systematic sets. Internalisation embodies explicit knowledge into tacit knowledge. Explicit knowledge can be internalised into individuals' tacit knowledge. These four modes of knowledge conversion are developed by Takeuchi and Nonaka (1995).
Shared knowledge base	Face-to-face interaction and shoulder-to- shoulder working processes are perceived as the most successful way to create common emotions and experiences, and as a result engineers articulate and combine their individual knowledge and create a common understanding and a shared knowledge base about the product.
Shoulder-to-shoulder working processes	Shoulder-to-shoulder working processes are defined as an activity; if engineers work together for a period of time, to explore a design relevant solution for new technologies and quality improvement.

Socialisation	Describes the process to pass tacit knowledge on to others, for example face-to-face contact and shoulder-to-shoulder working processes are effective facilitators of tacit knowledge transfer. If tacit knowledge is transferred to others, a kind of codification and externalisation occurs. Additionally, this knowledge is available for new applications. Engineers use this knowledge to form new ideas and explicit knowledge becomes the platform for new tacit knowledge - internalisation takes place. Therefore socialisation takes place in both directions it transforms tacit knowledge into explicit knowledge and on the other hand explicit knowledge can be the basis for new thoughts and builds new tacit knowledge in the product development process (figure 15, figure P2.16 and table P2.16).
Successful knowledge transfer	Project two showed that successful knowledge transfer requires that both parties develop an understanding of where desired knowledge resides within a given source, and that sender and receiver participate in the processes by which knowledge is articulated.
Tacit design domain	The primary characteristics of the tacit design domain are that it is un-diffused, un-codified and abstract. For product development teams, this means, tacit knowledge is personal, context specific, and therefore difficult to articulate and communicate. For example, complex design tasks in new product development require some form of estimation or judgement, which can hardly be expressed in plain language.
Unawareness of valuable knowledge	The term represents the difficulty to locate product development knowledge between different engineering disciplines. For example who possesses the right source of expertise for specific design tasks. Research examples are available in table 2, table P2.14 and in detail chapter 3.2.5.

1. Research overview and contribution

The research seeks to picture how product development teams frame and shape new product knowledge, how they interpret such knowledge, and how they apply knowledge to the product development process. The nature of knowledge being transferred, its tacitness versus its articulation, has an important impact on the ease of transfer.

To investigate how knowledge is transferred in product development processes, it is essential to understand the nature of knowledge to examine mechanisms and structures that facilitate the creation and transfer of knowledge in product development projects.

1.1 Theoretical perspective: Using the literature to define knowledge

The academic question of how knowledge should best be defined is a subject of a lively epistemological debate.

On one hand knowledge can be seen as a representation of the real world, on the other it can be conceptualised as a product of the interaction between individual cognition and reality (Krogh, 1998).

There are various perspectives on the definition of knowledge from the academic and practitioners' positions, but at least all schools of thought agree in presuming that knowledge is something different from information and data.

Principally there are two approaches to defining knowledge. One uses the concept of a value chain or hierarchical structure among data, information and knowledge, while the other focuses on the analysis of the process of knowing. These theoretical perspectives are complemented by an increasing amount of managerially focused practitioner research. Dretske (1999) regards knowledge as a product that is made from the raw material of information. Zack (1999) defines data as observation or facts, with information as data in a meaningful context and knowledge as a meaningfully organised accumulation of information. Kock and McQueen (1998) regard data as a carrier of information and knowledge, information as relating to descriptive and historical fact, and knowledge as new or modified insight or predictive understanding. Harris's (1996) definition states that data is known fact, information is analysed data, and knowledge is a combination of information, context and experience. Bohn (1994) suggests that knowledge is something that prescribes what to do, information is organised or structured data, and data is raw material. Kogut and Zander (1992) define information as factual statement and knowledge as a statement of how to do.

The common factor of those definitions is that knowledge is located at the top of a hierarchical structure. This indicates that information is one representation of knowledge, but information itself is not knowledge.

Churchman (1971) notes that to define knowledge as a collection of information does not take into account the complicated interactions between the users of information and the collection of information. The implication is that knowledge is a combination of a process element such as authentication, users perception, or context and information. Arguably, this viewpoint implies that knowledge and information are not radically different from each other but represent different aspects of the same, freely convertible into each other. Once information is processed through the user's brain, it becomes the user's knowledge. When the user articulates knowledge with the intent of transmitting it, it becomes information.

Blumentritt and Johnston's (1999) knowledge information model describes this viewpoint well, implying that a tool to support knowledge management can be developed on standard information technologies. The information technologies can be the platform for effective knowledge management.

However, within the value chain school of thought, there are different views on the status of knowledge created from information.

One group of researchers (Zack, 1999; Holsapple and Joshi, 1998; Tenkasi and Boland, 1996; Zeleny, 1987) regards knowledge as an object that is stored and manipulated. Once information has been proved to be true or useful in a context, then it becomes applicable knowledge and is stored.

The second school of thought defines knowledge as a process related to application (McDermot, 1999; Zack, 1999; Frappaolo and Capshaw, 1999; Bohn, 1994; Kogut and Zander, 1992). Detailed procedures of application or applicability depend on the users interpretative capabilities. This frequently adopted viewpoint corresponds with Blumentritt and Johnston (1999), Sveiby (1998), Takeuchi (1998), Marshall (1997), Nonaka and Takeuchi (1995) and Nonaka (1994).

For example Nonaka and Takeuchi (1995) identify both justified belief and commitment, anchored to the overall epistemological structure of the holder, as key ingredients of knowledge. Spender (1996) further adds to Nonaka and Takeuchi's definition, stating that to know is to be able to take part in the process that makes the knowledge meaningful.

Davenport, Long and Beers (1998) conclude that knowledge is a high-value form of information that is ready to be applied to decisions and actions.

A further key question of knowledge research concerns the relationship and interaction between tacit and explicit knowledge. Tacit knowledge resides in the individual's experience and action. Explicit knowledge is codified and communicated in symbolic form or language.

The Hungarian chemist, economist and philosopher Michael Polanyi (1958) first introduced this difference. He stated that personal or tacit knowledge is extremely important for human cognition, because people acquire knowledge by the active re-creation and organisation of their own experience (Polanyi, 1966).

A process model of knowledge creation builds on the crucial presupposition that human knowledge is created and enlarged by means of a social interaction between tacit and explicit knowledge. This interaction is called a knowledge conversion. It is further important to note that this conversion does not take place within individuals but between individuals within an organisation (Nonaka and Takeuchi, 1995).

Tacit knowledge is personal, context specific, and therefore difficult to articulate and communicate. Explicit or codified knowledge, in contrast, refers to knowledge that is transferable through formal and systematic language. The boundary between explicit and tacit knowledge, however, is not clear. Spender (1996) indicates that the boundary is both porous and flexible. This means that tacit knowledge is created by explicit knowledge and vice versa.

There are two main theoretical perspectives of the interaction types of tacit and explicit knowledge, embedded in an ontological and epistemological perspective of knowledge. From an ontological perspective, only individuals are able to create knowledge. Therefore an organisation need individuals to create knowledge and this creation takes place within a group of people and is a process of interaction, collaboration and communication. Brown and Duguid 1991, explored the way that informal groups evolve among individuals seeking to solve a particular problem or pursuing other commonly held objectives. Membership in these groups is decided by an individual’s ability to trade practically valuable information.

To classify, what knowledge is transferred, and to understand why some kinds of knowledge are easy to transfer and some kinds of knowledge need a lot of energy and effort to be transferred, I draw on Polany’s (1966) epistemological perspective of knowledge. In his work on *The tacit dimension* he made a clear distinction between tacit knowledge and explicit knowledge. Polany contends that human beings create knowledge by involving themselves with objectives; that is, through self-involvement and commitment. To know something is to create its image or pattern by tacitly integrating its particulars. In order to understand the pattern as a meaningful whole, it is necessary to integrate one body with the particulars. Individuals interact with subject and object, and knower and known.

While Polany argues the contents of tacit knowledge further in a philosophical context, Takeuchi and Nonaka (1995) expanded his idea in a more practical direction. In their profound study they showed that the articulation of tacit mental models, in a kind of mobilisation process is a key factor in creating new knowledge.

As a basis they used the theoretical distinction of explicit and tacit knowledge, but in a more practical and organisational context. Table 1 shows some characteristics of tacit and explicit knowledge, from the point of view of Takeuchi and Nonaka (1995).

Table1: Tacit and explicit aspects of knowledge

Tacit knowledge (Subjective)	**Explicit knowledge (Objective)**
Knowledge of experience: (body)	Knowledge of rationality: (knowledge of mind)
Simultaneous knowledge: (here and now)	Sequential knowledge: (there and then)
Analogue Knowledge: (practice)	Digital knowledge: (theory)
Source: Takeuchi and Nonaka 1995, The knowledge creating company, chapter 3, page 61	

For example, knowledge of experience tends to be tacit, physical and subjective, while knowledge of rationality tends to be explicit, metaphysical and objective. Tacit knowledge is created “here and now” in a specific practical context. Sharing tacit knowledge between individuals through communication is an analogue process; it requires a kind of simultaneous processing of the complexities of issues shared by the individuals. On the other hand, explicit knowledge is about past events or objects, “there and then”, and is orientated toward a codified form.

It is essential to understand the distinction between tacit and explicit knowledge, in order to understand the complexity of design knowledge. This research demonstrates that knowledge for new product development activities is mainly embedded in the tacit design domain. For example engineers produced in the survey a 82 % rate of agreement with the statement that they use mainly knowledge that comes from their past work experience as product developers, in order to solve complex design tasks. The underlying assumption of this finding is, that engineers are therefore mostly forced to transfer tacit design knowledge to solve complex design tasks.

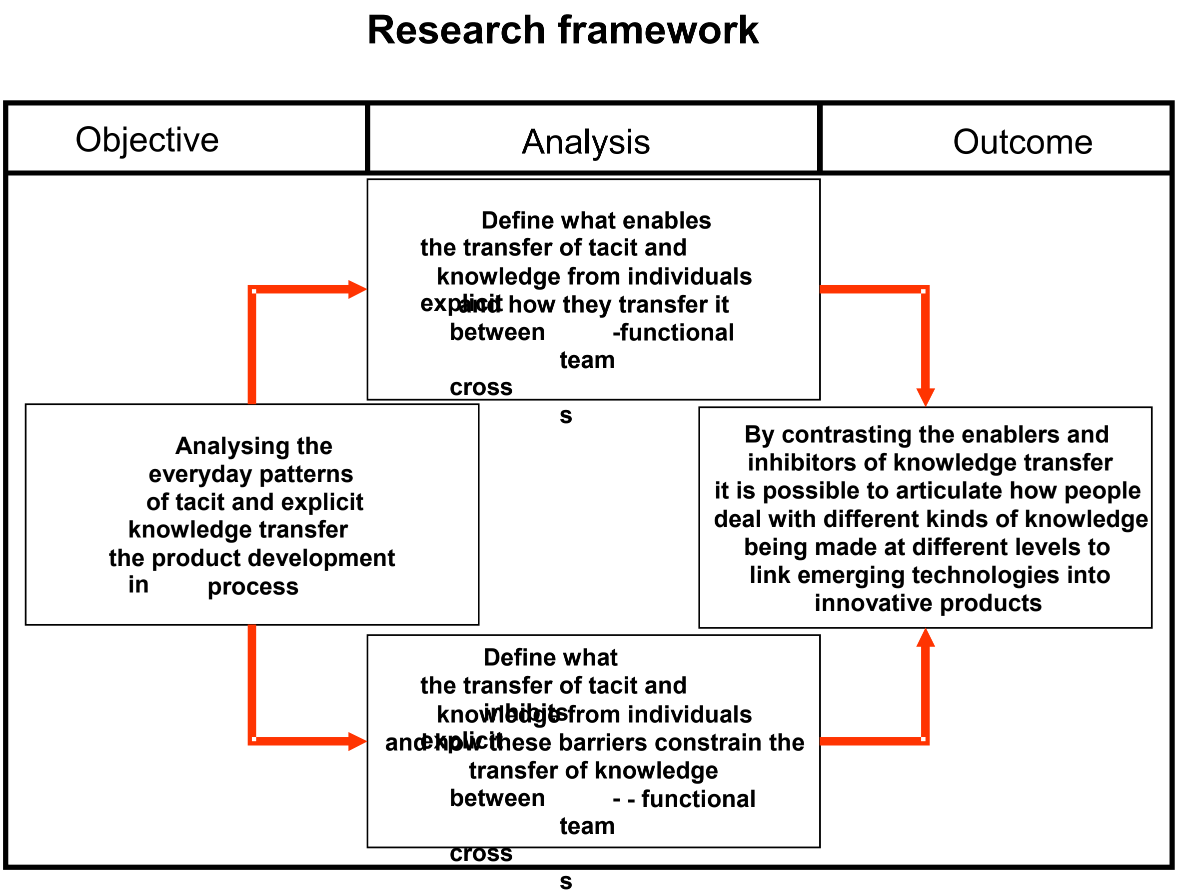
1.2 Research objectives

The research builds on three projects in the automotive industry, which aim to investigate how knowledge transfer takes place in new product development in the automotive industry.

The challenge in product development projects is to manage the transfer of domain-specific expertise, still created in functional departments, between various engineering disciplines. Today a vehicle development process requires a cross-functional team that can create collective expertise from individual expertise. From this perspective, engineers are forced to combine high functional expertise of different engineering disciplines, which requires a high degree of coordination between different departments in a company. Such combination and integration of expertise into the product development process is generated by means of knowledge transfer activities.

The focus of project one was to understand knowledge transfer activities in new vehicle development processes. Therefore, I used a retrospective case study method to explore what enables knowledge transfer and what inhibits knowledge transfer in new product development. To explore the transfer of knowledge between cross-functional teams, I draw down following research framework for project one:

Figure 1: Research framework – project one



In my research framework I used the following steps to identify and analyse the transfer of tacit and explicit knowledge in the product development process:

1. *Define what enables the transfer of tacit and explicit knowledge from individuals and how they transfer it between cross-functional teams.*

2. *Define what inhibits the transfer of tacit and explicit knowledge from individuals and how these barriers constrain the transfer of knowledge between cross-functional teams.*

3. *By contrasting the enablers and inhibitors of knowledge transfer it is possible to articulate how people deal with different kinds of knowledge being created at different levels, to link emerging technologies into innovative products.*

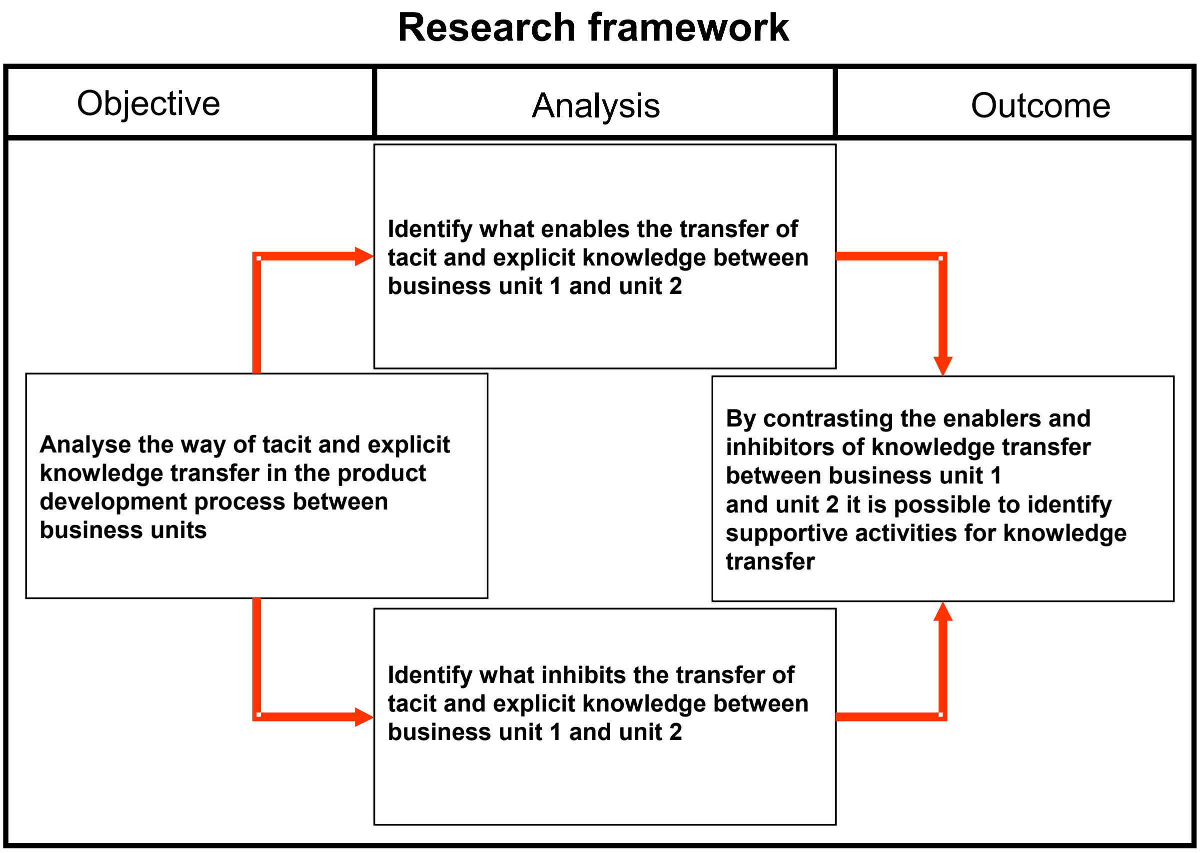
On the surface, engineering design knowledge appears to be concrete and declarable, but in reality we know that this externalised knowledge is not sufficient for new product development processes.

The study showed that the way knowledge is transferred during the vehicle development process strongly depends on the sort of design tasks engineers are required to solve. In the concept and technology phase of the product development process, where engineers are engaged with product concepts and new technologies, tacit knowledge transfer dominates. This is referred to hereafter as the tacit domain, because of this, the key enablers of tacit transfer and the activities that foster tacit knowledge exchange are the resources required for a value creation potential in the product development process.

In contrast, when the product development process moves into phase two, where engineers mainly engaged with product engineering and feasibility studies of process technologies, explicit knowledge transfer is heavily relied on. (This will be referred to as the explicit domain, in this study). For that reason the key enablers of explicit knowledge transfer and the activities to foster explicit knowledge exchange are the resources for a value creation potential in the product development process.

I used the finding of project one to frame project two. Similar to project one, I have used a case study method for data collection and subsequent validation, but the first differing point is, that project two was a contemporary study of the product development project and not a retrospective study as it used to be in project one. In project two, teams were geographically dispersed, so that knowledge transfer took place between different business units. This made management meetings and other ways of knowledge transfer more complicated. To explore the transfer of knowledge between these two business units, possessing different pools of expertise, I used following research framework for project two:

Figure 2: Research framework – project two



I used the framework shown in (figure 2) to identify and analyse the transfer of tacit and explicit knowledge in the product development process between business units.
By contrasting the enablers and inhibitors of knowledge transfer through the life cycle of project two, it was possible to identify major enablers and inhibitors of knowledge transfer. The knowledge combination and knowledge transfer processes are influenced constructively (by means of enablers), or destructively (by means of inhibitors). To understand the impact of enablers and inhibitors and their interdependence in relation to the knowledge transfer process, it is important to investigate them within major engineering tasks and objectives, to see when and why they come to light and what role they played in the product development process.

The challenge, in general, is that the crucial product design knowledge is usually not available in a readily retrievable format. Knowledge with both explicit and tacit elements is required. Project two put on view, how multicultural teams work together and manage the exchange of expertise to create a product that integrates new and sophisticated technologies.

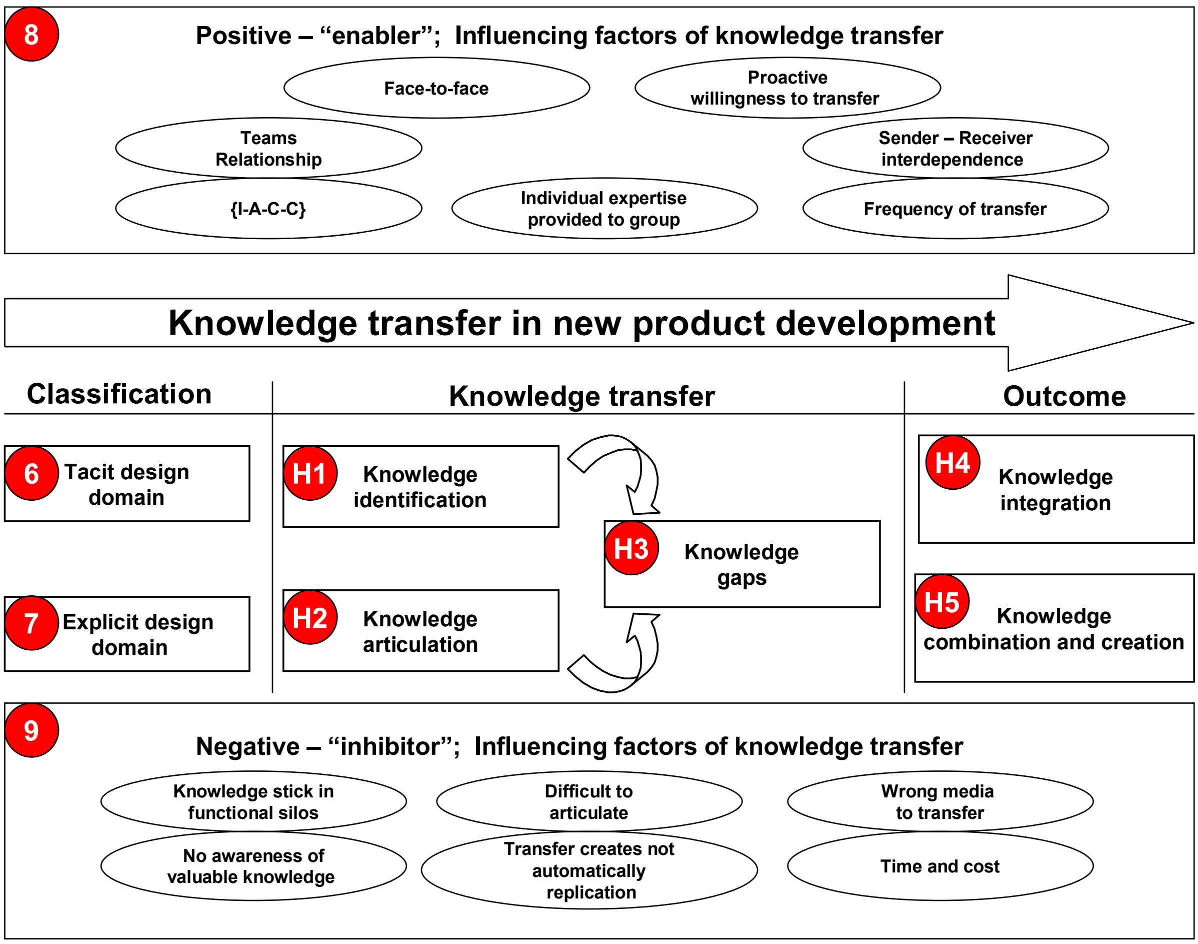
Taking note of the findings from projects one and two, I developed a model of knowledge transfer in new product development (figure 3), which integrates enablers and inhibitors related to the process of knowledge transfer in new product development.

The figure illustrates nine key factors affecting knowledge transfer in new product development activities.

Based on projects one and two, it is evident that successful knowledge transfer needs to classify to what degree relevant design knowledge is embedded in the tacit [6] or explicit [7] design domain. This strongly influences how hard it is to identify required knowledge and provide this to your development partners.

Knowledge identification [H1] and knowledge articulation [H2] are domains which are essential to share and combine knowledge for new product development activities. How difficult it is to identify and articulate knowledge can be assessed with a perspective on knowledge gaps [H3] in new product development processes.

Figure 3: Knowledge transfer in new product development – project three



The key question here is, is the product development team able to speak a common language in the product development process, or is the knowledge, provided and required, hardly understood between different engineering disciplines? The success of knowledge transfer activities relies very much on how provided knowledge is used and integrated [H4] by the development partner in need of this specific knowledge. Combining provided knowledge with existing knowledge creates new knowledge [H5] and if this specific knowledge is used in a tangible form, new technologies are implemented in the product development process.

The model of knowledge transfer in new product development (figure 3) is influenced by many factors identified in research project one and two as enablers [8] and inhibitors [9] of knowledge transfer. In those projects, I found that product development activities can be seen as transactions that are integrated into an overall system of identifying, assessing, collecting and combining knowledge, and the main output of this complex processing scheme is not a physical product, but a knowledge base about the new product.

Therefore, project three sets out to explore, using hypothesis one [H1], how knowledge is identified and integrated into the vehicle development process between development partners. Additionally, knowledge transfer success is also influenced by the extent to which knowledge can be verbalised, written, or otherwise articulated in the product development process. This subject is investigated in hypothesis two [H2] of this project.

The concept of a knowledge gap has been discussed by a number of researchers with respect to its potential impact on knowledge transfer (Hamel, 1991; Lane and Lubatkin, 1998; Dinur, 1998; Nonaka and Takeuchi, 1995). Hypothesis three [H3] focus on the impact of knowledge gaps and their influence in the knowledge transfer process for new product development processes.

Successful knowledge transfer takes only place if knowledge provided is integrated and implicated in the new product development project, which is explored in hypothesis four [H4].

Further, I plan to explore, using hypothesis five [H5], to what degree generated knowledge is integrated into new product development activities and to what degree it is reused.
The research envisages that product developers who are able to implement knowledge transfer and knowledge creation as a management discipline in their development process will be able to enhance their capabilities to create innovate products.

1.3 Research methodology

The first two projects sought to picture how product development teams frame and shape new product knowledge, and how they interpret such knowledge and apply it to the product development process.

To understand the knowledge transfer process and to visualise the power of enablers and inhibitors related to knowledge transfer, I used the case study method for data collection and subsequent validation in projects one and two.

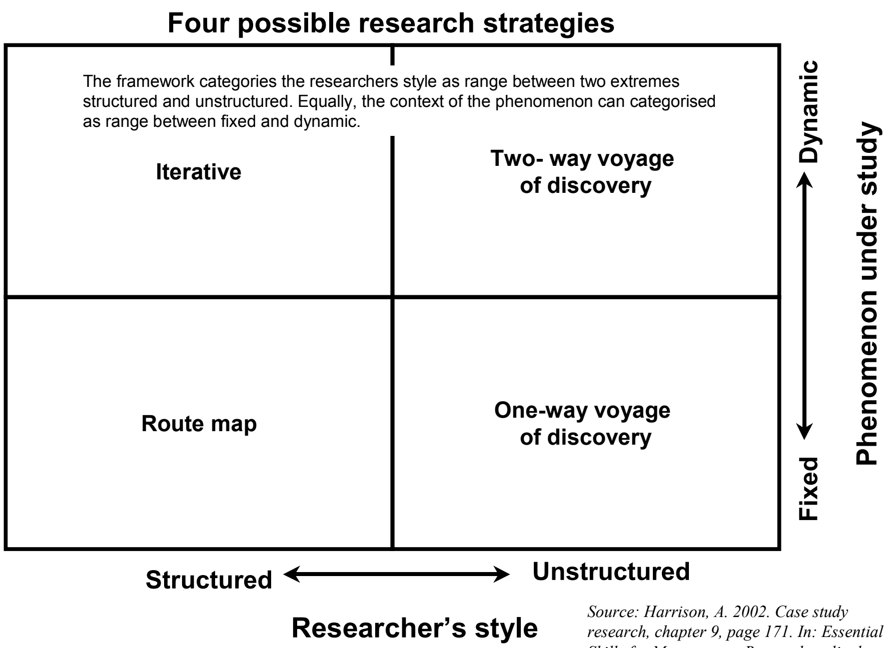
As Harrison (2002, p. 159) puts it, “case study research is of particular value where the theory base is comparatively weak and the environment under study is messy.” Both of these criteria were relevant to my research theme too.

By determining that the focus of the research is the knowledge transfer process in product development projects, I was able to select the right case to study.

Best case in practice actually means not only the best environment for exhibiting the phenomenon under study, but also the best from a point of view of ease of access and of management support (Harrison 2002, p. 171). Projects one and two took place in organisations, which I know very well, that saved a lot of time to identify the contacts for essential data collection.

To find my position as a researcher and to tackle the riches of data, I used the framework illustrated in (figure 4), to define the fit between the research style and the context of the phenomenon.

Figure 4: Research strategies and researchers style



Source: Harrison, A. 2002. Case study research, chapter 9, page 171. In: Essential Skills for Management Research , edited by David Partington, Sage Publications

With the framework, I was able to categorise the context of the phenomenon of projects one and two between the range of two extremes, which can verify between fixed and dynamic phenomenon's (Harrison 2002):

- *Fixed:* In project one the phenomenon is comparatively stable. By research start, the vehicle development process was already finished, so effects of uncertainty during the product development project have settled down. With a retrospective study, I had the opportunity to evaluate, based on past experience of the engineers engaged in project one, how knowledge was transferred.

- *Dynamic:* In project two the phenomenon under study is developing rapidly. By research start, the product development process was still in progress, so uncertainty about the project outcome was still evident. The technical complexity of the advanced floor module and the geographical distance created a more challenging role in identifying and assessing the relevant data to investigate how knowledge was exchanged between different business units and between different functional departments, in project two. With a contemporary study and a less structured research framework, I investigated in project two the knowledge transfer process between business units.

A second important point is the fit between the research style and the context of the phenomenon under study (Harrison 2002, p. 170). The researchers style could be broadly categorised as a range between two extremes, a structured or unstructured approach.

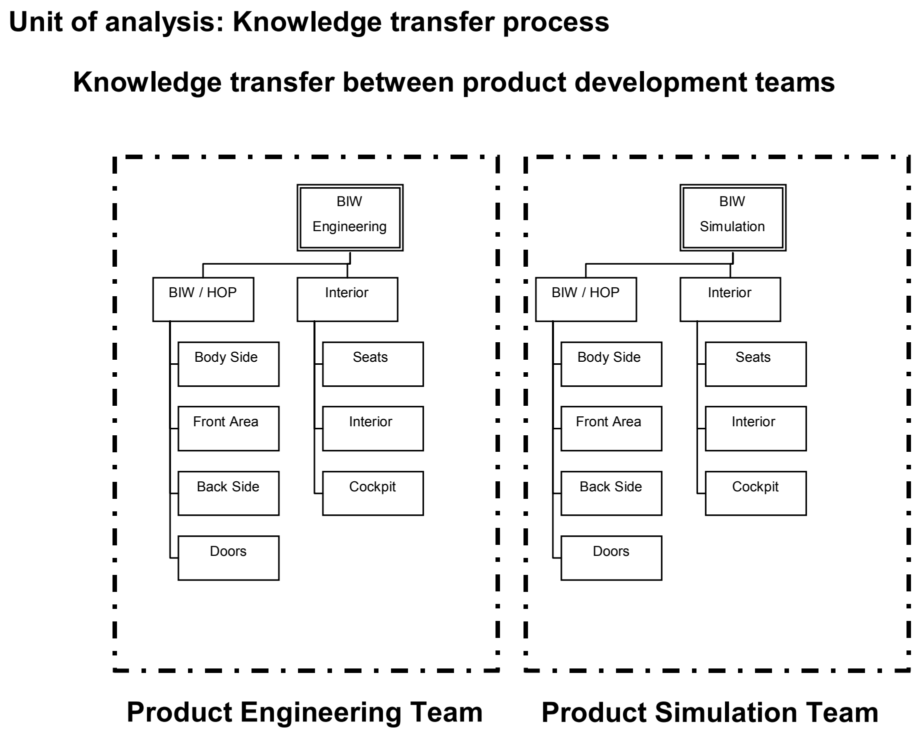
- *Structured:* As Harrison (2002, p.170) puts it, " the researcher develops a detailed game plan in the research design, identifying all of variables against which data will be collected, together with an interview framework and possible coding scheme". For example, I used for project one a structured interview with open ended questions, in order to allow the participants to respond of their own violation, free of the potential influence of preconceived answers. The research questions described in (chapter 2.3 and appendix one).
- *Unstructured:* As Harrison (2002, p.170) puts it, " the researcher chooses not to make any detailed game plan, but to view the research as a voyage of discovery, which have should have no preconceived format that may otherwise act as a restriction to what is observed. For example, I used for project two a more unstructured approach as in

project one to investigate the dynamics of knowledge transfer. I collected data for this study from several sources; interviews, e-mail communication, minutes of meetings and my own participation in the project. I interviewed 8 engineers and I used a structured interview with open-ended questions (described in chapter 3.1.4 and appendix two). The interview questions focused on developing an overall understanding of the process of knowledge transfer between business units engaged with new product development activities. Out of the interviews I was able to identify different cause and effects of major design tasks during the product development process. To identify the right case examples of major design tasks, I used additional to interviews e-mail communication and minutes of meetings. The major purpose to use this additional source of information was to select relevant examples of knowledge transfer during the product development process in relation to the technical complexity. The minutes of meetings were a valuable source to identify the major design steps and objectives from a technical context. In project two the main objective was to substitute the conventional floor pan of a car with a sheet moulding floor module to reduce number of parts and allow vehicle platforms to vary in length and width. To understand and explore why several enablers and inhibitors played a significant role it was important to select and compare design tasks containing simple and complex product development steps. To frame and describe specific design tasks, I used in project two, twelve minutes of meetings of design reviews and scanned approximately hundred e-mails related to the design reviews in detail described in (chapter 3.2.2 – chapter 3.2.4).

Case orientated research is based on the application of multiple methods, structured interviews, field studies and surveys are possible methods which can be deployed under the case study banner. Throughout the data gathering process it is important to keep the research under control. Does this data make sense? – against my research objective and existing theory. To keep the data gathering process aligned to research objective, it is important to clearly keep in mind the unit of analysis.

The unit of analysis (figure 5) in project one is the knowledge transfer process between the product engineering team and the product simulation team, who are between them responsible for three main modules; body structure module, body exterior module and interior module.

Figure 5: Unit of analysis – project one



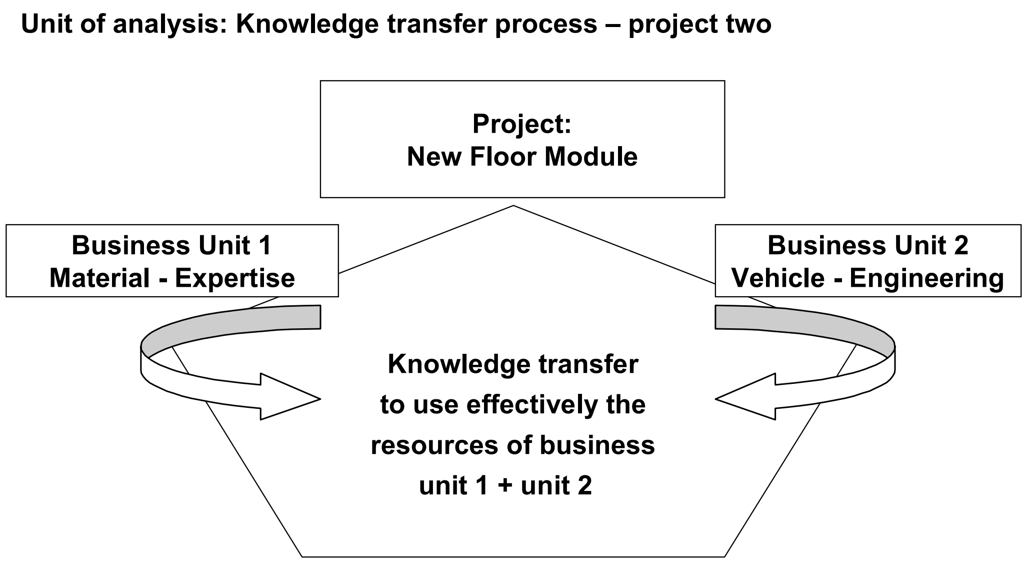
The unit of analysis assists to identify, the right data collection method. It helps to identify the informants of different functional areas and provides a control mode related to the research objective. The sampling of data collection must reflect a balanced picture of the investigated case. Therefore I interviewed all informants from all twenty project groups.

Additional the unit of analysis helps to answer the key question, what is / what is not included in the research objective. This is very important if the phenomenon under study is developing, for example as it used to be in research project two.

The unit of analysis of project two shown in (figure 6) is the knowledge transfer process between business units belonging to the same parent company, (a tier one supplier in the automotive industry).

The team, which was created out of both business units, is engaged with the task of developing a vehicle floor module, which should have the advantage of extending the platform variable in length and width, and additionally improve the integration of functionality, such as channels for wire and harness, carpet and acoustic systems already integrated in the floor module.
All these features would enhance the functionality and also reduce costs, in comparison to a conventional vehicle floor system.

Figure 6: Unit of analysis – project two



Similar to project one is the unit of analysis the knowledge transfer process, but the product development team is geographical dispersed and founded out of two different business units. To build on project one, I used for project two the same research framework (figure 2) and a similar data collection method and coding procedure for the interviews. Additional my personal engagement with the project two was over a year, so that observations at any time during the course of the project were likely to be witnessed due to my active role in the project.

During the data analysis I read interview transcripts, created notes out of e-mail conversations and meeting minutes, and scanned through documents of design reviews looking for themes and patterns (Milles and Hubermann, 1994).

First, I coded all data into a number of categories according to the proposed theoretical model (Yin, 1994). These categories are enablers and inhibitors of knowledge transfer. Then I created subcategories using classifications identified in project one, and which also emerged in project two from informant descriptions.

For example, time and financial resources were grouped into economical constraints and were identified as inhibitor in project two.

Figure 7: Example of data coding and categories – project two

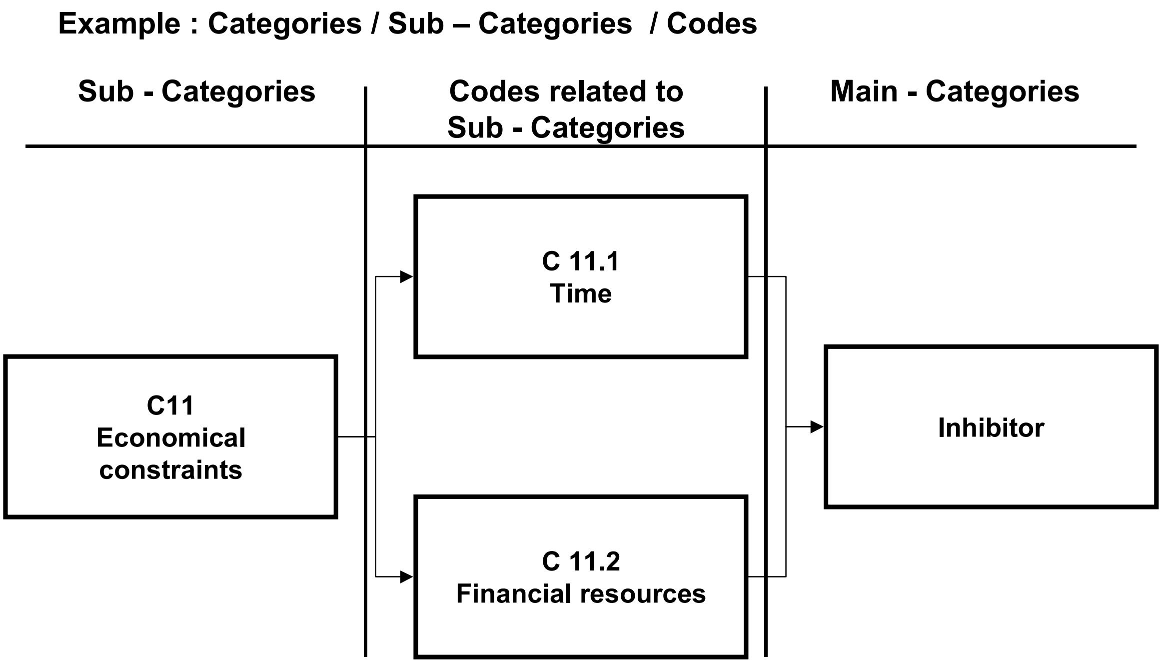


Figure 7, combined with following description, explains how the interview transcriptions were used to identify codes related to subcategories and classified them into the main categories of enabler or inhibitor of knowledge transfer.

Example of interview question – project two:

In what ways was knowledge transferred between business unit one and business unit two?

Interviewee's statement:

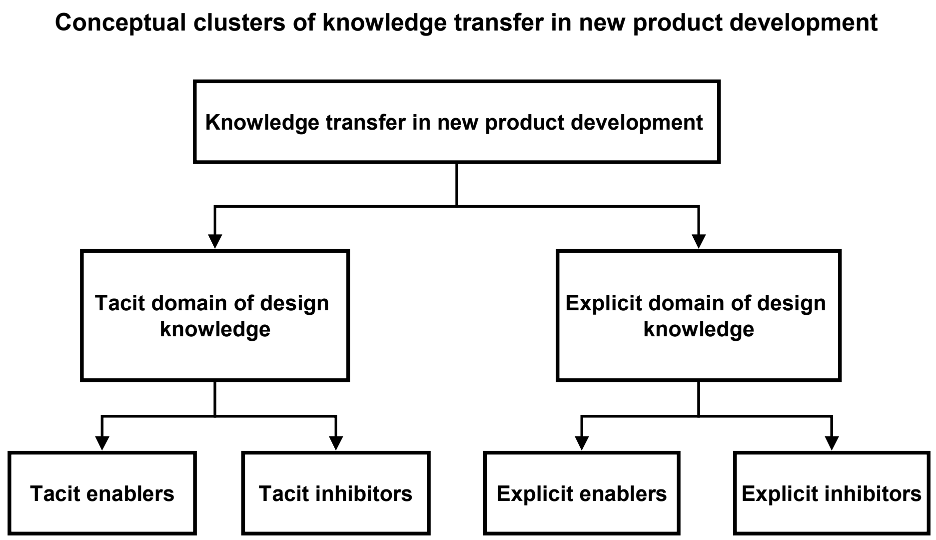
Several management meetings are essential, to determine the expertise possessed in the business units and to align resources to project objectives. In this phase, we found out how difficult it is to reapply team and individuals knowledge at distance. Time consuming (C11.1) co-ordination of management meetings, taking into account that many key players are engaged in several projects of their parenting unit as well. Also financial resources put an upper limit (C11.2) on what you can expect from the knowledge transfer processes. Management Meeting (face-to-face) are perceived as one of the strongest activities to transfer expertise, but to create a knowledge flow based only on face-to-face contact would increase the project costs to a level, no one likes to pay. (C11.2)

As shown in (figure 7), engineers perceived time consuming activities and limited financial resources as inhibitors of knowledge transfer. These expressions are classified in main categories, subcategories and codes related to subcategories. Table P2.1 provides an overview of categories, subcategories and codes related to subcategories.

As the study progressed, I sorted these statements (available in detail in appendix two) and grouped them to arrive at conceptual clusters (Berg, 1989). Conceptual clusters are sets of closely related analytic ideas.

In project two, I identified two conceptual clusters (figure 8) of knowledge transfer in new product development projects. Firstly, complex design tasks rely more on a tacit domain of design knowledge and are therefore more strongly influenced by tacit enablers and inhibitors. On the other hand basic design tasks, for example described in technical specifications, rely more on an explicit domain of design knowledge and therefore they are more influenced by explicit enabler and inhibitors.

Figure 8: Conceptual cluster of knowledge transfer – project two



I systematically compared the emergent theoretical interpretations contained in codes and categories with the evidence from several case examples investigated in project two, in order to assess how well or poorly they fit the case data (Eisenhardt, 1989).

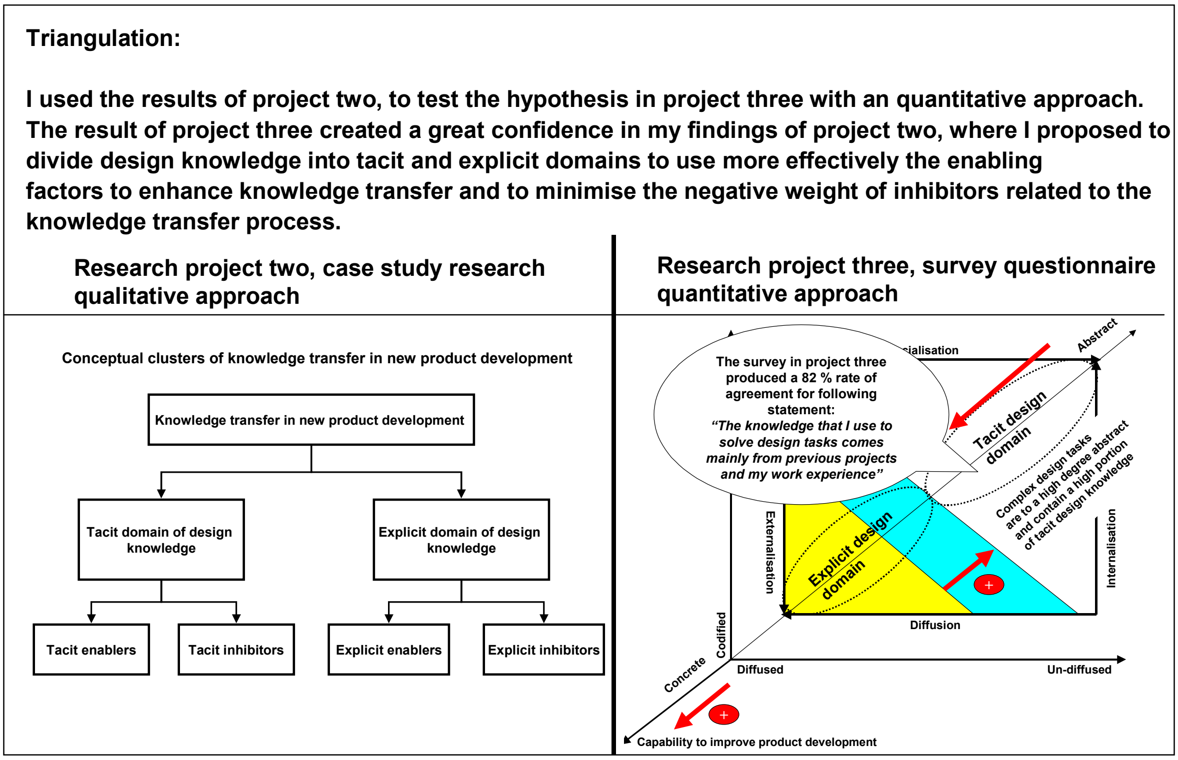
This iterative process of comparing theory and data led to a detailed description of the dynamics of knowledge transfer in new product development projects. To test the credibility of my findings, I checked my emerging insights on an ongoing basis with my informants, through several meetings and informal face-to-face discussions (Hirschmann, 1986; Lincoln und Guba, 1985). These member checks served to revise and sharpen the findings discussed in detail in research projects one and two.

In project three I used a survey questionnaire approach to test the hypotheses that were framed out of the case study research results of project one and project two.

Many management research textbooks refer to the advantages of mixing quantitative and qualitative approaches. However, the use of multiple methods, or triangulation, reflects to secure an in-depth understanding of the phenomenon and researcher can be more confident of their results (Jick 1979, p. 608).

As a researcher I made the same experience (figure 9), that my qualitative findings out of project two are clearly supported by the quantitative approach I used in project three.

Figure 9: Triangulation, application of multiple methods - project three



In project two, I propose to divide design tasks into two domains depending on their level of explicitness and tacitness (figure P2.10). Design tasks with higher demands on tacit skills are more influenced by tacit enablers and inhibitors. On the other hand design tasks with higher demand on explicit skills, are more influenced by explicit enablers and inhibitors.

While I was unable to develop statistical evidence in project two, case examples show the enormous effort that we invested in knowledge transfer of complex design tasks.

The survey results of project three (figure 9) supports my previous findings that knowledge for new product development activities is mainly embedded in the tacit design domain. For example engineers produced in the survey a 82 % rate of agreement with the statement that they use mainly knowledge that comes from their past work experience as product developers, in order to solve complex design tasks. The underlying assumption of this finding is, that engineers are therefore mostly forced to transfer tacit design knowledge to solve complex design tasks.

Additional, project two shows that most of the knowledge needed to solve complex design tasks must be individually developed to cope with specific design tasks. For that reason the identification, combination and presentation of knowledge is an active process that depends on the willingness of the engineers involved. Therefore to support the transfer of tacit design knowledge, product decision makers must create an environment that facilitates interaction and collaboration to share knowledge embedded in individuals as their experience and expertise.

As a consequence of these findings, product developers must be aware that engineers confronted with complex design tasks in automotive development use mainly tacit knowledge to develop new solutions for new product development.

To create a convergence between qualitative findings of project one and two, with the quantitative research method of project three it was very important to target a population of engineers in project three that have participated in similar product development projects to those where the case studies took place.

Both the project one and project two case studies took place in major automotive engineering companies, which are in a direct cooperation with major automotive manufacturers.

Both surveyed companies in project three are product development partners of BMW, a Bavarian Automotive Manufacturer, very well known for its premium brands. These companies are engaged in vehicle development contracts with market launch scheduled in three or four years time from now.

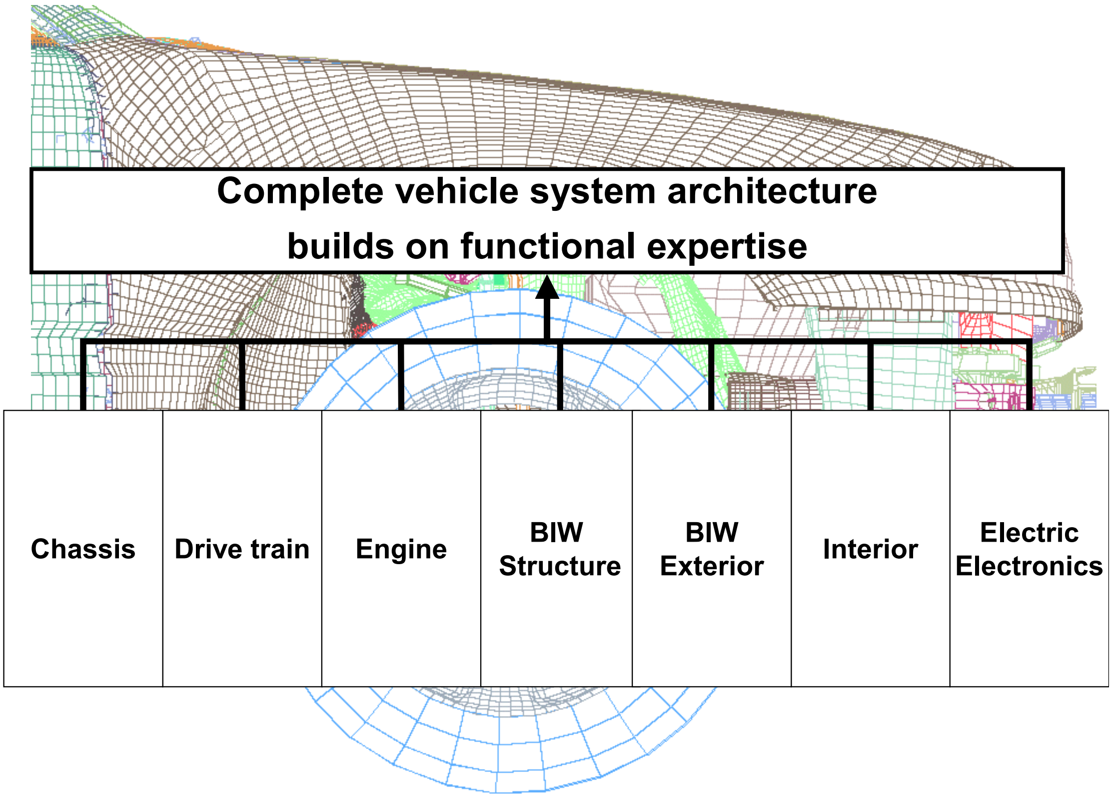
Unlike to a classic mail survey , I used my personal contacts to the managing directors of EDF Engineering and Magna Engineering to provide the engineers personally with the questionnaires.

The unit of analysis for testing the hypothesis in project three is the individual, and all measures reflect the engineer's perceptions of and experiences with knowledge transfer activities in the new product development process in the automotive industry.

1.4 Research projects

The research project one is based on a recently finished vehicle development project, which was outsourced by an OEM to an engineering service house. Vehicle development is a process where engineers create a shared understanding of how the vehicle should perform and look. Vehicle engineering is an activity that links emerging technologies with existing technologies to create improved, or even new, components. From these components modules (figure 10) are developed and from these modules a new vehicle is generated. This is not a simple matter of snapping parts together; it contains the intensive transfer of tacit versus explicit knowledge between different functional areas.

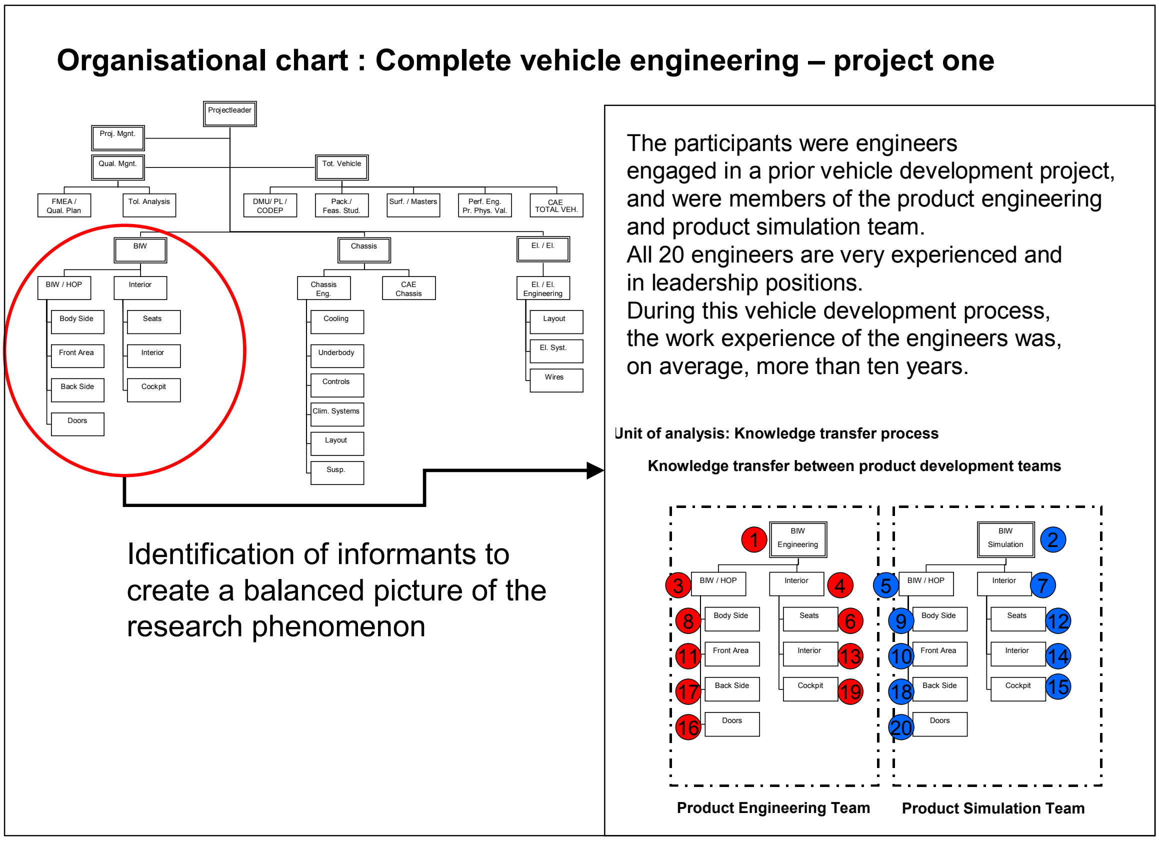
Figure 10: Complete vehicle system architecture – project one



Cross-functional teams of various engineering disciplines are part of this vehicle development process and this interaction indicates a complexity in technology and human interaction. The challenge for knowledge transfer is to understand how people share different domain-specific knowledge and bundle it together in cross-functional activities.

From this point of view, it was important to ensure variety in the study, therefore I selected the informants from different engineering disciplines (figure 11), to secure a balanced view of the researched phenomenon.

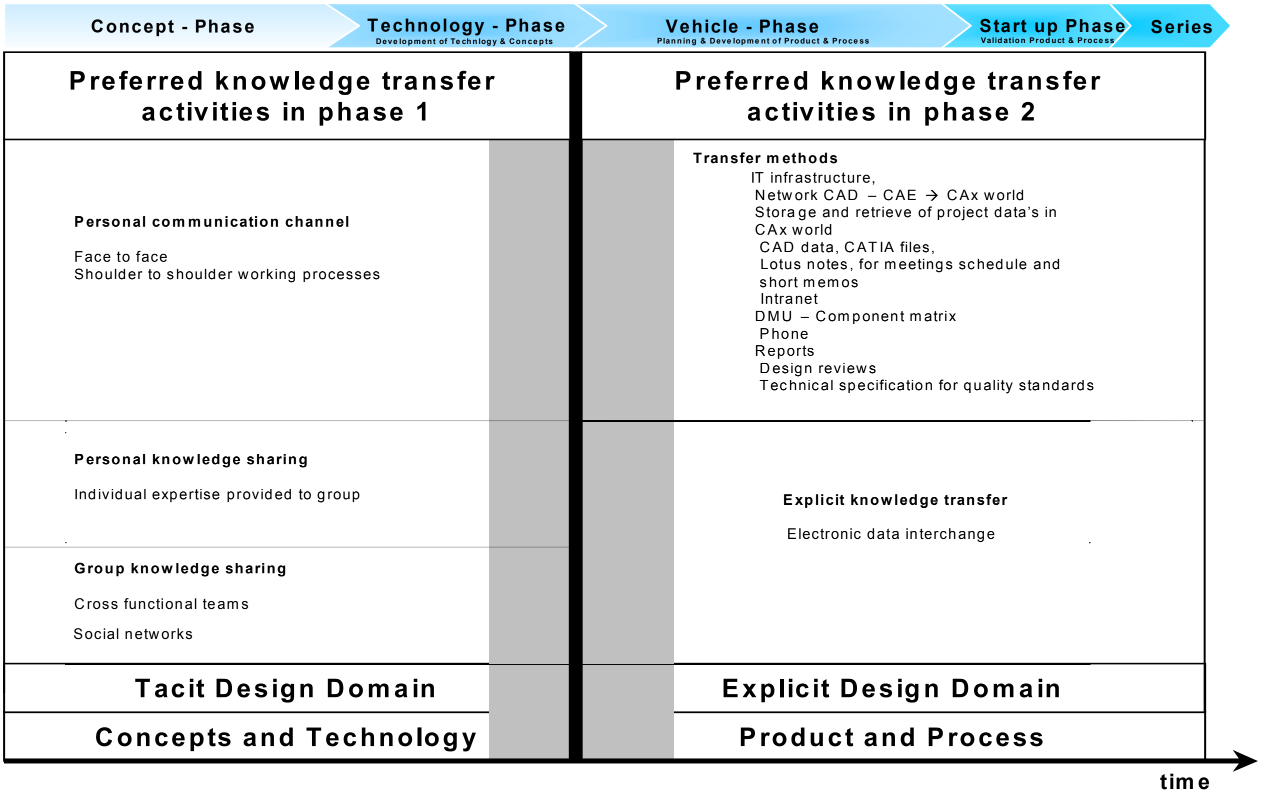
Figure 11: Selecting the informants to create a balanced view of the researched phenomenon - project one



With a structured interview (chapter 2.3), meeting minutes, reports and e-mail communications, I identified key enablers and inhibitors (table P1.1) of knowledge transfer between product development teams, and evaluated their influence on the knowledge transfer process. The most prevailing finding in project one demonstrates that the methods by which knowledge is transferred change during the vehicle development process (figure 12).
As shown in (figure 12), in the concept and technology phase of the product development process, where engineers are engaged with the product concept and new technologies (referred to as the tacit design domain in my research); tacit knowledge transfer dominates and so the key enablers of tacit transfer and the activities to foster tacit knowledge exchange are the resources for a value creation potential in the product development process (figure 18).

In this phase of the product development process an environment for tacit knowledge sharing would enhance the product development process; the key is to facilitate knowledge transformation across different engineering disciplines identified as enablers of knowledge transfer in the research project (table P1.1). The research shows that if the vehicle development process reaches phase two, where most of the interfaces are clearly defined, knowledge transfer is very efficient and process orientated. In this phase the main focus is on product and process engineering. An environment that creates an optimised exchange of explicit knowledge, which is supported by advanced information technology to store and accumulate explicit knowledge between product development teams, will be the source for a value creation potential in the product development process.

Figure 12: Knowledge transfer in vehicle development process related to the life cycle of the product development process – project one



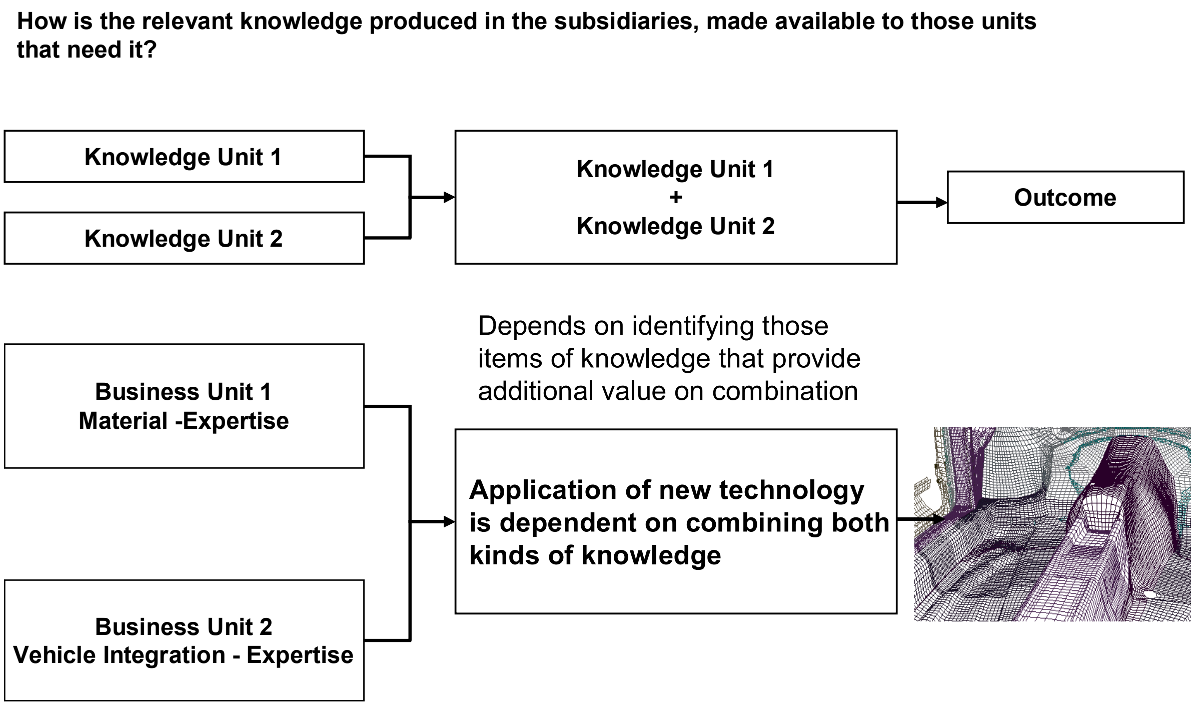
Certainly there is no clear borderline between the tacit domain and explicit domain of design knowledge, as it is simplified shown in (figure 12), but a clear outcome of the research is that, in the tacit domain, engineers strongly favour shoulder-to-shoulder working processes, and face-to-face meetings as the most efficient approaches to make tacit knowledge available to other team members and transferring it, as a next step, between different functional teams. This finding is in line with the theory of Takeuchi and Nonaka (1995), which explores knowledge creation through conversion between tacit and explicit knowledge.

Additional this finding had an influence to select the next case, to investigate, what it means to integrate a systematic approach of knowledge transfer; how engineers try to implement a methodology to break down complex knowledge requirement into receiver

needs. This involved tackling the challenge of transferring knowledge containing explicit and tacit elements, and how engineers combine knowledge to create a new knowledge base. Similar to project one, project two takes also place in the automotive sector.
The project team, combined from both business units (figure 13), belonging to the same parent company, (a tier one supplier in the automotive industry), was engaged to develop a new concept for a vehicle floor module. This module would allow vehicle platforms to vary in length and width, and should integrate channels for wire and harness and aircon systems.

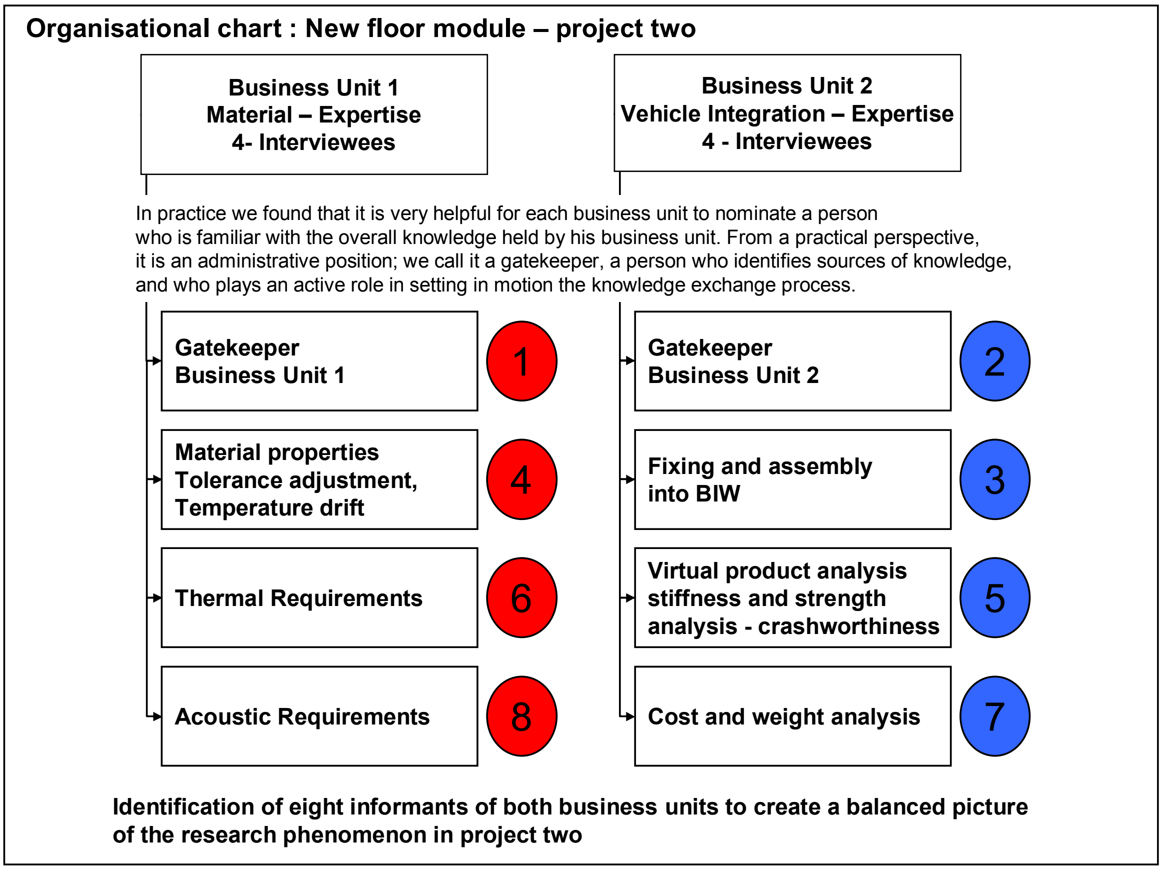
All these features would enhance the functionality and reduce cost, because the number of single components would be reduced in comparison to a conventional vehicle floor system.

Figure 13: Combination of knowledge between business units – project two



From the research strategy it is important to identify enablers and inhibitors of knowledge transfer and their impact on the knowledge transfer process, in order to investigate their positive impact and negative constraints for knowledge exchange and knowledge creation between business units.
Similar to project one it is important to ensure variety in the study, therefore I selected the informants from both business units (figure 14), to secure a balanced view of the researched phenomenon.

Figure 14: Selecting the informants to create a balanced view of the researched phenomenon - project two



To investigate the dynamics of knowledge transfer, I collected data for project two from several sources; interviews, e-mail communication, minutes of meetings and my own participation in the project. Interviews commonly lasted from 60 to 90 minutes.

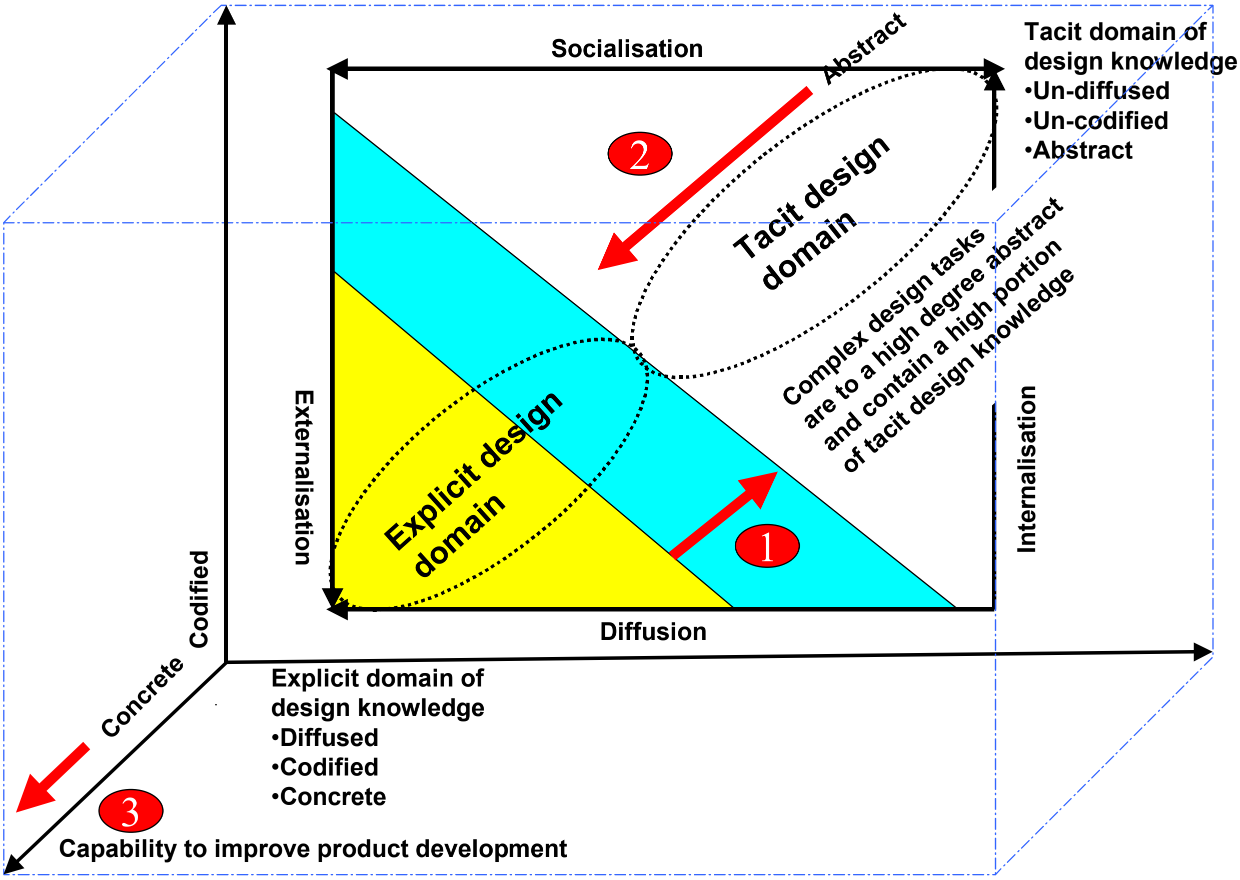
I interviewed 8 engineers and I used a structured interview with open-ended questions (described in appendix two and chapter 3.1.4).

All 8 engineers (figure 14) were very experienced and were tasked with tracking the project to the agreed technical specification, which was defined at the concept and resource allocation phase.

Based on my research findings, I developed a theoretical framework (figure 15), where I propose that knowledge can be represented in tacit or explicit domains. Complex design tasks are a combination of both domains but to be successful completed, they rely more on the tacit domain of design knowledge.

To structure in a conceptual framework around why successful knowledge transfer increases the capabilities of a firm to improve product development, I defined the position of tacit design knowledge and explicit design knowledge in the knowledge space.

Figure 15: Using knowledge transfer to create the capabilities to improve product development – project two



As it is illustrated in (figure 15), the primary characteristics of the tacit design domain are that it is un-diffused, un-codified and abstract. On the other hand the explicit design domain is diffused, codified and concrete.

- *Externalisation* describes the codification of tacit knowledge, it is one way to transform tacit into explicit knowledge.
- *Socialisation* describes the process to pass tacit knowledge on to others, for example face-to-face contact and shoulder-to-shoulder working processes are effective facilitators of tacit knowledge transfer. If tacit knowledge is transferred to others, a kind of codification and externalisation occurs. Additionally, this knowledge is available for new applications. Engineers use this knowledge to form new ideas and explicit knowledge becomes the platform for new tacit knowledge - internalisation takes place. Therefore socialisation takes place in both directions it transforms tacit knowledge into explicit knowledge and on the other hand explicit knowledge can be

the basis for new thoughts and builds new tacit knowledge in the product development process.

- *Internalisation* describes learning by doing, and documented knowledge can play a helpful role in this process. For example technical specifications or design guidelines are useful to support the product development process.
- *Diffusion* identifies the degree to which the knowledge has been communicated. A particular act of diffusion may have many potential audiences: in a product development project your audience is on a cross-functional level, owning different fields of expertise.
- *Abstract – Concrete axis* identifies the degree of improvement potential. If you achieve a common understanding over socialisation and diffusion, abstract design tasks are transformed into concrete design tasks and therefore they are understood by a broader audience, which helps to increase the capabilities to improve product development.

Based on the conceptual framework, we have three paths to improve product development over knowledge transfer (figure 15).

Firstly, to expand the explicit design dimension, tacit knowledge must be transferred and "come to live" in the product development team. Recognising this objective, it is obvious that the right use of enabling factors will enhance the knowledge transfer process.

On the other hand knowing, for particular procedures, what role the inhibitors played in the product development process, helps to minimise their negative weight on knowledge transfer processes. Using the effects of enablers and inhibitors of knowledge transfer in the knowledge space to expand the explicit design domain is intensively discussed in (table P2.17).

Figure 15 and (figure P2.16) illustrate why knowledge transfer builds on diffusion, socialisation, externalisation and internalisation, and how they facilitate in expanding the explicit design domain.

Innovative products hold a higher degree of tacit design knowledge than commodity products. Based on this assumption, it is apparent how important it is to transfer tacit design knowledge to others, thus making complex design tasks more concrete. Engineers of different engineering disciplines are able to understand the requirements in a broader context. This creates the basis to implement new technologies into products and additionally, this shared knowledge base gives birth to new findings. In other words the capabilities to improve the product development has increased, which is illustrated as the third path in the conceptual framework (figure 15). I would not claim that this theoretical framework is the recipe for generating product successful products.

A clear limitation is that complex design knowledge is not static, it is linked to the life cycle of the product development process and therefore it is continuous rebuilt.

It is recognised in the research that externalisation of knowledge embedded in the tacit design domain faces a fundamental limitation: not all tacit design knowledge is capable of being codified, because it is a continuous activity of knowing", (Nonaka 1994).

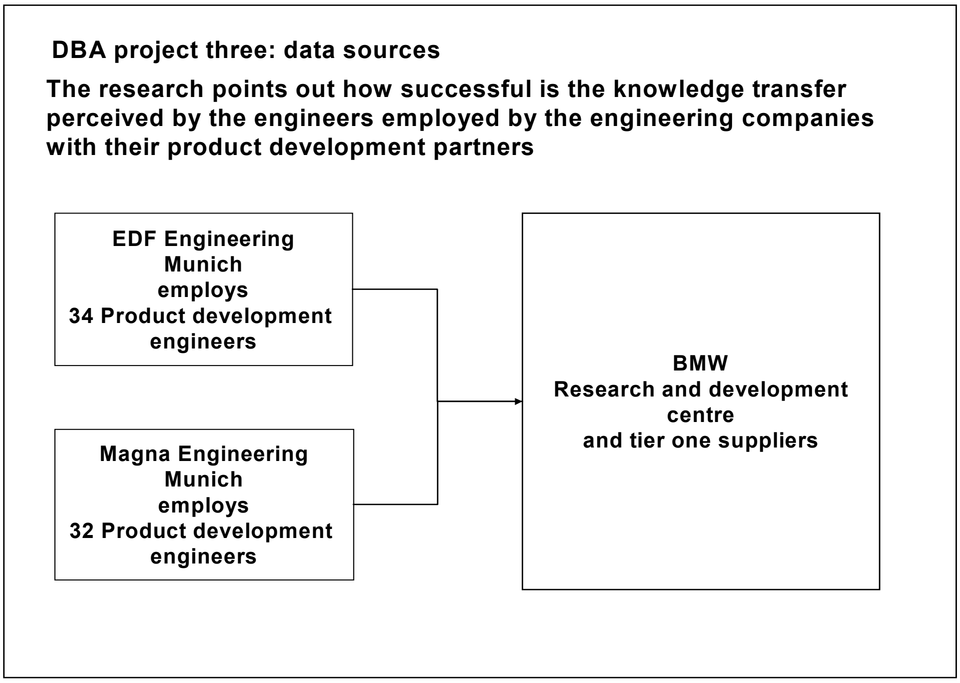
In contrast to its limitation gives the framework product developers a tool to use several tactics to enhance knowledge transfer. The framework helps to classify, what knowledge we need to close technological gaps and how realistic it is to transfer this sort of knowledge.

By classifying the design tasks in explicit and tacit domains, product developers will gain insight as to how, whom, where and when should they co-locate, to implement tacit design knowledge into product development process.

Another important issue is that product decision makers can use the framework to define how, to what extent, they should share product development knowledge with their external partners to facilitate product innovation.

Taking note of the findings from projects one and two, I use project three, to explore how knowledge is identified, articulated and integrated into the vehicle development process between development partners, with the aim to combine and create new knowledge for innovative products. Based on projects one and two, it is evident that successful knowledge transfer needs to classify to what degree relevant design knowledge is embedded in the tacit or explicit design domain. This strongly influences how hard it is to identify required knowledge and provide this to your development partners. A major challenge for product developers is to transfer intangible ideas and findings, and here we face the difficulty of a successful knowledge transfer process, because the knowledge used in the product development process is not static. Rather it develops under dynamic conditions, due to the fact that product development is a continuous process of improvement, design trade offs and new learning loops. Knowledge is embedded in people and the domain specific expertise they posses. In order to release this expertise and share it among others involved in product development activities, communication tools and social networks are used to transfer and share this expertise. Therefore, I used project three to explore, how knowledge is identified, articulated and integrated into the vehicle development process between development partners, with the aim to combine and create new knowledge for successful products.

Figure 16: Knowledge transfer between product development partner – project three



To link my previous findings out of projects one and two with the hypothesis tested in project three, it was very important to target a population of engineers that have participated in similar product development projects as the companies, were the case studies took place.

Both companies (figure 16) where the survey took place are product development partners of BMW a Bavarian Automotive Manufacturer, and are engaged in vehicle development contracts similar to the companies, where research projects one and two took place.

Unlike to a classic mail survey , I used my personal contacts to the managing directors of EDF Engineering and Magna Engineering to provide the engineers personally with the questionnaires (see statements S1-S25 in table P3.1 to test the hypothesis 1-5).

The questionnaire used tick-box type questions, (figure P3.3 and appendix 3) and rating questions, whereby respondents could rate a particular issue ranging from negative to positive.

The extent of use of knowledge transfer practices was measured with a five-point Likert scale, where 0 represents completely disagree and 4 represents completely agree.

The unit of analysis for testing the hypothesis is the individual, and all measures reflect the engineer’s perceptions of and experiences with knowledge transfer activities in the new product development process in the automotive industry.

To combine and transfer knowledge in new product development, engineers must identify, articulate, collect and combine knowledge to create innovative solutions for complex products.

Project three demonstrates (chapter 4.4.3, table P3.5 and table P3.6) that knowledge identification and articulation is an intensive process of interactions between product developers. The knowledge for successful product development builds on a high degree of experience and therefore, to transfer this sort of knowledge intensive interaction, is necessary to articulate and transfer the knowledge mainly embedded in the tacit design domain.

Therefore successful new product development builds on the effective transfer of tacit design knowledge.

Such a process would entail the use of multiple presentations, discussions, and dialogues about the knowledge across multiple teams within both the engineers owning the knowledge and engineers in need of knowledge.

For example, if you prepare knowledge to meet receiver expectations (chapter 3.2), a kind of codification and diffusion takes place. Further, this knowledge is available for new applications. Engineers use this product knowledge base to form new ideas and explicit knowledge becomes the platform for new tacit knowledge internalisation takes place. This process is facilitated through knowledge identification and articulation: pre-knowledge creation takes place.

Identification and articulation of knowledge benefits from the interaction between teams, and provides the opportunity for the teams to put the knowledge into action. For example previous research has shown that role-playing or case-related activities, help to convert tacit knowledge into explicit knowledge (Nonaka, 1994) and reflective, *"learning by doing",* (Weick, 1979) is used by business strategy professors to transfer business strategy knowledge to students. This also in line with Nonaka and Takeuchi (1995) and their process model of knowledge creation. This builds on the crucial presupposition that human knowledge is created and enlarged by means of a social interaction between tacit and explicit knowledge. This interaction is called a knowledge conversion. It is further important to note that this conversion does not take place within individuals but between individuals within an organisation.

With respect to the research finding of project three that knowledge identification and articulation plays a significant role for successful knowledge transfer, the work of Cooper (1998) and Wheelwright and Clark (1992) is relevant. They found that companies with the desire to enhance the product development process are in need of people who are able to generate new products with existing systems, technologies, and market experiences. This is facilitated if the product development team is able to articulate a product concept to all members' involved, so sustained improvement in product development relies heavily on articulated knowledge.

This closes the loop with project two which put on view, that to expand the explicit design domain, tacit knowledge must be transferred and "come to live" in the product development team.

1.5 Research summary and contribution

All three research projects had the strategic aim to investigate how knowledge transfer takes place in new product development in the automotive industry. The challenge in product development projects is to manage the transfer of domain-specific expertise, still created in functional departments, between various engineering disciplines. Today a vehicle development process requires a cross-functional team able to create group expertise out of singular expertise.

From that perspective, engineers are forced to combine high functional expertise from different engineering disciplines, which requires a high degree of coordination between different company departments.

This combination and integration of expertise into the product development process is generated through knowledge transfer activities. Product development teams comprise experts from a wide variety of functions and disciplines and this diversity can create serious barriers for a common understanding. Team members come from different disciplines and even from different organisations and it can sometimes be very challenging to collect and combine product knowledge embedded in different technical disciplines and organisations, and share it in the product development team on a cross-functional level.

Further it raises the question:

How should companies be organised in order to support the development of new products?

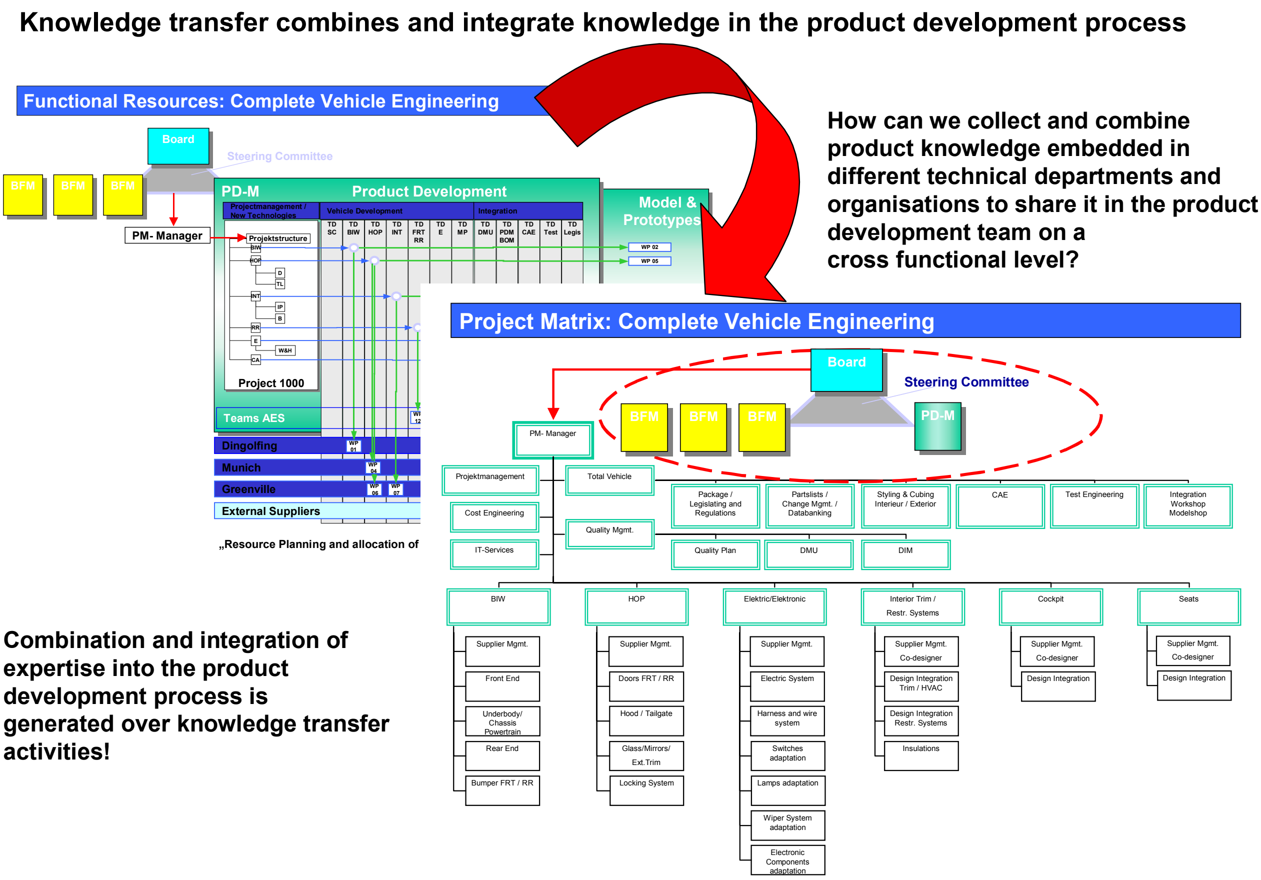
Larson and Gobeli (1985) identified five different project management structures; first is the traditional functional organisation, whereby the development project is divided into segments and assigned to functional units with the heads of each functional group responsible for their segment of the project. At the other end of the spectrum is the project-orientated organisation. Here a project manager is formally assigned to manage a selected group of professionals who operate outside the normal boundaries of the organisation to complete the project. This approach to project management is often referred to the literature as a “project orientated organisation “, “venture team” or “task force team”.

In between these two extremes there are different types of matrix structures. A matrix is a hybrid organisation in which the normal vertical hierarchy is “overlaid” by a lateral project management system. A *functional matrix* occurs when the project manager’s role is limited to coordinating the efforts of the functional groups involved. The project manager basically acts as a staff assistant with indirect authority to expedite and monitor the project.

Conversely, a *project matrix* refers to an arrangement in which the project manager has direct authority to make decisions about personnel and work flow activities. The project manager is responsible for the completion of the project, whereas the contribution of functional managers is limited to providing resources and advisory support.

Finally the *balanced matrix* is the pure matrix in which the project manager is responsible for defining what needs to be done, while the functional managers are concerned with how it will be accomplished. Both parties work closely together and jointly approve workflow decisions.

Figure 17: Collect and combine product knowledge in the vehicle development project



In vehicle development projects a large number of different technologies and disciplines contribute illustrated in (figure 17). Therefore product development managers must provide an organisational structure to communicate the goals of the new product development project, so that everyone can work towards the same end. Further, project managers must be able to sustain commitment among diverse groups of professionals with unique and sometimes incompatible interests and targets.

With this in mind it would be very interesting, but complex, to investigate what structure is needed to create successful knowledge transfer in new product development.

Larson and Gobeli (1988) analysed the relationship between project structure and success. The research revealed that organisations engaged in new product development projects perceived the project matrix as the most successful structure. They grouped the success criteria in their study around following areas; meeting schedules, controlling cost, technical performance and overall performance. These criteria provide an overall picture about the success, or otherwise, of a project. As a second step, they investigated the project structure of successful and unsuccessful projects, and out of this comparison they identified a tendency that favours a project matrix structure for product developments projects.

A major challenge in creating the right project structure for the knowledge transfer processes is that knowledge transfer among product development teams takes place between both individuals and teams.

The second challenge is that product development knowledge is not a static knowledge base; it changes during the life cycle of the product development process.

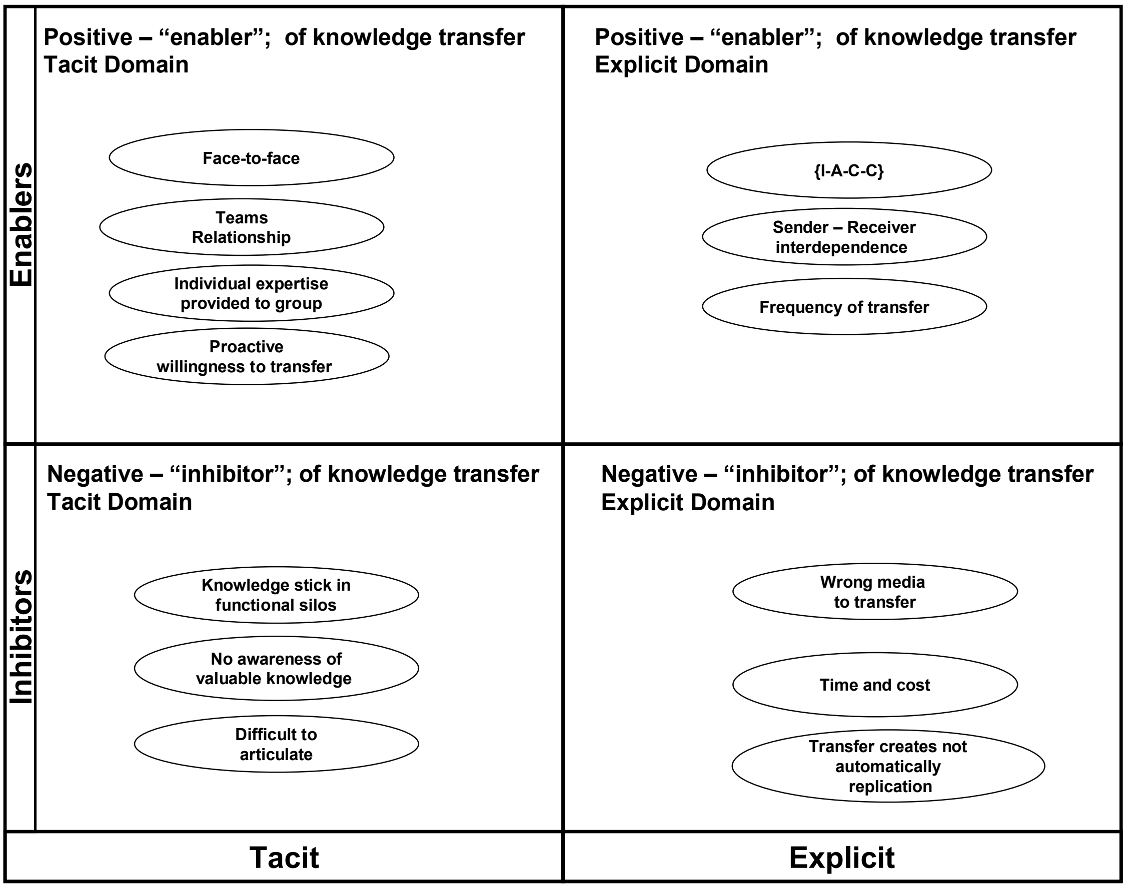
Although Larson and Gobeli (1988) identified the project matrix as perceived as the most successful structure for new product development, new technologies are created in specialised functional departments and therefore product development managers must purposefully construct strategies and structures to enhance knowledge transfer between functional departments and the product development team.

From a knowledge transfer perspective there is no right or wrong project structure. What is important is that product development managers are aware that knowledge transfer is a dynamic process and positively influenced by several factors classified in my research as enabling factors of knowledge transfer. To enhance knowledge transfer in new product development, product developers must recognise that innovative products hold a higher degree of tacit design knowledge than commodity products, for example, engineers produced in the survey a 82 % rate of agreement with the statement that they use mainly knowledge that comes from their past work experience as product developers, in order to solve complex design tasks. Based on this assumption, the challenge for knowledge transfer in new product development is, that the crucial product design knowledge is usually not available in a readily retrievable format. It is often held in the minds of a handful of key persons and it combines

different types of knowledge. To consolidate this conclusion, I propose to divide design tasks into two domains depending on their level of explicitness and tacitness. In general, complex design tasks are not purely tacit or explicit, but rely more on either a tacit set of skills or an explicit set of skills, or more
often a combination of both. Similarly, inhibitors and enablers have more or less importance related to certain activities. The theoretical framework (figure P2.15), distinguishes between tacit and explicit design domains and also integrates the power of enablers and inhibitors of knowledge transfer (table P2.16).

It demonstrates the importance of knowledge transfer as a tool to identify, articulate and combine new knowledge (mainly embedded in the tacit design domain) with existing knowledge (mainly embedded in the explicit design domain), in order to generate knowledge. Thus it assists the strategic aim of integrating technological innovation into new products.

Figure 18: Tacit and explicit domains of inhibitors and enablers of knowledge transfer



In general, to implement new technologies into new products, product developers must be able to transfer tacit design knowledge. This knowledge is embedded in people, tools and routines. The issue is how many knowledge elements and related networks must be created to pass tacit design knowledge on to others. In projects one and two, I identified enablers of knowledge transfer for the tacit and explicit design domains illustrated in (figure 18). Understanding the impact of enablers and inhibitors related to knowledge transfer activities creates the opportunity to draw down several tactics to enhance knowledge transfer in future product development activities. To expand the explicit design domain, tacit knowledge must be transferred and "come to live", in the product development team (figure P2.17).

Recognising this objective, it is obvious that the right use of enabling factors will enhance the knowledge transfer process (table P2.17). On the other hand, knowing what role the inhibitors played for particular procedures, in the product development process helps to minimise their negative weight on knowledge transfer processes.

Based on this assumption it is worthwhile to classify enablers and inhibitors in relation to their positive or negative effect to sort out what facilitate knowledge transfer and knowledge creation (table P2.16).

To identify and articulate tacit design knowledge engineers used following approaches:

- Face-to-face contact
- Shoulder – to shoulder working processes
- Individual expertise provided to group
- Creation of social networks

Product development in general is a dynamic process, so knowledge created changes over the life cycle of the product development process; new knowledge is created and must be transferred and shared.

In vehicle development, non-routine tasks are highly complex, and to solve such complex design tasks, a high degree of task interdependence between technical disciplines is necessary. To evaluate and investigate proper design solutions, team members must have an understanding of the complete product system architecture, which is briefly discussed in project one.

To create such an understanding, engineers need to transform individual knowledge to group knowledge, which is enhanced by collaboration and communication. Talking with others, face-to-face interaction and shoulder-to- shoulder working processes are perceived as the most successful way to create common emotions and experiences, and as a result engineers articulate and combine their individual knowledge and create a common understanding and a shared knowledge base about the product. Nonaka and Johansson (1985, p.183) describe this as involving "...an organisational process where individual knowledge is shared, evaluated and integrated with others in the organisation".

Additionally, project three showed that engineers felt that it was very important that both parties involved in the product development process need sufficient interaction with the transferred know-how to develop an intimate understanding of it, which creates the ability to combine knowledge for new applications in product development. This finding is aligned with previous research. For example Leonard-Barton (1995) stated that individuals develop knowledge commitment to the extent that they see the value of the knowledge, and therefore they develop competence in using the knowledge.

Project three also demonstrates, in several correlations (table P3.7), that engineers use intensive collaboration with their development partners to define objectives and targets to deliver requested design solutions for new products.

Therefore, to facilitate the transfer of tacit design knowledge, product decision makers must create an environment that facilitates interaction and collaboration.

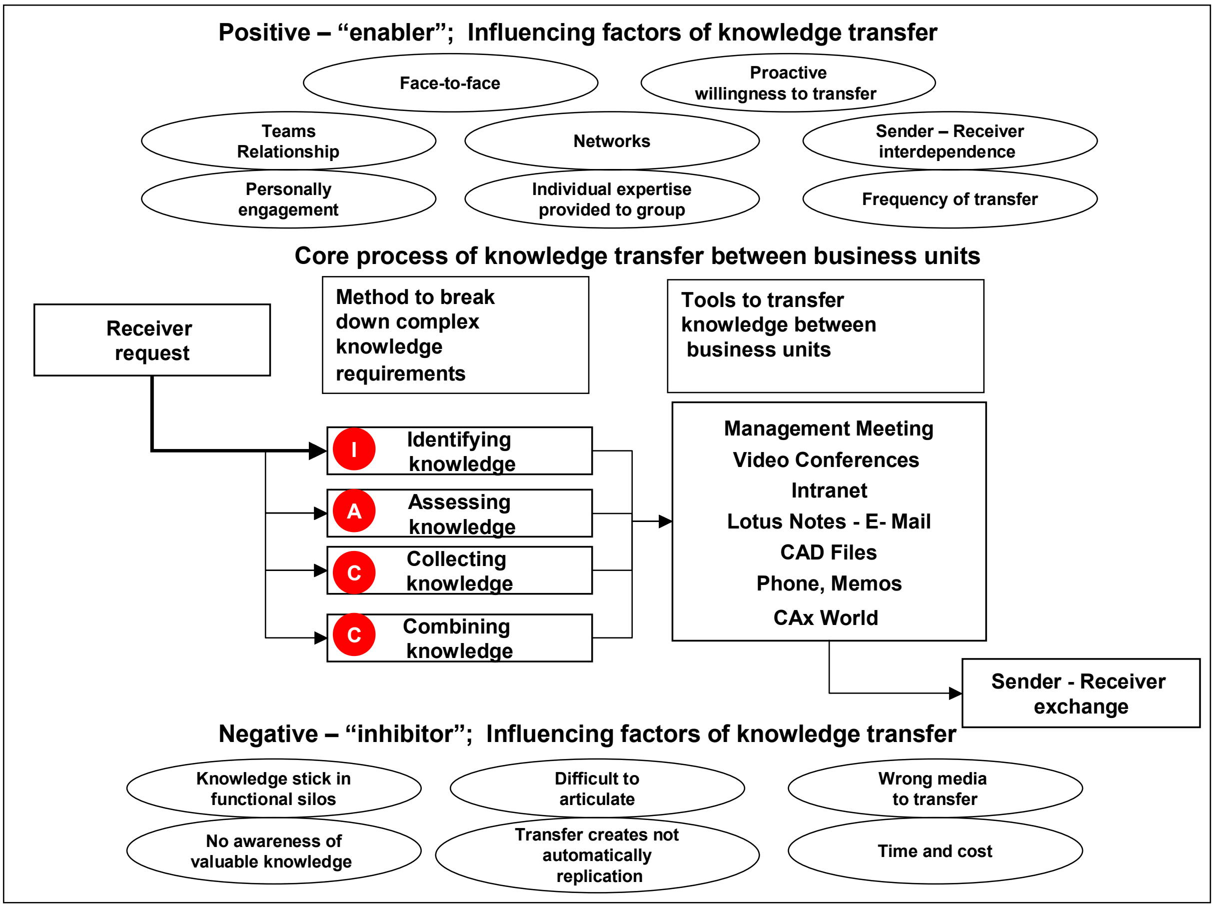
The research visualises that intensive interaction, communication and collaboration are efficient ways to pass tacit knowledge on to other product developers. This view is aligned with the findings of previous research, where product development is described as a knowledge intensive process (Balasubramanian and Tiwana, 1999; Davenport and Prusak, 1998; Drucker, 1993; Nonaka and Takeuchi, 1995). It can be described as an information transformation process where information is gathered, processed and transferred in a creative way. As a result, communication and collaboration is a vital and basic necessity in integrating, combining and creating tacit design knowledge in new product development processes.

Project two showed that successful knowledge transfer requires that both parties develop an understanding of where desired knowledge resides within a given source, and that sender and receiver participate in the processes by which knowledge is articulated.

In project two, I framed out of the research findings a systematic process of knowledge transfer called ***{I, A, C, C},*** illustrated in (figure 19).

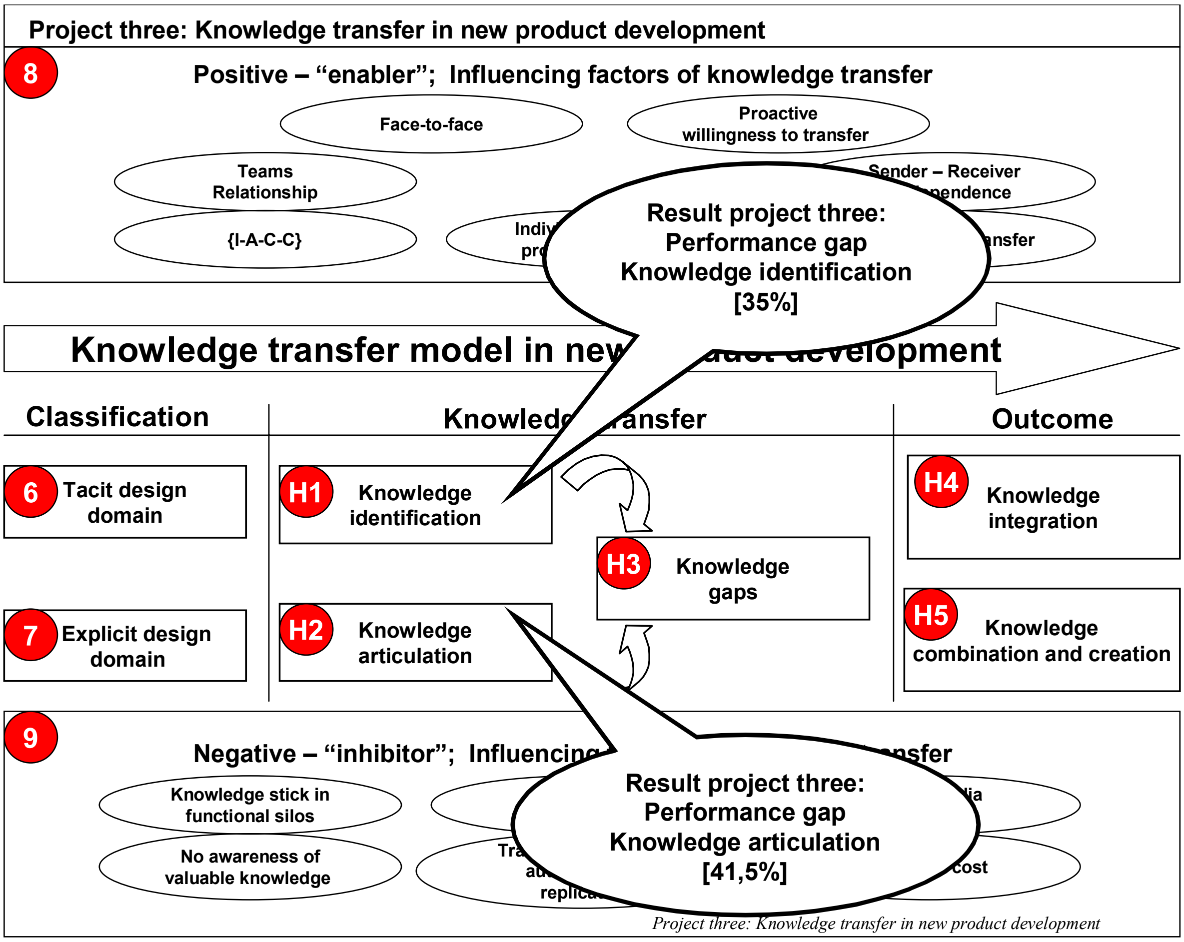
This procedure *{I}* identify, *{A}* assess, *{C}* collect and *{C}* combine knowledge, is a course of actions to structure knowledge and express it a way that it is appropriate to receiver needs. Externalisation takes place if knowledge is from the tacit domain is transformed into explicit domain. It is described as the core process of knowledge transfer in research project two. The major constraint of this systematic approach is to break down complex knowledge requirements, because not all knowledge existing in the tacit domain is capable of being codified, or in some cases the effort to codify is too high and therefore there is no prospect of value creation. But by selecting the right content of tacit knowledge and codifying it, pre-knowledge creation takes place, and this expands the explicit design domain and therefore amplifies the innovation potential in the product development process (figure P2.16).

Figure 19: Core process of knowledge transfer – project two



Additional knowledge *identification and articulation* is a core activity to transform tacit knowledge into explicit knowledge. Based on these findings, we can define that effective knowledge exchange is positively influenced if both parties have a clear identification of knowledge elements. This means that engineers must know where the required knowledge resides and whom and where to ask to collect and combine the requested expertise. In order of the size of the identified percentage gap in project three, knowledge identification [35%] and articulation [41.5%] are the most significant areas for value creation through improved knowledge transfer processes in the future illustrated in (figure 20).

Figure 20: Results project three knowledge identification and articulation



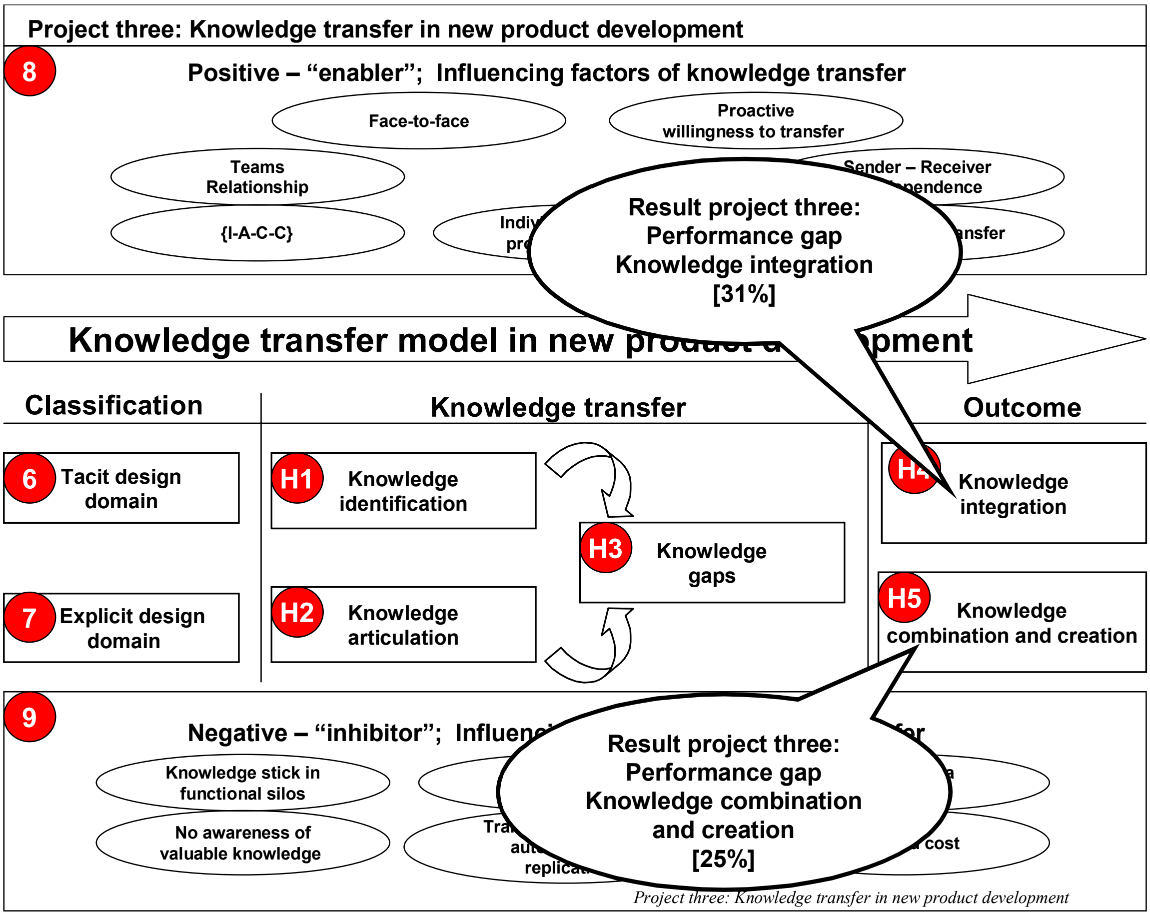
If knowledge is articulated and identified, project managers can establish a structured knowledge transfer process.

An involvement of both parties in the identification articulation and combination of knowledge procedure helps to create an understanding of the knowledge elements that need to be transferred, and the description of knowledge creates an interaction between both parties, and can be seen as a knowledge creation process.

The results of project three demonstrate that the receiving development partner integrates new knowledge, if they feel a sense of responsibility for the provided expertise. Knowledge ownership between both parties is created if sender and receiver discuss this know-how. A result of this interaction is that new knowledge elements are generated and integrated in social networks. Knowledge "comes to live" in the process; it is subject to negotiations and argument and as such it is integrated into the product development process. The interdependence of development partners actively influences the frequency of knowledge transfer, by itself. As a result, the people involved created social networks where a combination of new knowledge is shared and actively used. These networks proved to be essential in incorporating knowledge for new applications in new product development processes. This finding is aligned with previous research, where it was identified that knowledge sharing and transfer depends on personal networks and the willingness of individuals to share (Jones and Jordan, 1998; Ruggles, 1998; Ulrich, 1998).

To produce efficient knowledge transfer in new product development, product developers must be able to integrate and combine knowledge that is embedded in people, tools and routines. The issue is how many knowledge elements and related networks must be created to pass on tacit and explicit design knowledge to others. In order of the size of the identified percentage gap, in project three knowledge integration [31%] and knowledge combination and creation [25%] still leave a significant performance gap to close illustrated in (figure 21).

Figure 21: Results project three knowledge integration and combination



Both fields rely on active interaction between people engaged in product development projects in order to assist knowledge transfer with the aim of integrating and combining new technologies to generate successful products.

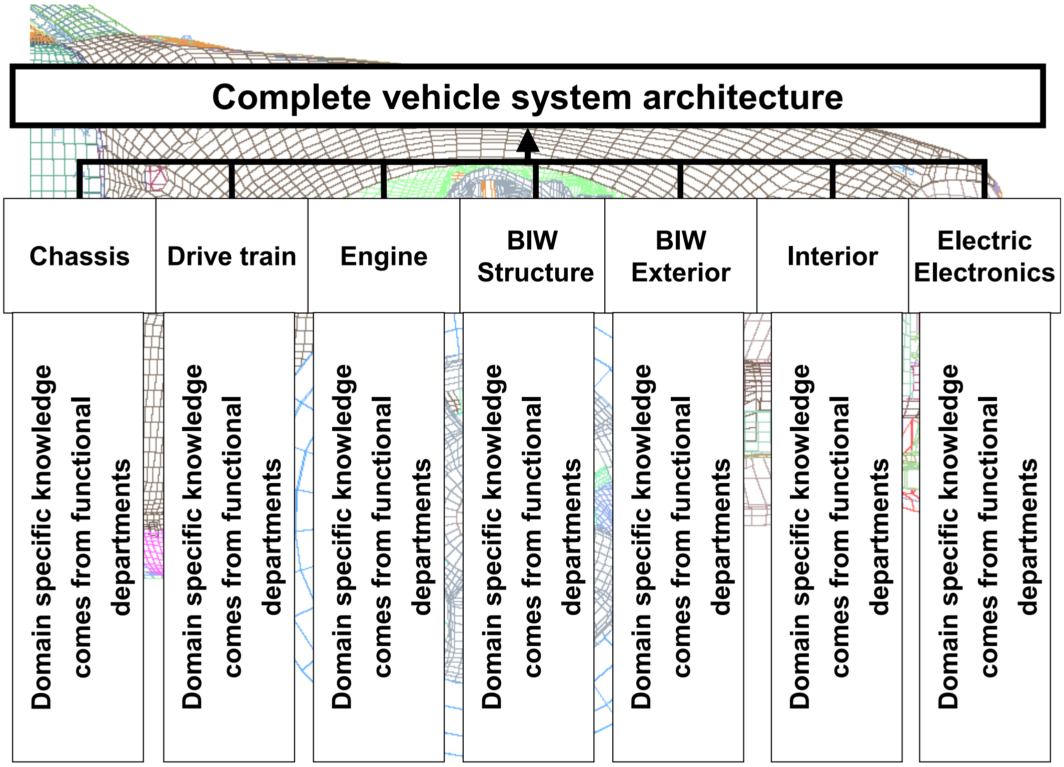
With respect to the positive effects of articulation and identification, in new product development projects we face many constraints to creating a seamless knowledge transfer process.

A fundamental limitation is that tacit design knowledge is hard to communicate, because it is deeply rooted in action, involvement and commitment of the engineers involved in the product development process, "It is a continuous activity of knowing", (Nonaka 1994).

Managers engaged in innovative product development projects must be aware that engineers confronted with complex design tasks need to reduce the degree of uncertainty to integrate new technologies into new products. Engineers are frequently unable to identify and combine knowledge to create a common understanding, because the sender and receiver expertise differs widely in context. As a result, engineers are not able to allocate valuable knowledge, because the requirements of the development partner are poorly understood.

People engaged in this process get the feeling that knowledge sticks in functional departments of the organisation and cannot be transferred illustrated in (figure 22).

Figure 22: Complete vehicle system architecture



The concept of a knowledge gap has been discussed by a number of researchers with respect to its potential impact on knowledge transfer (Hamel, 1991; Lane and Lubatkin, 1998; Dinur et al., 1998; Nonaka and Takeuchi, 1995). Additional in previous research it is noted that difficulty in codification and transfer is a central attribute of tacit knowledge (Grant, 1996; Nonaka, 1994; von Hippel, 1994; Zander and Kogut, 1995).

Further, Stasser (1995) and Wegner (1987), found that group performance increased when everyone in a group was informed of each other member's expertise. Argote, Moreland (1996) confirmed that group training about who knows what produces better group performance, and disruptions to a group's knowledge about who knows what (through the reassignment or turnover of people) hurts group performance.

Another major inhibitor of knowledge transfer is that domain specific and design relevant knowledge to solve complex design tasks is very hard to explain, because the reason a particular solution was or was not chosen cannot always summarised in words. It is a combination of experience and theory that influences the decisions.

Therefore, complex design tasks require some form of estimation or judgement, which cannot be easily expressed in plain language. This is classified in the research as the tacit domain of design knowledge. Previous research points out, that to enhance the product development process, people must be able to generate new products with existing systems, technologies, and market experiences, and must be able to articulate product concept to all parties involved. So sustained innovation also relies heavily on articulated knowledge (Cooper, 1998; Wheelwright and Clark, 1992).

Therefore product developers need to combine knowledge, socialisation, diffusion, externalisation and internalisation in order to transfer knowledge from people owning the expertise to people in need of expertise. To close these technological gaps, product developers must define what knowledge they need and how realistic it is to transfer it.

Project two has shown that in general face-to-face meetings are necessary even when the team is physically dispersed, because of these issues with the tacit domain of knowledge. Although they are time consuming and expensive, there is no chance of keeping them from the agenda. Teece (1977) provides strong evidence that technology transfer costs play a significant role in development costs; he points out that product development projects with complex technology demand more resources for technological transfer.

Additionally, we face the constraint, that from product development perspective we know that tacit knowledge is only capable of codification to some degree, and even if it is codified and transferred, it is not guaranteed that knowledge is recreated in the receiver unit.

Knowledge exists but it must be embedded in networks and routines to be successfully implicated. As recognised in previous research, assessing and creating replication is difficult. There is significant evidence that effective re-creation also requires that the knowledge package is made accessible to or de-conceptualised for the recipient so that the recipient can convert it, adapt it or reconfigure it to its specific needs (Devadas and Argote, 1995; Dixon, 1994; Leonard-Barton, 1988; Moreland, 1996).

This research shows that in new product development projects, engineers are confronted with a high degree of uncertainty, which has it origin in the combination and application of new technologies. The degree of uncertainty created out of new technologies can be seen as a critical factor.

Project two, showed that a lack of common understanding has a negative impact on the overall performance of the project. A clear definition of the targets, and the right organisational process to allow teams to work together effectively, are key issues from a management perspective.

A clear identification of expertise is key, so product development partners must identify what relevant knowledge each development partner posses and what activities are necessary to combine the knowledge of different development partners to generate new products. Product development activities can be seen as transactions that are integrated into an overall system of identifying, assessing, collecting and combining knowledge. The main output of this complex process is not a physical product, but more a knowledge base about the new product. Results of my research so far reveal that there are many factors that affect the successful management of knowledge transfer in new product development projects.

Product development managers must purposefully construct strategies and structures to enhance the knowledge transfer process. With this in mind, I identified and grouped nine key factors to optimise knowledge transfer. Based on my first two projects, it is evident that successful knowledge transfer needs to distinguish between design knowledge that is embedded in the tacit or explicit design knowledge domains.

Project three provides a powerful demonstration that knowledge integration, combination and creation in product development need intensive interaction and collaboration.

The research challenges the classical project management techniques, which are heavily aligned to the "targets to perform mentality". Implementing innovation should not adopt such a rigid approach.

For example the concept of *"front loading"* on product development performance, has been discussed in previous research studies (Thomke and Fujimoto 2000; Clark and Fujimoto, 1989; Ward, Sobek and Liker 1995, 1998 and 1999), and is broadly accepted in the product development processes of all automotive manufacturers. However, the term *"pre-knowledge creation"* is widely ignored in the vehicle development process.

In vehicle development, non-routine tasks are high on complexity. Engineers need to identify, access and combine design relevant knowledge in order to create an understanding of the complete product system architecture. These activities can be seen as a pre-knowledge creation. The result is a shared product knowledge base, which makes it possible for people engaged in the vehicle development process to use different kinds of knowledge, to capture and link new technologies into innovative products. This may require a cultural shift by vehicle manufacturers in terms of how they steer and allocate resources to future vehicle development programmes.

Building on four years engagement with knowledge transfer research, I conclude that organisations in the automotive sector still rely on methods and processes that were successful in the past and strictly directed to exploit tangible assets. To integrate pre-knowledge creation, as a new found discipline in product development projects, creates an enormous potential to integrate and combine knowledge in an efficient way for future product development projects.

1.6 Research limitation and further research

The results of this study are of course subject to a number of limitations. First, the research in general integrates a lot of specific project characteristics of vehicle development projects. For example new product development in the computer industry may have different paradigms regarding how they build up and use the knowledge for relevant product development.

To break it down further, the research builds on the control mode of existing literature. Taking the broad spectrum of knowledge management literature into account, which spans from strategy and leadership, culture and climate, nature of knowledge down to innovation and technological learning, I used mainly the part of literature which integrates knowledge transfer activities into the field of study as a control mode and link to previous findings.

While every attempt was made to avoid such a generalisation by including only constructs in evidence in each of the building literature the range of the knowledge transfer model (figure P3.1), which was developed out of projects one and two and tested in project three necessarily including enablers and inhibitors simplifies reality.

On the other hand the research classify enablers and inhibitors in relation to their positive or negative effect in the knowledge space, to analyse what facilitates knowledge transfer and knowledge creation. Further I used previous research findings to control my theory building. The combination of existing literature with my research findings, helps to move the boundary bit further for researcher concerned with the dynamics of knowledge transfer in new product development.

To facilitate successful knowledge transfer in new product development, tacit knowledge must be transferred and “come to live” in the product development team. Recognising this objective, it is obvious that the right use of enabling factors will enhance the knowledge transfer process. On the other hand knowing, for particular procedures, what role the inhibitors played in the product development process, helps to minimise their negative weight on knowledge transfer processes.

With the case study research method, I had the advantage to investigate and capture the dynamics of knowledge transfer processes.

I was able to develop a knowledge transfer model that integrates the power of enablers and inhibitors and their effect related to the knowledge transfer process in new product development projects.

On the other hand research that incorporates dynamic processes will always face no generally accepted theory and certainly no systematic evidence, therefore several limitations of the study should be acknowledged.

First, all three research projects took place in new product development projects in the automotive industry. Automotive product development in general builds on well – known, rational processes and combines new technologies with existing technologies to generate new application in new vehicle generations. The application of new technologies are carefully planned and tested before market launch. One of the most important reason for this careful planning and testing are the enormous amount of warranty costs car manufacturers face if new technologies fails. The underlying assumption of this product development process is that knowledge identification, knowledge articulation and knowledge combination between multifunctional teams and suppliers plays a significant role to secure product quality in the product development process.

On the other hand the development of personal computers, for which technology and markets are still rapidly and unpredictable evolving need a different product development process. This fast product development processes are sometimes improvisational, they combine real time learning through design iterations and extensive testing with the focus to achieve product functionality. For example new applications substitute design solutions, which fail to create functionality, and engineers maybe use completely different approaches for the next design iteration. Therefore the knowledge transfer model (figure 3), which builds on the basic assumption that knowledge created is collected and combined and reused in future application has for such a dynamic product development environment a limited value creation potential. Therefore generalisation of my findings to other industry sectors should be made with caution.

Additional the conceptual framework (figure 15, figure P2.17 and table P2.17), with the three paths to improve product development over knowledge transfer needs further testing on a larger number of product development projects.

The knowledge transfer model (figure 3) developed out of project one and project two and tested in project three needs some further testing because the study’s small sample size, although consistent with many studies of knowledge transfer (Zander and Kogut, 1995; Lane and Lubatkin, 1998; Szulanski, 1996), limits the finding’s statistical power. An additional restriction for the knowledge transfer model is that the research is restricted to automotive product development projects. In other industry sectors with quickly shifting markets and technologies an application of the knowledge transfer model maybe creates a limited value creation potential.

Finally and there is no limitation to any industry sector, I think future research should pay more attention to the informal aspects of knowledge transfer, identified in my research as enablers and inhibitors of knowledge transfer.

Table 2 summarises the informal aspects of knowledge transfer and envisages that successful knowledge transfer builds on interaction and collaboration of individuals. Additional these findings are supported by previous research reviewed in right column of the following table.

Table 2: Research finding: enablers and inhibitors of knowledge transfer in new product development and their link with previous research

Research finding: enablers	**Link with previous research**
Face-to-face and shoulder-to-shoulder working processes: Face-to-face increases the frequency of rich communication, necessary for resolving the ambiguous situation, which is natural if you start with a new project.	Face-to-face working processes imply a common language and achieve a high level of understanding. (Dougherty, 1992; Brown & Duguid, 1991)
Team Relationship: The knowledge required for complex design tasks is embedded in people, tools and routines. The issue is how many knowledge elements and related networks must be created to be transferred to the receiving unit.	Knowledge transfer and creation of new knowledge is a dynamic process, and is dependent on the ability to create, transfer and utilise knowledge assets, as Teece (2000, p. 35), puts it: "the value creation potential of knowledge assets strongly depends on the extent, to which knowledge is transferable and usable in the firm."
Individual expertise provided to group: The degree of knowledge needed to solve complex design tasks must be individually developed to cope with specific design needs. For that reason the identification and combination of knowledge and presentation of knowledge is an active process, that depends on the willingness of the engineers involved.	Knowledge ownership also relates to the degree that an individual invests energy, time, effort, and attention in the knowledge. Additionally, individuals develop knowledge commitment to the extent that they see the value of the knowledge, develop competence in using the knowledge (Leonard-Barton, 1995).

Continuous table 2: Research finding: enablers and inhibitors of knowledge transfer in new product development and their link with previous research

Research finding: enablers	Link with previous research
{I-A-C-C} ***I=Identifying knowledge*** ***A=Assessing knowledge*** ***C=Collecting knowledge*** ***C=Combining knowledge*** The research illustrated, that project managers should establish a structured knowledge transfer process. This procedure should, identify, assess, collect and combine knowledge, which is a course of actions to structure knowledge and express it a way that it is appropriate to receiver needs. *Identifying knowledge* refers to the activity of spotting within business units, existing knowledge resources requiring knowledge, and to provide that knowledge in an appropriate representation to receiver requirements. *Assessing knowledge* is similar to identification. The main distinction is that it manipulates knowledge resources already existing in the organisation. An engineer described this practice with following words, "*matching the existing expertise to requested requirements"*. *Collecting knowledge* is the activity to select and categorise from existing knowledge. Receiver requirements are *"give them the expertise they need, not everything you possess"*. *Combining knowledge* is a course of action to structure knowledge and express it a way that is appropriate to receiver needs. In other words, "to tailor the selected solution to knowledge transfer requirements". During the research, we found that successful knowledge transfer requires that both parties develop an understanding of where desired knowledge resides within a given source, and that both business units participate in the processes by which knowledge is made accessible.	Krone, Jablin and Putnam (1987) observe that all communication systems consist of a sender (source), a message, a receiver, a channel, and coding/decoding schemes. People and organisations have already developed frameworks to organise a systematic knowledge flow in organisations. Today's frameworks*, examples are shown in table P2.7* can be classified as either prescriptive, descriptive, or a combination of the two. Prescriptive frameworks provide direction on the types of knowledge management procedures without providing specific details of how those procedures can or should be accomplished. In contrast, descriptive frameworks identify attributes of knowledge management important for their influence on the success or failure of knowledge management initiatives. (Rubenstein-Montano, 2001). Knowledge transfer success is also affected by its articulability, or the extent to which knowledge can be verbalised, written, drawn or otherwise articulated (Bresman 1999).

Continuous table 2: Research finding: enablers and inhibitors of knowledge transfer in new product development and their link with previous research

Research finding: enablers	**Link with previous research**
Proactive willingness to transfer: The challenge, in general, is that the crucial product design knowledge is usually not available in a readily retrievable format. It is often held in the minds of a handful of key persons and it combine different types of knowledge. For example the design knowledge necessary to track a new product development process requires that the expertise involved contains explicit theories and formulae on the one hand. On the other, the knowledge of applying such theories requires the understanding of the theories as well as expressing the components of estimation/judgement and, "best trade", on what and how to apply when and where. Knowledge with both explicit and tacit elements is required.	The process model of knowledge creation builds on the crucial presupposition that human knowledge is created and enlarged by means of a social interaction between tacit and explicit knowledge. This interaction is called a knowledge conversion. It is further important to note that this conversion does not take place within individuals but between individuals within an organisation (Nonaka and Takeuchi, 1995
Sender / Receiver interdependence: A involvement of both parties in the identification and combination of knowledge procedure helps to create an understanding of the knowledge elements needing to be transferred, and the description of knowledge creates a interaction between both parties, and can be seen as a knowledge creation process.	Product development is a knowledge intensive process (Balasubramanian and Tiwana, 1999; Davenport and Prusak, 1998; Drucker, 1993; Nonaka and Takeuchi, 1995). It can be described as an information transformation process where information is gathered, processed and transferred in a creative way. Therefore, communication is a vital and basic necessity for product development activities especially when team members are geographically distributed.
Frequency of transfer: In the research project, the unit in need of expertise to move forward with the development is more proactive in requesting the needed knowledge. So the interdependence of the business units had an active influence by itself on the frequency of knowledge transfer. As a result, the people involved created social networks where a combination of new knowledge is shared and actively used. These networks proved to be essential to move the development process forward.	Knowledge sharing and transfer depends on personal networks and the willingness of individuals to share (Jones and Jordan, 1998; Ruggles, 1998; Ulrich, 1998). Nonaka and Takeuchi (1995) believe that organisations leverage individual talents into collective achievements through networks of people who collaborate.

Continuous table 2: Research finding: enablers and inhibitors of knowledge transfer in new product development and their link with previous research

Research finding: Inhibitors	Link with previous research
Knowledge stick into silos: For the knowledge transfer process, it is very difficult to create a common understanding if the sender and receiver expertise differs greatly in context. People are not able to allocate valuable knowledge, because the requirements of receiving parties are poorly understood. So people engaged in this process get the feeling that knowledge sticks in functional departments of the business units and cannot be transferred.	The concept of a knowledge gap has been discussed by a number of researchers with respect to its potential impact on knowledge transfer (Hamel, 1991; Lane and Lubatkin, 1998; Dinur et al., 1998; Nonaka and Takeuchi, 1995). Additional in previous research it is noted that *difficulty in codification and transfer* is a central attribute of tacit knowledge (Grant, 1996; Nonaka, 1994; von Hippel, 1994; Zander and Kogut, 1995).
Unawareness of valuable knowledge: The term represents the difficulty to locate product development knowledge between different engineering disciplines. For example this quote shows how engineers were confronted with a lack of experience to locate and transfer knowledge: *In general it was, for all parties involved, doing something new. So we had to learn to do something new, strongly based on communication of information between business units. Key was to identify knowledge and to organise the exchange of knowledge transfer between the units.* *It was difficult in the beginning, to locate the knowledge; for example who possesses the right source of expertise for specific design tasks.* *It was obvious that we know that our Swiss unit owns material know-how and our Italian unit owns the vehicle integration know-how, but that is not enough to develop a new floor module. These are only the basic resources to carry out such a complex project.* *How should we work together; who has the helm in the project; and how to share responsibility?*	Stasser (1995) found that group performance increased when everyone in a group was informed of each other member's expertise. That is, when group members were informed about who knows what (the people–people network), the group's performance increased (Wegner, 1987). Moreland (1996) research confirmed that group training about who knows what produces better group performance, and disruptions to a group's knowledge about who knows what (through the reassignment or turnover of people) hurts group performance.

Continuous table 2: Research finding: enablers and inhibitors of knowledge transfer in new product development and their link with previous research

Research finding: Inhibitors	**Link with previous research**
Difficult to articulate: Quote: *Domain specific and design relevant knowledge is very hard to explain, for why or why not a particular solution was done cannot always summarised in words. It is a combination of experience and theory and this combination influence the decisions.* Complex design tasks require some form of estimation or judgement, which can hardly be expressed in plain language. This is classified in the research as tacit domain of design knowledge.	Tacit knowledge is hard to communicate and is deeply rooted in action, involvement and commitment within a specific context: It is "a continuous activity of knowing" (Nonaka, 1994, p. 16). To enhance the product development process people must be able to generate new products with existing systems, technologies, and market experiences, and must be able to articulate product concept to all parties involved, so sustained innovation also relies heavily on articulated knowledge (Cooper 1998, Wheelwright and Clark 1992).
Wrong media to transfer: The constraint of using videoconferences in product development projects is that an efficient transfer of multiple data sets through one communication channel is very difficult to achieve. As one engineer stated: *Real design knowledge, which integrates a high portion of tacit and informal knowledge, is transferred mainly by face-to-face interactions. Very disappointing outcome with videoconference, there was no way to articulate relevant knowledge to develop a new floor module. Even if you see your partners on the screen, how do you explain a technical idea sketched on a drawing; how do you draw down the thoughts and comments of your development partners on the other side to frame this new idea into a solution? Most of the time we agreed to meet each other in a few days, to discuss this personally to sort out the next design steps.* A successful knowledge transfer process needs the right medium for transfer and a method to break down complex knowledge requirements, to transform intangible ideas and findings into an explicit form, to create a valuable sender receiver exchange.	A technological approach to knowledge transfer can often be unsatisfactory. In fact, many tools proposed as knowledge transfer applications are actually still designed or used to support just data and information processing, rather than knowledge transfer. (Borghoff and Pareschi, 1999). The natural characteristics of a technology do not absolutely allow one to define it as a knowledge transfer tool: this evaluation is dependent on the context of its use (Sarvary, 1999).

Continuous table 2: Research finding: enablers and inhibitors of knowledge transfer in new product development and their link with previous research

Research finding: Inhibitors	**Link with previous research**
Time and cost: Interviewees statement: *Several management meetings are essential, to determine the expertise possessed in the business units and to align resources to project objectives. In this phase, we discovered, how difficult it is to reapply team and individuals knowledge at distance. Time consuming co-ordination of management meetings, taking into account that many key players are engaged in several projects of their parenting unit as well. Also financial resources put an upper limit, on what you can expect from the knowledge transfer processes.* *Management meetings and, face-to-face meeting are perceived as one of the strongest activities to transfer expertise, but to create a knowledge flow based only on face-to-face contact, would increase the project costs to a level, no one likes to pay.* Face-to-face meetings are possible if the team is physically dispersed, but be aware they are time consuming and expensive but there is no chance to keep them from the agenda.	The radicalness of a new product and the newness of the technologies that it embodies will increase the level of development uncertainty. A team con-confronted with high uncertainty will have to process additional technical and conceptual information and develop new ways of performing the task at hand (Brown and Utterback, 1985; Dewar and Dutton, 1986). Implementing the technology abroad is more costly due to technology transfer costs. More complex technology demands larger resources for technology transfer. Teece (1977) provides strong evidence for the existence of such technology transfer costs.
Transfer does not automatically creates replication: From a product development perspective, we know that tacit knowledge is only capable of codification to some degree, and even it is codified and transferred, it cannot be taken for granted that knowledge is recreated in the receiver unit. Knowledge exists but is not embedded in networks and routines to be successful implicated.	Previous research shows that assessing and creating replication is difficult. There is significant evidence that effective re-creation also requires that the knowledge package is made accessible to or de-conceptualised for the recipient, so that the recipient can convert it, adapt it or reconfigure it to its specific needs (Devadas and Argote, 1995; Dixon, 1994; Leonard-Barton, 1988; Moreland, 1996).

The research findings summarised in (table 2) and linked to previous research findings can serve as a framework for developing a future research agenda, which incorporates the dynamics of knowledge transfer identified in my research as enablers and inhibitors of knowledge transfer. To understand the dynamics, how product developers share, combine and create new knowledge to create innovative products has an enormous value creation potential for future product development projects.

Further, it would be very interesting, but complex due to the fact that every product development project has its own characteristic, to investigate what structure is needed to create successful knowledge transfer in new product development.

Title page project one

Title of DBA Research:

An explorative study of knowledge transfer processes in new product development in the automotive industry

Abstract:

The study takes a multidisciplinary approach in order to first explore key characteristics of vehicle development processes, where the number of models is increasing and the product life cycles are decreasing. In these circumstances, future project management techniques must combine high functional expertise with high integration capabilities of different engineering disciplines. This combination of expertise is generated through knowledge transfer activities. The research shows that knowledge transfer is influenced by several factors, which are classified in the research project as enablers (positive factors) and inhibitors (negative factors), affecting the knowledge transfer process.

In general, complex design tasks are not purely tacit or explicit, but often rely on a combination of tacit and explicit skills. Similar inhibitors and enablers may have more or less importance depending on the activities they relate to. To understand the impact of enablers and inhibitors, and their interdependence in relation to the product development process, the research investigates major design tasks; when and why they come to light and what role they play in the product development process in relation to the knowledge transfer process. The findings suggest that in the first phase of the product development process an environment for tacit knowledge sharing would enhance the product development process, whilst in the second phase an environment that creates an optimised exchange of explicit knowledge will be the source for a value creation potential. In general the research outcome helps to understand the value creation potential of knowledge transfer in new product development activities. It links theory and practice to offer practical indications to enhance knowledge transfer during the product development process.

2. Background and a theoretical perspective on project one

This study maps out the way in which knowledge is transferred and used in the vehicle development process. The vehicle development processes is an interaction of many functional areas, from styling through to manufacturing, which involves the co-operation and collaboration of multi-disciplinary people who need to communicate and exchange information. Technical tools such as product data management (PDM) software and computer-aided design (CAD), manufacturing CAM), and engineering (CAE) systems, have helped companies to reduce the time it takes to bring a new vehicle to the market from around five years to about three. Hooking all these internal systems together is not only an organised transfer of information; it also creates the need for managing the transfer of knowledge in the vehicle development process.

New products are the manifestation of an organisation's knowledge (Leonard-Barton, 1995), and an organisation's ability to engage in "technology linking", as Burgelman (1983) calls it, is central to the effective use of that knowledge. Research demonstrates that the more thoroughly people merge deep knowledge of technological possibilities with detailed knowledge of application contexts (by linking knowledge of customer needs, market opportunities, technologies, and operational constraints) the more successfully they develop new products (Cohen and Levinthal 1990; Levinthal and March 1993; Dougherty, 1992; Moorman, 1998).

Researchers have established that market-technology linking is vital to product innovation, and have formed a good understanding of the knowledge content (Day, 1990; Griffin and Hauser, 1993). However, much less is known about how people carry out technology linking for streams of new products, in a modular product development process, which is a typical approach to developing new vehicles.

Today a modular vehicle development process requires a cross-functional team able to create group expertise from disparate singular expertise. The question concerns how people engaged in the vehicle development process interpret and develop knowledge patterns of technology linking, which are transferred between cross-functional teams. In this research I try to explore how product development teams frame and shape the technology knowledge, how they interpret such knowledge and what they do with it in the product development process.

I intend to describe the characteristics and the structures of these areas of knowledge and what enables teams to bridge them, in order to create group expertise from singular expertise. Pulling together various types of information and expertise in a meaningful way is the key to create group expertise, but people cannot collectively use knowledge unless they first make shared sense of it.

The vehicle development process builds on existing knowledge and creates tacit knowledge. This process of knowledge creation builds on the crucial presupposition that human knowledge is created and enlarged by means of a social interaction between tacit and explicit knowledge. This social interaction is a part of knowledge creation and knowledge transfer, and it is therefore a factor in seeing how product development teams use and transfer tacit and explicit design knowledge between different functional levels.

One of the most revealing works on the vital role of tacit knowledge in the innovation process was carried out by Nonaka and Takeuchi (1995). They present a dynamic model for the creation of new knowledge that begins with deep tacit understanding, continues through the explication of this vague creative force in the form of an innovative product, and ends with the absorption of new knowledge into the organisation as a whole.

This "spiral of knowledge creation" offers profound insights into the essentially human aspect of innovation. They refer to the social interaction element as a knowledge conversion. It is important to appreciate that this conversion does not take place within individuals but between individuals within an organisation (Nonaka and Takeuchi, 1995).

The boundary between explicit and tacit knowledge, however, is not clear. This means that tacit knowledge is created by explicit knowledge and vice versa. Tacit knowledge is knowledge that has not been articulated yet. The task of knowledge management is to identify and facilitate the utilisation of valuable tacit knowledge that is potentially useful when it becomes explicit, not to elucidate tacitness itself.

Nonaka and Takeuchi (1995) described how the interaction between tacit and explicit knowledge can go in four different directions:

Socialisation; the exchange of experiences where personal knowledge is being created in the form of mental models. Examples of situations where this happens are master-fellow relationships, on-the-job training, trial-and-error policy, imitating others, constructive brainstorm sessions, practising and training, the exchanging of ideas and a lot of conversation.

***Externalisation*;** personal or tacit knowledge is made explicit in the form of metaphors, analogies, hypotheses and models, e.g. in language. One usually finds externalisation in the design process when conversations and collective consideration are used to boost the process. Nonaka and Takeuchi find externalisation the key process in knowledge conversion because it is here that, from tacit knowledge, new and explicit designs are born.

Combination; notions are synthesised into a knowledge system. People exchange knowledge, and this knowledge is combined through documents, meetings, telephone conversations and the exchange of information via media like computer networks. New knowledge can also be created through the restructuring of existing information by sorting, adding, combining and categorising explicit knowledge. Combination is the kind of knowledge creation that we usually encounter in education and training. Examples of combination are knowledge and information systems.

Internalisation; a process in which explicit knowledge becomes part of tacit knowledge. This can happen through learning-by-doing and documented knowledge can play a helpful role in this process. Internalisation can be seen when new engineers "relive" a project by studying the archives. Internalisation can also be seen when experienced managers or technicians give lectures, or when authors decide to write the biography of an entrepreneur or enterprise. The four kinds of interaction between tacit and explicit knowledge form a kind of spiral, which goes from socialisation through externalisation and combination to internalisation, then further socialisation, externalisation etc. In relation to the product development process, active knowledge transfer includes both ambiguous, tacit knowledge and articulated knowledge (Nonaka and Takeuchi, 1995; Spender, 1996).

Product developers must understand how to transfer design-relevant knowledge, which is usually embedded in tacit knowledge between all members of the product development team.

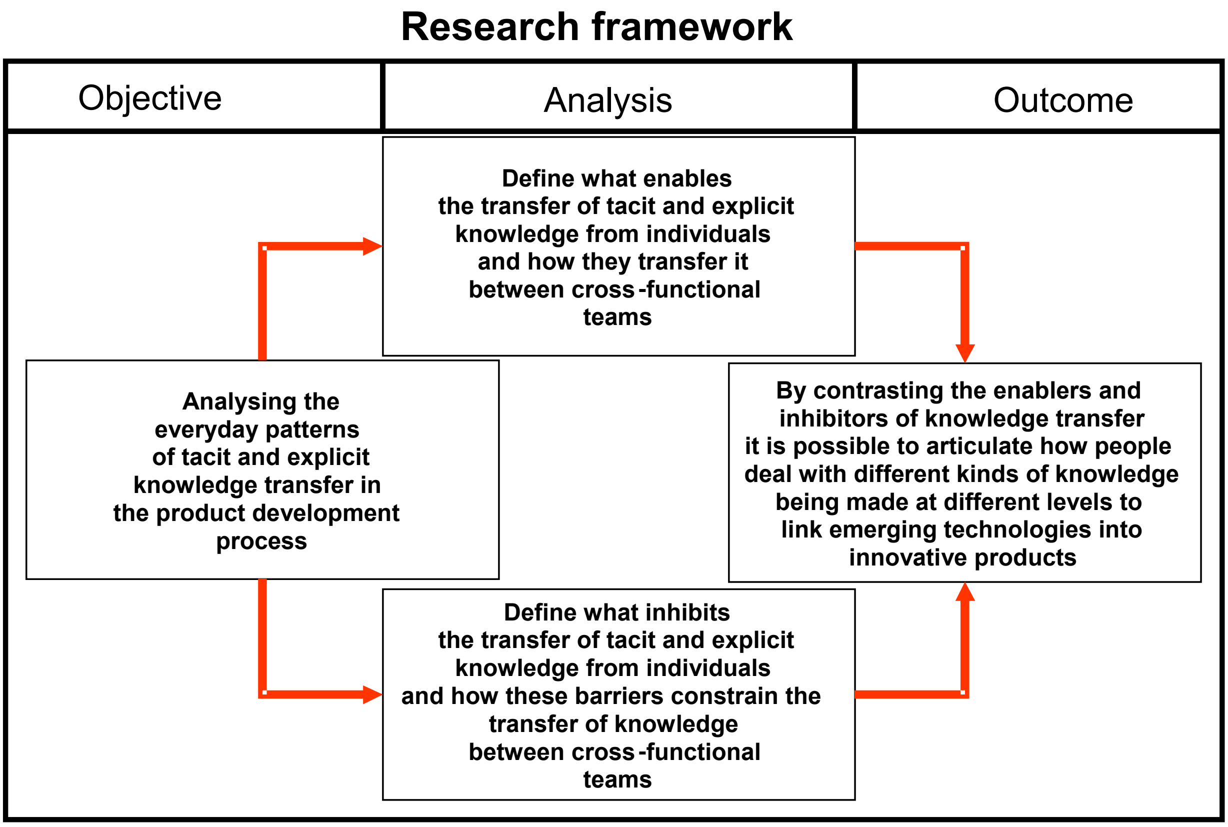
Engineers often cannot articulate problem solving activities or emerging technologies, which involve such ambiguities as unforeseen interactions among components and choices of technology paths between different functional expertises.

To enhance the product development process, people must be able to generate new products with existing systems, technologies, and market experiences, and must be able to articulate product concept to all parties involved. Thus sustained innovation also relies heavily on articulated knowledge (Cooper, 1998; Wheelwright and Clark, 1992).

2.1 Research framework - project one

The research concentrates on the transfer of tacit versus explicit knowledge between cross-functional teams. Even a single product needs technology from several divisions, and so we see how important it is to establish a framework that enables the transfer of knowledge and greats group expertise from singular expertise. To explore the transfer of knowledge between cross-functional teams, I draw down following research framework:

Figure P1.1: Research framework



In my research framework I used the following steps to identify and analyse the transfer of tacit and explicit knowledge in the product development process:

1. *Define what enables the transfer of tacit and explicit knowledge from individuals and how they transfer it between cross-functional teams.*

2. *Define what inhibits the transfer of tacit and explicit knowledge from individuals and how these barriers constrain the transfer of knowledge between cross-functional teams.*

3. *By contrasting the enablers and inhibitors of knowledge transfer it is possible to articulate how people deal with different kinds of knowledge being created at different levels, to link emerging technologies into innovative products.*

On the surface, engineering design knowledge appears to be concrete and declarable, but in reality we know that this externalised knowledge is not sufficient for new product development processes.

Chapter one showed that the categorisation of knowledge is a very complex process, but fundamentally, knowledge comes down to individual practice and experience. The way we make knowledge descriptive, "knowledge patterns", and how we link them together needs a deep understanding of how people share different domain specific knowledge and bundle it together in cross-functional activities.

The study showed that the way knowledge is transferred during the vehicle development process strongly depends on the sort of design tasks engineers are required to solve. In the concept and technology phase of the product development process, where engineers are engaged with product concepts and new technologies, tacit knowledge transfer dominates. This is referred to hereafter as the tacit domain, because of this, the key enablers of tacit transfer and the activities that foster tacit knowledge exchange are the resources required for a value creation potential in the product development process.

In contrast, when the product development process moves into phase two, where engineers mainly engaged with product engineering and feasibility studies of process technologies, explicit knowledge transfer is heavily relied on. (This will be referred to as the explicit domain, in this study). For that reason the key enablers of explicit knowledge transfer and the activities to foster explicit knowledge exchange are the resources for a value creation potential in the product development process.

Certainly there is no clear borderline between the tacit domain and explicit domain of design knowledge, but a clear outcome of the research is that, in the tacit domain, engineers strongly favour shoulder-to-shoulder working processes and face-to-face meetings to draw down knowledge patterns. It is important to understand (table P1.4), what engineers mean by the terms face-to-face and shoulder-to-shoulder working processes. *Face-to-face* meetings are defined as communication between single persons, to form and generate a common understanding about the product development process. *Shoulder-to-shoulder* working processes are defined as an activity; if engineers work together for a period of time, to explore a design relevant solution for new technologies and quality improvement. Use of these processes enabled the engineers to articulate their tacit knowledge and make it visible to other team members, so that it can then be transferred between different functional teams.

The way knowledge is transferred changed significantly when the product development process moved into the explicit domain, product engineering and process technology. In this case it is mainly explicit knowledge that is transferred and engineers extensively used the IT infrastructure and CAx tools for knowledge transfer.

2.1.1 Methods - project one

I have used the case study method for data collection and subsequent validation. Yin (1994) describes this technique as:

> an empirical inquiry that investigates a contemporary phenomenon within its real life context, especially when the boundaries between phenomenon and context are not clearly evident and it relies on multiple sources of evidence.

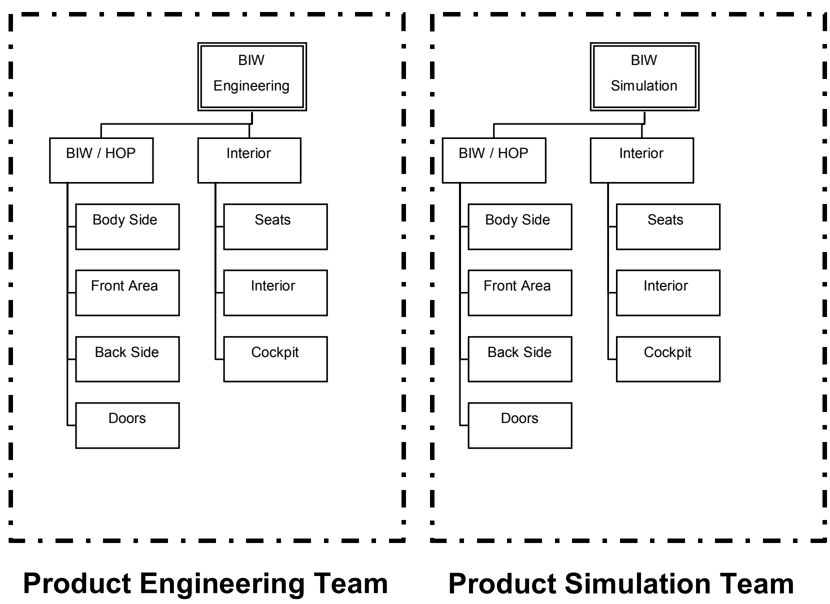
A single case allows this study to investigate the phenomenon in depth, in order to provide rich description and understanding and, as Darke (1998) cautions that statistical generalisation is not the goal of case studies, deep insight into dynamics of processes and situations. Case study methodology also provides deep insights into knowledge related facts during the vehicle development process.

To examine the patterns of knowledge transfer in the vehicle development process, I interviewed 20 lead engineers engaged in the vehicle development process. The unit of analysis (figure P1.2) is the knowledge transfer process between the product engineering team and the product simulation team, who are between them responsible for three main modules; body structure module, body exterior module and interior module. The people engaged in this process were asked to describe how they transfer knowledge in the vehicle development process.

Figure P1.2: Unit of analysis

Unit of analysis: Knowledge transfer process

Knowledge transfer between product development teams



The research is based on a recently finished vehicle development project, which was outsourced by an OEM to an engineering service house.

With a retrospective study of the project, I had the opportunity to evaluate, based on the past experience of the engineers engaged in this project, how knowledge was transferred. By contrasting the inhibitors and enablers of knowledge transfer, I could then articulate the way in which people deal far more effectively with the ambiguities of knowledge transfer to create, out of different kinds of expertise at different levels, a capability to link emerging technologies into innovative products.

Top engineers interviews were typically between 90 minutes to two hours long. I used a structured interview with open-ended questions, in order to allow the participants to respond of their own violation, free of the potential influence of preconceived answers. I used nine open-ended questions, in detail described in chapter 2.3 and appendix one.

2.1.2 Data sources project one

As already mentioned, the participants were engineers engaged in a prior vehicle development project, and were members of the product engineering and product simulation team as it is shown in (figure P1.2). All 20 engineers are very experienced and in leadership positions. During this vehicle development process, the work experience of the engineers was, on average, more than ten years.

2.1.3 Surfacing and articulating key themes

The research challenge was to identify and articulate themes that capture the differences between enablers and inhibitors of knowledge transfer, taking into account that vehicle development is cross-functional in approach but expertise is held by individuals.

By contrasting the inhibitors and enablers of knowledge transfer, one is able to articulate the way in which people deal far more effectively with the uncertainty of technology linking to create, out of singular component expertise, a bridge to manage modular system expertise.

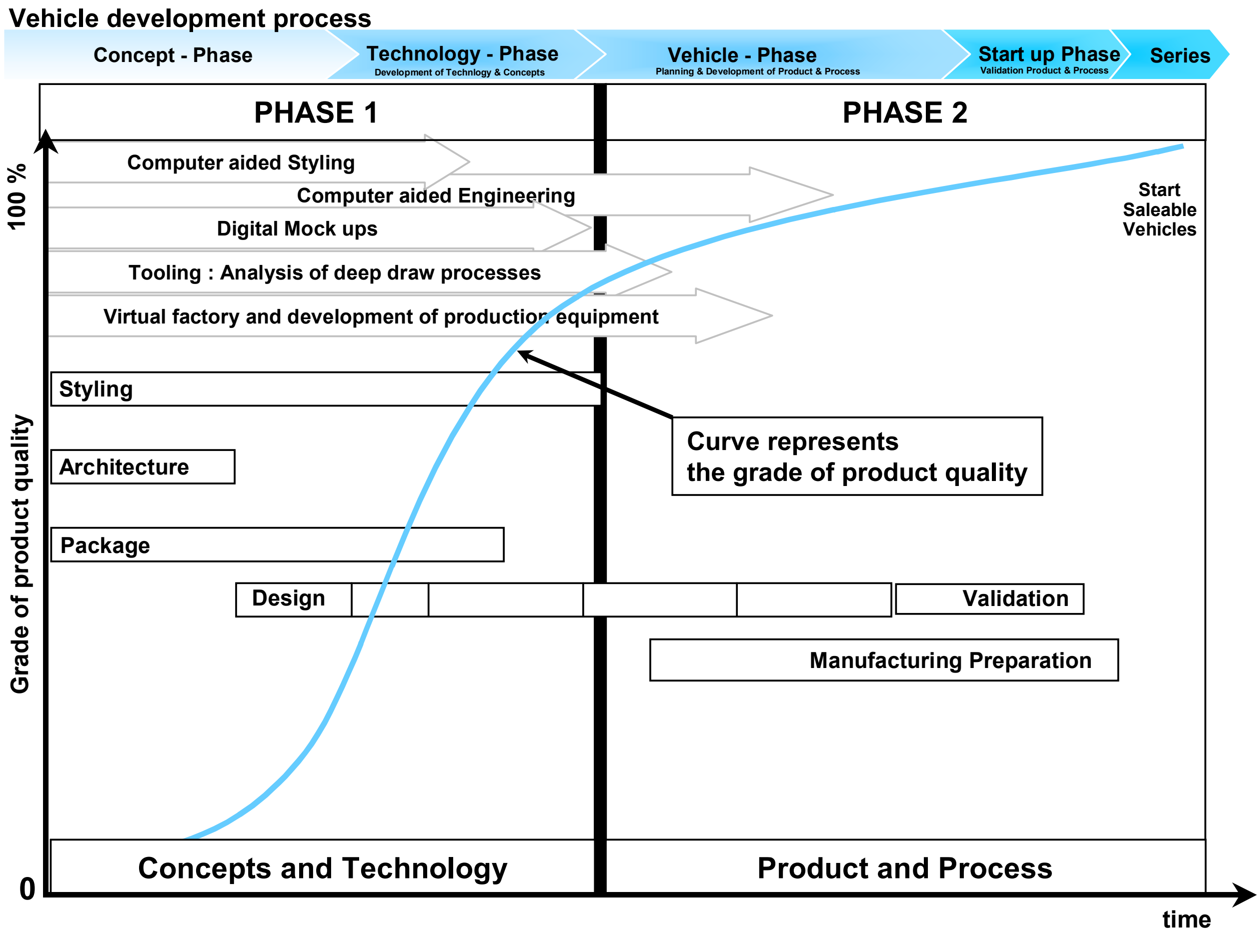
The vehicle process itself stands on clearly defined programme management, but the transfer of knowledge during the project is still not aligned to a process or procedure; people are aware that in the future it will be important to have know how which spans across all modules, because the car should be still a single product which creates a distinct and different appeal to the customer, even when commonality architecture plays a major role in the modular vehicle development strategy.

A car assembled out of different modules creates the need for clearly defined build-up stages to keep the product development under control.

The correlation between cross-functional teams originates the need for efficient transfer of design-relevant knowledge between different functions involved in the development process.

2.2 The vehicle development process and its relation to knowledge transfer

Figure P1.3: The vehicle development process



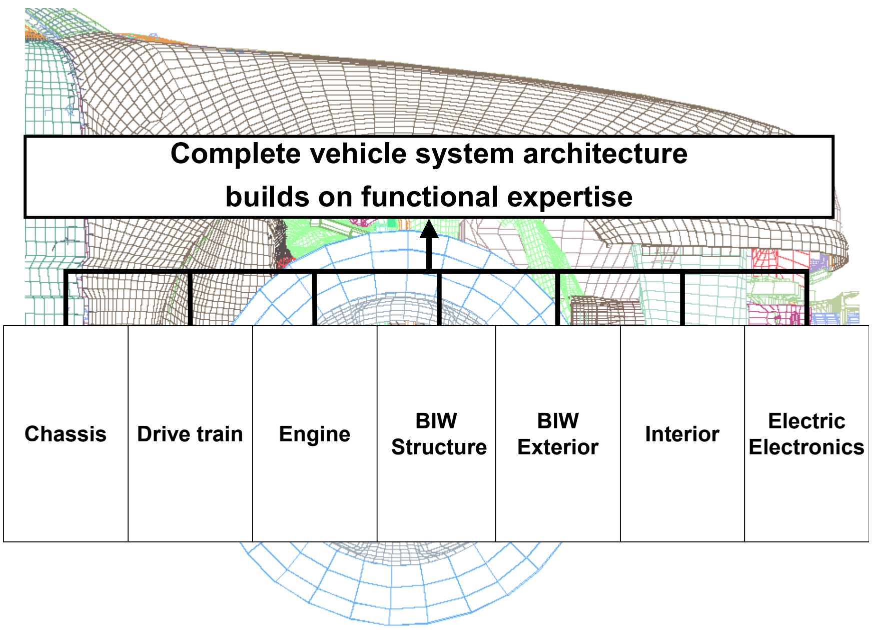
The vehicle development process is divided into two major phases. Phase one (figure P1.3) includes the concept and technology phase where the product concept and new technology is defined. This phase is where a lot of space must be created for ideas and innovation. The car exists in a conceptual form, styling and package are still under development and there are still few alternatives for components, interior and exterior layouts under investigation. As it is shown in (figure P1.3) engineers use computer aided styling tools, computer engineering tools, digital mock ups and analysis of deep draw processes to map out the possibilities, along with associated feasibilities for production. In phase one, where mainly tacit knowledge is used to architecture a new product. In this phase, concept and style are defined and new ideas and technologies are integrated into the new vehicle. So during phase one, an environment must be created which encourages the implementation of new thoughts and ideas into the future vehicle generation.

In phase two, where the product is defined and the process technology is decided, the main perspective is on manufacturing preparation and launch of the product. In phase two the product development is already matured, which is also illustrated through the steep increase of the blue curve (figure P1.3) by the end of phase one. The car is already in digital form existing and all major subsystems have already production feasibility. These parts of the product generation process are more dedicated to technical specification and quality standards. This is the explicit domain of the product development process and engineers are trading more with explicit, rather than with tacit, knowledge during these vehicle development phase.

2.2.1 Knowledge transfer to diffuse the barriers of functional expertise

The definition of vehicle architecture shows a strong alignment with the theory of " Architectural Competence", which enables organisations to integrate knowledge in new and flexible ways (Henderson and Cockburn, 1994) and is also basis for the future vehicle development process, bearing in mind that a vehicle in the future will be divided into seven main modules (see figure P1.4) and therefore you need an effective knowledge transfer between these different engineering disciplines.

Figure P1.4: Complete vehicle system architecture

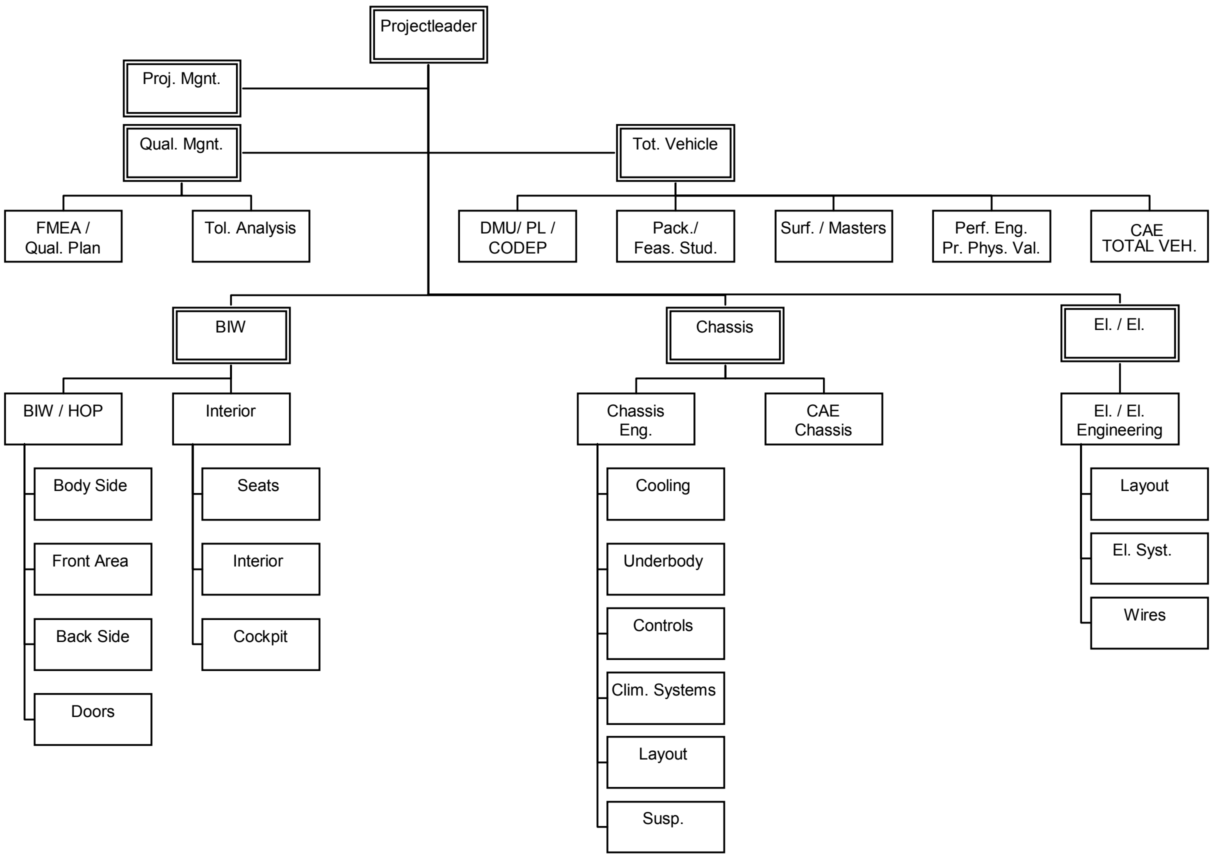


Clearly the modular engineering concept outlined (figure P1.4) makes it obvious how efficiency will be improved if engineers can commit to transfer their expertise at a cross-functional level.

2.2 Knowledge transfer between product development teams

Knowledge transfer between product development teams varies significantly depending on the structure the teams and how they exchange their expertise within the organisational structure. In general, the project structure (figure P1.5), must align the available resources and facilitate an active knowledge transfer between different engineering disciplines.

Figure P1.5: Organisational chart complete vehicle development



Engineers engaged in complete vehicle development programmes are confronted with a variety of challenges during the project, as we know even a single product needs technology from various divisions. Thus it can be seen that it is very important to create an environment that supports the ambition to build group expertise from singular expertise.

Vehicle engineering is an activity that links emerging technologies with existing technologies to create improved, or even new, components. From these components modules (figure P1.4) are developed and from these modules a new vehicle is generated. This is not a simple matter of snapping parts together; it contains the intensive transfer of tacit versus explicit knowledge between different functional areas.

Cross-functional teams of various engineering disciplines are part of this vehicle development process and this interaction indicates a complexity in technology and human interaction. The challenge for knowledge transfer is to understand how people share different domain-specific knowledge and bundle it together in cross-functional activities. In order to sort out the relationship between separate functional areas it is very important to evaluate and define how knowledge transfer occurs between engineers assigned to several engineering disciplines.

From this point of view it is important to understand how knowledge is transferred and what information systems are used to foster tacit and explicit knowledge exchange.

2.2.3 The role of information systems in the vehicle development process

The development of systems to assist in managing knowledge has been a topic of considerable interest. Nonaka and Takeuchi (1995) suggest that information systems can assist proponents and champions of knowledge management (KM) systems in serving as catalysts of *knowledge creation* and as *connectors* of present and future initiatives.

Today the vehicle development process moves into mathematically based development e.g. digital mock-ups, where engineers have a virtual car available to analyse crash worthiness and assembly conditions. So the backbone for the process is certainly the CAx world, which contains technical tools such as product data management (PDM) software, computer aided design software (CAD), computer aided engineering software (CAE) and computer aided manufacturing software (CAM). As already mentioned, these have greatly reduced product-to-market time.

This research shows that although engineers are very familiar with these tools, they do present clear barriers for knowledge transfer, especially, if we focus on the transfer of tacit knowledge.

One part of this research focuses on why engineers use several ways to exchange tacit knowledge and why they use other approaches to transfer explicit knowledge.

2.3 Clarifying the key enablers and inhibitors of knowledge transfer between product development teams

The main research strategy is to clarify the enablers of knowledge transfer, through the use of interviews, meeting minutes, reports and e-mail communications. Identifying the enablers will support future knowledge transfer between product development teams. It is also obvious that a successful product development process must be able to transfer intangible ideas and findings as well, and it therefore needs a procedure to manipulate the enablers and inhibitors of knowledge transfer.

If the portion of explicit to tacit knowledge is high, the transfer can be seen as a process-orientated approach. With increasing complexity, the tacit dimension of knowledge grows and the transfer of knowledge is more influenced by tacit enablers and inhibitors of knowledge transfer.

This study used the following questions to identify key enablers and inhibitors of knowledge transfer between product development teams, and evaluate their influence on the knowledge transfer process.

Interview questions to analyse the knowledge transfer process between product development teams:

1. In what ways was knowledge transferred between the engineering team and the product simulation team during the vehicle development process?
2. What influenced the transfer of knowledge during the project?
3. Were there different types of knowledge that were transferred?
4. Were there any types of knowledge that could not be transferred?
5. How did the knowledge groupings differ from those that that could not be transferred?
6. Was this knowledge transferred within the product development group, between the product simulation groups, or between both groups?
7. What type of knowledge was transferred between your engineering group and the other engineering group?
8. Does the transfer of knowledge within your group differ from that transferred between the different functional engineering groups?
9. Was there anything about the project structure that hindered the transfer of knowledge?

Using the results, the research aims to identify a pattern of relationships in order to explain and describe how the engineers tracked the knowledge transfer process of a new product-development activity. To identify patterns of relationships I grouped factors together under codes. Main codes were assembled from several related sub-codes.

Table P1.1 gives an overview of significant codes and sub-codes and categories of the knowledge transfer activities in project one.

Table P1.1: Research results; Enabler and Inhibitors of knowledge transfer

Main Codes to build categories	**Sub-Codes**	**Categories (E=enabler, I=inhibitor)**	**Frequency of occurrence [%]**
C1 Transfer methods	C 1.1 IT infrastructure, C 1.2 Network CAD – CAE → CAx world C 1.3 Storage and retrieve of project data in CAx world C 1.4 CAD data, CATIA files, C 1.5 Lotus notes, for meetings schedule and short memos C 1.6 Intranet C 1.7 DMU – Component matrix C 1.8 Phone C 1.9 Reports provided C 1. 10 Design reviews C 1. 11 Technical specification for quality standards	E	16.4
C2 Personal communication channel	C 2.1 Face-to-face C 2.2 Shoulder-to-shoulder working processes C 2.3 Creation of knowledge patterns	E	12.4
C 3 Personal Knowledge sharing	C 3.1 Individual expertise provided to group C 3.2 Proactive – willingness to transfer and share individual knowledge	E	11.6
C4 Group knowledge sharing	C 4.1 Teams C 4.2 Relationships C 4.3 Creation of knowledge groups	E	14.4
C5 Barriers of knowledge transfer	C 5.1 Functional knowledge stick in silos C 5.2 Unawareness of valuable knowledge C 5.3 Difficult to articulate C 5.4 Uncertainty	I	24.8
C 6 Explicit knowledge transfer	C 6.1 Project structure C 6.2 Communication channels C 6.3 Categories and standardisation of knowledge groups C 6.4 Routines	E	15.2
C7 Economical Constraints	C 7.1 Time C 7.2 Financial resources	I	5.2

As we see in (table P1.1), I used the transcription of interviews (see appendix one), to identify the main codes and sub–codes, and classify them in categories, in order to identify the importance of enablers and inhibitors, based on the role they played during the project and why they were perceived by engineers as more or less important, for the efficiency of the knowledge transfer process.

In some cases the frequency of occurrence is not directly related to the importance of the enablers and inhibitors. Therefore the research outcome gives more weight to several enablers and inhibitors, related to in the importance of their role within the project.

An advantage of the case study is that the simple questions regarding what is going on and *how* things are proceeding, call for a reasonable description of the phenomena observed. As Bernard (1998, p. 317) puts it, such analyses "make complicated things understandable by reducing them to their component parts".

To understand why the engineers perceived several codes and categories as significant, it is important to understand the dynamics and situations of the product development process, which is simply a task and a problem solving process, with different situations during the life cycle of the project.

Therefore I used additional interviews e-mail communication and minutes of meetings. The major purpose to use this additional source of information was to select case examples to analyse of knowledge transfer during the product development process in relation to the performed design stages. The minutes of meetings were a valuable source to identify the major design steps and objectives from a technical context.

To frame and describe specific design tasks, I used in project one six minutes of meetings of design reviews and scanned approximately fifty e-mails related to the design reviews to identify and describe the technical context of the selected design tasks in detail described in (chapter 2.4.1 – chapter 2.4.5).

This study attempts to explain what role several enablers and inhibitors played in the vehicle development process in relation to the knowledge transfer activities. The analysis could have great value creation potential for future knowledge transfer processes, if some of the findings are implemented in order to track efficiently the product development processes that are performed by product development teams containing different engineering disciplines and different fields of expertise.

2.4 Identifying the transfer methods of knowledge transfer in the vehicle development process

Vehicle development is a process where engineers create a shared understanding of how the vehicle should perform and look. In the concept stage, options are created and evaluated; in the pre-engineering phase requirements and constraints become better understood and judgement and interactions between team members shape new ideas. Engineers use a variety of design tools to manage these actions.

If we take into account that vehicle development is relying more and more on virtual product development techniques, the importance of knowledge transfer methods is obvious.

Complex design tasks are a combination of tacit and explicit knowledge. For example, managing the digital network of product development data is a daily routine for automotive engineers. This process contains an explicit portion of knowledge but also knowledge not embedded in the digital product or technical specification, the tacit portion of design knowledge.

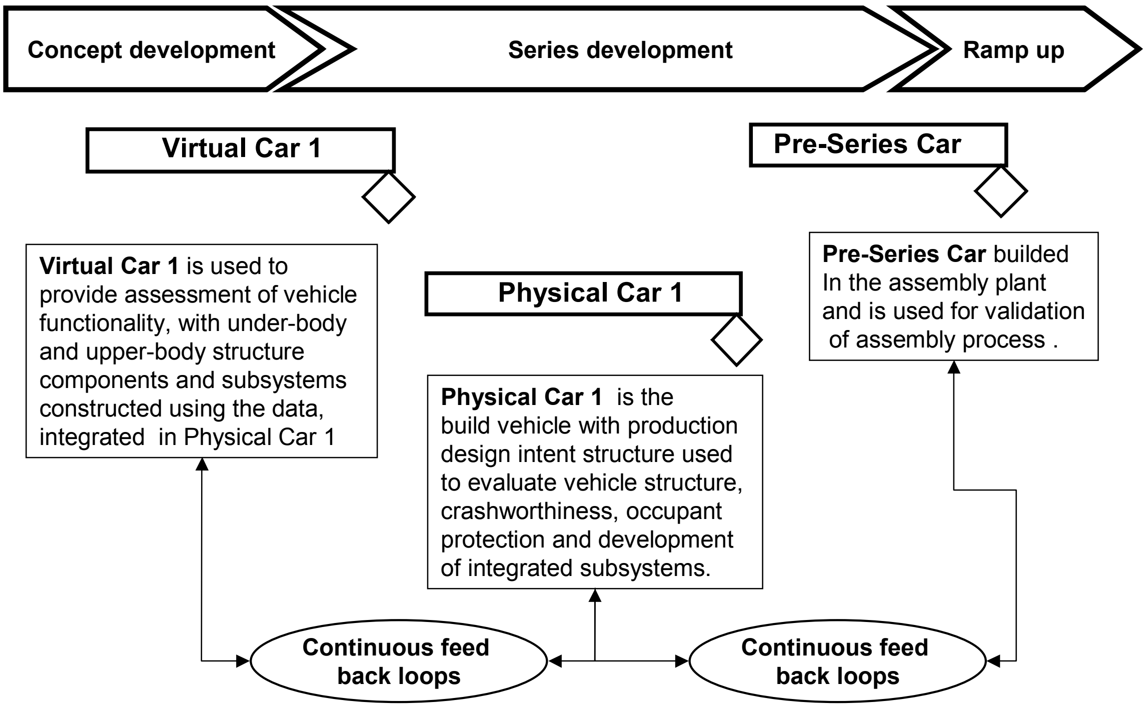
For example, knowledge of experience tends to be tacit, physical and subjective, while knowledge of rationality tends to be explicit, metaphysical and objective. Tacit knowledge is created “here and now” in a specific practical context. Sharing tacit knowledge between individuals through communication is an analogue process; it requires a kind of simultaneous processing of the complexities of issues shared by the individuals. As the research envisage it is mainly transferred in shoulder-to-shoulder working processes and face-to-face contact.

To develop a car in a timeframe between 24 to 36 months, the product development process requires integration of knowledge from different engineering disciplines (figure P1.4). The active coordination of knowledge transfer among product development teams takes place between individuals and teams, so from this point of view it is worthwhile to investigate how knowledge is transferred, and what supports and inhibits the transfer of knowledge between product development teams.

Earlier research on innovation processes had already identified extensive communication as a relevant antecedent to continuous innovation in rapidly changing environments (Burns and Stalker, 1961; Henderson, 1994; Brown and Eisenhardt, 1997). However, my findings from project one suggest that extensive communication is only one aspect of a broader framework; the second important aspect is the ability to create group expertise from individual expertise, which is related to the richness and frequency of contact and information exchange among cross-functional teams.

If we look into the vehicle development process (figure P1.6), we see that there are several vehicle-build stages to integrate product improvement, based on the experience made by previous design stages. To orchestrate product improvement in the product development process, a knowledge correlation between virtual-build vehicle and design and physical builds of vehicle, is necessary.

Figure P1.6: Vehicle build stages



The vehicle build up stages show that collaboration between teams is the centrepiece of continuous product improvement in the vehicle development process.

As we see on the figure above, a continuous vehicle development process is dependent on an active interaction between team members, supported by transactional communication links. Engineers engaged in this process use several transfer methods for knowledge exchange.

The backbone of today's vehicle development is the digital car - information embedded in CAD models, used for design work, simulation and process verification.

In the development process, engineers also rely very much on the transfer of knowledge that is not explicit in printed matter such as manuals or in the CAx world. This knowledge is based on informal, cooperative relationships that build a common understanding, which is essential for conceptualising cross-functional linkages in the vehicle development process.

To transfer explicit knowledge, engineers use a more process-orientated approach (table P1.2). They are very familiar with their transfer methods, and they use them on a daily basis for knowledge exchange.

Table P1.2: Example research interviews

Question 2: What influenced the transfer of knowledge during the project?			
	Interviewees Statements	**Codes**	**Categories**
Interview 10 TL Front Area Simulation	CAx world and PDM systems are easy to share (C1), whereas complex knowledge requirements are very hard to explain, and for this reason it is not easy to share this in design teams. A common understanding needs to be established, which means compatible processes must be integrated. (C 6.3); (C 6.4)	**C1 Transfer methods** C 1.1 IT infrastructure, C 1.2 Network CAD – CAE → CAx world C 1.3 Storage and retrieve of project data in CAx world C 1.4 CAD data, CATIA files, C 1.5 Lotus notes, for meetings schedule and short memos C 1.6 Intranet C 1.7 DMU – Component matrix C 1.8 Phone C 1.9 Reports provided C 1. 10 Design reviews C 1. 11 Technical specification for quality standards	Enablers
		C 6 Explicit knowledge transfer C 6.1 Project structure C 6.2 Communication channels C 6.3 Categories and Standardisation of knowledge groups C 6.4 Routines	Enablers
Interview 12 TL Seats Simulation	Backbone Network Structure, CAx world, (C1) is straight forward and process driven. The seats are in general stand-alone modules developed by the supplier and integrated by the OEM or engineering service (C6) into the car.	**C1 Transfer methods** C 1.1 IT infrastructure, C 1.2 Network CAD – CAE → CAx world C 1.3 Storage and retrieve of project data in CAx world C 1.4 CAD data, CATIA files, C 1.5 Lotus notes, for meetings schedule and short memos C 1.6 Intranet C 1.7 DMU – Component matrix C 1.8 Phone C 1.9 Reports provided C 1. 10 Design reviews C 1. 11 Technical specification for quality standards	Enablers
		C 6 Explicit knowledge transfer C 6.1 Project structure C 6.2 Communication channels C 6.3 Categories and Standardisation of knowledge groups C 6.4 Routines	Enablers

This study shows that to create a virtual car and align different engineering disciplines, the CAx world is perceived as the backbone of knowledge transfer, but with clear constraints.

Complex design tasks are difficult to solve, involving different functional departments, experience of engineers, judgement and tradeoffs. This is the knowledge base about the product, which I classified as the tacit domain of design knowledge. To transfer these sorts of knowledge, engineers rely more on individual knowledge exchange.

If we link these findings to the product development process, we can divide design knowledge into two domains; the explicit domain knowledge is descriptive and available in technical specifications and manuals for example. The tacit domain, on the other hand, involves knowledge that is not available in print-form, is hard to explain and therefore hard to transfer. Engineers face different situations depending on whether they are transferring tacit or explicit knowledge, or a combination of both. The research shows that engineers use different knowledge transfer methods during the different stages of the development process. As stated in section 2.2, in phase one, where the future concept, segmentation and styling is defined, the tacit transfer dominates, to develop the ideas and concepts for a new product generation. Thus the enablers and inhibitors of tacit knowledge transfer have a big influence on the activities related to the product development process.

In phase two, where the product is defined and process technology and preparation for manufacturing is the core activity, engineers are more focused on explicit knowledge. In this stage of the product development lifecycle explicit transfer dominates, and for that reason the enablers and inhibitors of explicit knowledge transfer are perceived as most important.

Figure P1.7: Tacit and explicit domains of inhibitors and enablers of knowledge transfer

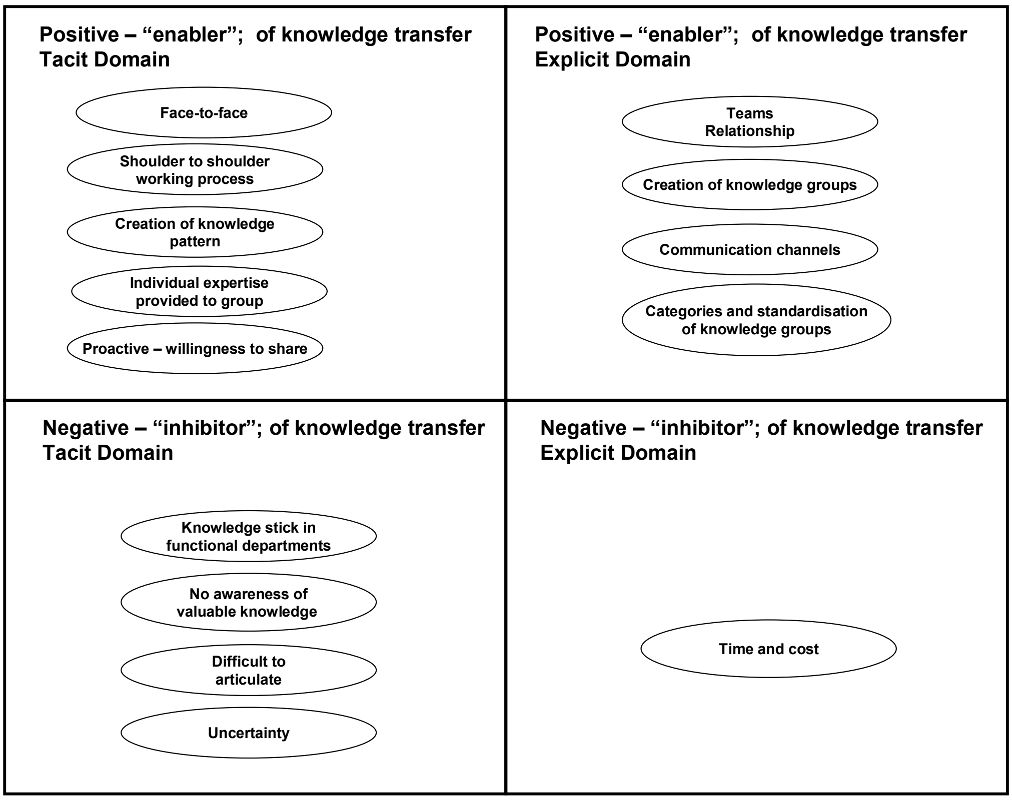


Figure P1.7 gives a graphical classification of enablers and inhibitors. In reality we know that such strict borderlines do not exist, but it is a useful simplified representation.

To understand the impact of enablers and inhibitors, and their interdependence in relation to the product development process, the research investigates major design tasks; when and why they come to light and what role they played in the product development process in relation to the knowledge transfer process.

To take a deeper look into the interdependence of enablers and inhibitors of knowledge transfer in relation to the product development, I have selected the cockpit team. I look at their collaboration with other modular teams, in order to investigate how knowledge is made descriptive and how they create knowledge patterns, to transfer knowledge between different functional areas.

2.4.1 Case example: Tacit design domain in relation to enablers of knowledge transfer

To understand how engineers deal with different kind of knowledge being made at different levels to link emerging technologies into innovative products we focus in detail on the cockpit team and how they used key enablers of knowledge transfer and try to overcome the key inhibitors of knowledge transfer.

The design of an instrument panel is a critical part of a new car design and it plays several important roles; it provides structural support for heating, ventilation and air conditioning, switches, gauges, audio components; it provides storage areas and safety through airbag and energy absorbing; it also plays an aesthetic role - the look, feel and even smell of an instrument panel can affect the appeal of the car and distinguish one car from another.

To combine these different kinds of expertises, teams must be able to develop an understanding of the essential considerations and constraints of all aspects of the instrument panel development (table P1.3) and in addition the know-how must be linked between several technical departments.

Table P1.3: Example research interviews

<table>
<tr><th colspan="4">Interview Question 5:
How did the knowledge groupings differ from those that that could not be transferred?</th></tr>
<tr><th></th><th>Interviewees Statements</th><th>Codes</th><th>Categories</th></tr>
<tr><td rowspan="3">Interview 15
TL Cockpit
Simulation</td><td rowspan="3">There is no problem sharing Digital World, Product plans, PDM with a broad audience. Knowledge existing electronically or in a coded form is easy to transfer. (C1)
Design specific knowledge regarding the modularity and how to create an instrument panel as a complete module (out of 287 parts), and the understanding between subsystems, to assemble them to a functional module, are not enclosed in clearly defined processes. This makes it very hard to create an effective use of the existing expertise.
The valuation of essential design knowledge is still not defined and is still most successful transferred in face-to-face meetings and close co-location of teams. (C2)</td><td>C1 Transfer methods

C 1.1 IT infrastructure,
C 1.2 Network CAD – CAE → CAx world
C 1.3 Storage and retrieve of project data in CAx world
C 1.4 CAD data, CATIA files,
C 1.5 Lotus notes, for meetings schedule and short memos
C 1.6 Intranet
C 1.7 DMU – Component matrix
C 1.8 Phone
C 1.9 Reports provided
C 1. 10 Design reviews
C 1. 11 Technical specification for quality standards</td><td>Enablers</td></tr>
<tr><td>C2 Personal communication channel
C 2.1 Face to face
C 2.2 Shoulder to shoulder working processes
C 2.3 Creation of knowledge patterns</td><td>Enablers</td></tr>
<tr><td>C 6 Explicit knowledge transfer
C 6.1 Project structure
C 6.2 Communication channels
C 6.3 Categories and Standardisation of knowledge groups
C 6.4 Routines</td><td>Enablers</td></tr>
</table>

In order to develop the ideas created in phase 1 (tacit domain), it is necessary to make this tacit domain explicit. The new shape of future products must be created through drawing and modelling, to implement the aspects of innovation through to manufacturing. To make their individual know-how understandable and articulate what they need to say, people need to frame it in knowledge patterns,

This transformation of individual knowledge to group knowledge is greatly enhanced by close personal contact, talking with others and face-to-face interaction, which facilitates a sharing of common emotions and experiences. As a result of this contact, engineers combine their individual knowledge and create a shared knowledge base about the product.

In the concept phase of products with an important appeal to the customer, like body exterior style or the cockpit, a lot of emotional factors are considered; what is the product identity; what does it stand for? These characteristics are generated through styling; the shape of a product gives people the right impression, and defines the brand characteristics. The key issue of styling is, how do we transfer know-how and perception of a new product, and link it to the product development process. In general a *product plan* (figure P1.8) links different issues of information together; availability of development resources; life cycles of current products; expected life cycles of competitive offerings; timing of major production system changes; availability of product technologies. To combine all these different fields of expertise engineers work in shoulder-to-shoulder working processes.

Figure P1.8: Product plan instrument panel

Product Plan Instrument Panel

Input

1. Voice of the customer
2. Business plan / marketing strategy
3. Product / process benchmark data
4. Product / process assumptions
5. Product reliability studies
6. Consumer inputs

1. Design goals
2. Reliability and quality goals
3. Preliminary BOM
4. Product and process characteristics
5. Product assurance plan

Product plan Instrument panel

Instrument panel components	Number of unique parts	Development costs £ millions	Tooling costs £ millions	Manufacturing costs £ millions	Comments
Air-con system	45	2,5	5,7	127	Duct work and support structure different motors and other components
Dash cover and structure	52	2,5	4,5	77,5	Share some brackets and components with other models
Electrical equipment	115	2,5	1,5	265	Share switches with other models
Cross-car beam	12	1,3	1,3	22	Entirely different
Steering system and airbags	26	1,3	0,1	126	All components different
Instrument and gauges	16	0,6	0,2	14	Can share instruments with other models
Moulding and trim	10	0,3	0,2	7	All different
Insulation	3	0,1	0,2	5	All different
Audio and radio	8	0,1	0	189	Same options for all models
TOTAL	**287**	**11,2**	**13,7**	**832,5**	

The Differentiation Plan: ***" What creates a different appeal and impression for the customer Sportive versus Comfort"***

Possibility to create Differentiation	Sportive appeal
Design, curvature of windshield	More curvature
Styling of Instrument panel	Sportive design, racing touch
Relationship between driver and instrument	Driver sits low to ground, distant from steering wheel, with seat
Hard Point: Cowl Top, Dash PNL, A-Pillar lwr	Different package of seating position
Colour & Texture	Darker colours and mix of leather and textile
Suspension & handling	Stiff for improved handling
Acoustic	Some engine noise, desirable
Possibility to create Differentiation	**Higher comfort**
Design, curvature of windshield	Straight vertical
Styling of Instrument panel	Highly functional
Relationship between driver and instrument	Driver sits higher, closer, more upright
Hard Point: Cowl Top, Dash PNL, A-Pillar lwr	Different package of Seating position
Colour & Texture	Practical surfaces and colours
Suspension & handling	Softer , for improved comfort
Acoustic	Noise minimised

Output

Product knowledge base

" Which is communicated and shared with other engineering disciplines"

Product knowledge must be collected and combined so that it can be transferred between different functional teams. Knowledge transfer only takes place if the receiving parties understand it, and thus it must be descriptive, in order to support decisions made on this knowledge base.

For example a product plan (figure P1.8) articulates the needs and customer wants regarding the appeal of an instrument panel (sporty versus comfortable). The engineers used it as a gateway to bridge different fields of expertise (marketing, styling and product engineering) and discuss the feasibility of different styles and trends.

This is a piece of technical context, which is able to create an understanding between different functions, and helps to implement the final shape of a new instrument panel. Here we see, that, even before the product comes alive, it must be shaped in people minds and communicated through all functional levels involved.

The creation of the product plan contains intensive face-to-face contact, and shoulder-to-shoulder working processes between different engineering disciplines. It is not a piece of paper, it is a common understanding in knowledge groups, and this expertise is combined in knowledge patterns and made descriptive, and therefore communicable.

Table P1.4: Example research interviews

Interview Question 6: Was this knowledge transferred within the product development group, between the product simulation groups, or between both groups?			
	Interviewees Statements	**Codes**	**Categories**
Interview 19 TL Cockpit Engineering	The problem is to capture the know-how of different engineering disciplines, because of the complexity of a module; and further on, to combine modules in a vehicle is a working process, which creates some tensions. It is not always a smooth process to link knowledge and combine knowledge in product development processes. A common understanding in knowledge groups would help to create knowledge patterns, to define what expertise we need to create an excellent product. (C2.3)	**C2 Personal communication channel** C 2.1 Face-to-face C 2.2 Shoulder-to-shoulder working processes C 2.3 Creation of knowledge patterns	Enablers

Continuous Table P1.4: Example research interviews

Interview Question 6: Was this knowledge transferred within the product development group, between the product simulation groups, or between both groups?			
	Interviewees Statements	**Codes**	**Categories**
Interview 15 TL Cockpit Simulation	To define what is transferred we must be able to classify essential design knowledge and important know-how to create future products. (C6.3) Focus. for example. in the future what technology do we need to create future instrument panels, which cover innovation, and market needs for 2007 - 2010? How to make such know how transferable; how should it be collected; what project structure do we need to link such individual know how of different engineering and marketing disciplines? (C 6.1)	**C 6 Explicit knowledge transfer** C 6.1 Project structure C 6.2 Communication channels C 6.3 Categories and Standardisation of knowledge groups C 6.4 Routines	Enablers
Interview 16 TL Doors Engineering	People working shoulder-to-shoulder have intensive transfer of knowledge. They also establish a common approach to knowledge sharing. (C2)	**C2 Personal communication channel** C 2.1 Face to face C 2.2 Shoulder to shoulder working processes C 2.3 Creation of knowledge patterns	Enablers

In general, the collaboration and interaction of personnel can be seen as a key driver in transferring complex design knowledge within the product development process. A project structure, which facilitates face-to-face contact, where individuals can meet each other relatively easily, is generated in a co-location environment. Co-location means sharing of place and is not a new approach to break up the silos of expertise between different functions.

For example Ford used a co-location strategy in 1993 to develop the Ford Mustang. Different engineering sub-teams were co-located, and this created an atmosphere of knowledge sharing. Engineers were able to collaborate with each other to reach common styling and technical goals in a relatively shorter amount of time (Peitrangelo, 1993).

In vehicle development, non-routine tasks are high on complexity, and cannot be solved by single persons or functions, so co-location has a positive influence in knowledge transfer. However, it is a more complex relationship, because intensive collaboration of engineers does not automatically create successful knowledge transfer.

A high degree of task interdependence between technical disciplines requires that team members have an understanding of the product system architecture (figure P1.4). This means that engineers must have access to a basic knowledge of the compatibility and interaction effects of the various vehicle modules and components.

This creates the need to identify, access, combine and share the product knowledge base, which makes it possible that people engaged in the development process use different kinds of knowledge to capture and link new technologies into innovative products.

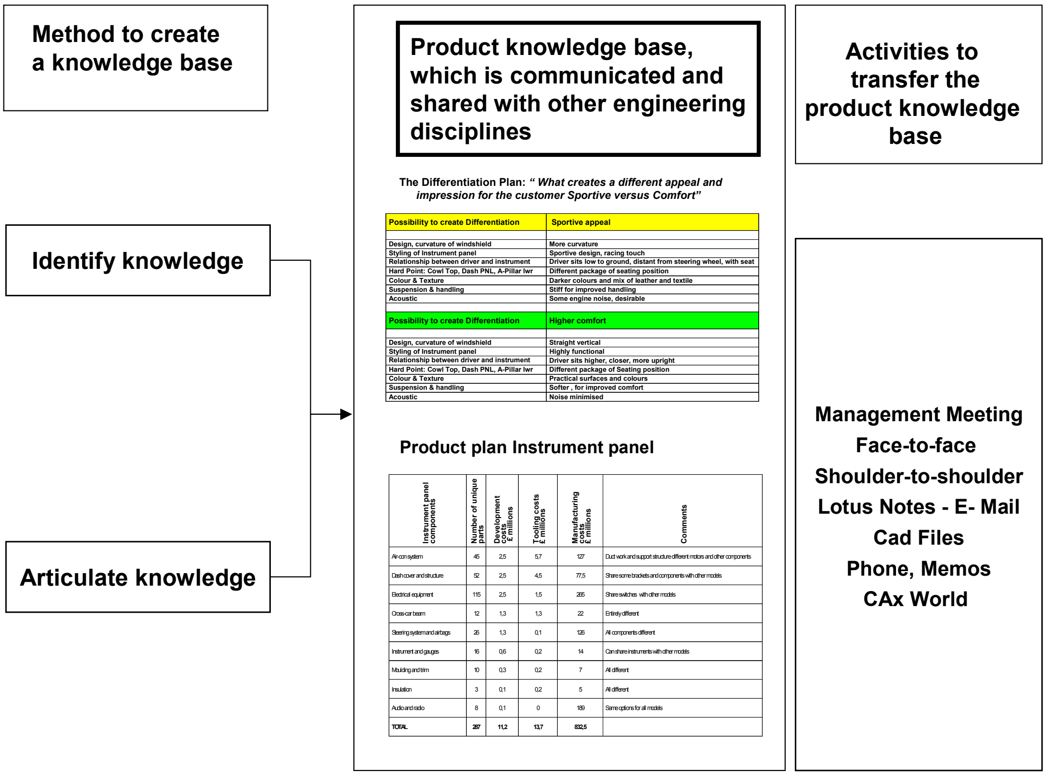
2.4.2 Identifying and combining knowledge to create a product knowledge base

To create a knowledge base about the new product, an identification of knowledge takes place: what is the right expertise; who posses the expertise; and how should we combine this expertise so that we can develop a new product? Very often the expertise relies on individuals, and therefore it is important in product development activities that individual expertise is provided to the product development group, and shared between different functions.

The complexity of vehicle development activities makes it obvious that a single person cannot perform the entire activity, and even not a single department is able to develop a car. Therefore engineers of several engineering disciplines must create a common understanding and shared vision to develop a new vehicle. Nonaka and Johansson (1985, p. 183) describe this as involving "...an organisational process where individual knowledge is shared, evaluated and integrated with others in the organisation". While individuals are the agents through which organisations learn, individual learning must be communicable, shared publicly, and integrated for it to become "organisational" (Duncan and Weiss, 1979; Nonaka and Johansson, 1985).

Communication, knowledge sharing and information distribution processes are instrumental in making individual insights and know-how accessible to others (Nonaka and Johansson, 1985).

Figure P1.9: Identify and articulate knowledge to create a product knowledge base



Possibility to create Differentiation	Sportive appeal
Design, curvature of windshield	More curvature
Styling of Instrument panel	Sportive design, racing touch
Relationship between driver and instrument	Driver sits low to ground, distant from steering wheel, with seat
Hard Point: Cowl Top, Dash PNL, A-Pillar lwr	Different package of seating position
Colour & Texture	Darker colours and mix of leather and textile
Suspension & handling	Stiff for improved handling
Acoustic	Some engine noise, desirable

Possibility to create Differentiation	Higher comfort
Design, curvature of windshield	Straight vertical
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Instrument panel components	Number of unique parts	Development costs £ millions	Tooling costs £ millions	Manufacturing costs £ millions	Comments
Air-con system	45	2,5	5,7	127	Duct work and support structure different motors and other components
Dash cover and structure	52	2,5	4,5	77,5	Share some brackets and components with other models
Electrical equipment	115	2,5	1,5	265	Share switches with other models
Cross-car beam	12	1,3	1,3	22	Entirely different
Steering system and airbags	26	1,3	0,1	126	All components different
Instrument and gauges	16	0,6	0,2	14	Can share instruments with other models
Moulding and trim	10	0,3	0,2	7	All different
Insulation	3	0,1	0,2	5	All different
Audio and radio	8	0,1	0	189	Same options for all models
TOTAL	**287**	**11,2**	**13,7**	**832,5**	

From this perspective a product knowledge base (figure P1.9) about the product creates a pattern of expertise and gives an overview about the different functional areas involved in the development process. It is therefore a systematic entry gate for further discussions and it defines a link between different functional areas.

A high degree of single expertise has to be linked to create a common understanding of the development process, if we take into account that an instrument panel is built out of around 300 unique parts.

To create a knowledge base of a product, it must be translated into a form that it is available for product development teams, so knowledge must be identified and combined. Identifying and combining knowledge means deciding what describes the product, in a manner that other functional departments can use and handle the information provided by the specialist.

The gathering together of information, which can be considered as a pre-knowledge creation activity, needs some energy and time, but so soon as the product knowledge is available in a visual context, embedded in a presentation or CAD model, it is able to be transferred and shared between different parties.

As previously mentioned, a real challenge for all engineers involved in this activity is to create group expertise from individual expertise (table P1.5) and make this group expertise descriptive so that it can be transferred.

Table P1.5: Example research interviews

Question 2: What influenced the transfer of knowledge during the project?			
	Interviewees Statements	**Codes**	**Categories**
Interview 5 PM BIW HOP Simulation	Through team communication (4.1), you can create a common understanding (C4.3), which creates the ability to work effectively on a cross functional basis; for example from styling concept down to manufacturing.	**C4 Group knowledge sharing** C 4.1 Teams C 4.2 Relationship C 4.3 Creation of Knowledge groups	Enablers
Interview 9 TL Body Side Simulation	Problem solving is dependent on the relationship of teams (C 4.2), how they share knowledge in groups(C 4.3) and create a common understanding.	**C4 Group knowledge sharing** C 4.1 Teams C 4.2 Relationship C 4.3 Creation of Knowledge groups	Enablers

Continuous table P1.5: Example research interviews

Interview Question 3: Were there different types of knowledge that were transferred?			
Interview 9 TL Body Side Simulation	Selecting the right resources of knowledge is the key, to combine group expertise to create modular design knowledge. (C4.3) Cars are divided in modules and every module is created by a subsystems, so engineers need the skills to facilitate know-how existing in subsystems and link them together to a knowledge base of a complete module. (C4.1 +C4.2). Different functions must align their know-how to create a shared understanding in knowledge groups (C4.3) different functions must have a common understanding of the module, a key for successful vehicle development.	**C4 Group knowledge sharing** C 4.1 Teams C 4.2 Relationship C 4.3 Creation of Knowledge groups	Enablers
Interview Question 4: Were there any types of knowledge that could not be transferred?			
Interview 12 TL Seats Simulation	Knowledge transfer is to some extent a definition of processes, but strongly influenced by individuals and their role they play in the teams. (C3)	**C 3 Personal knowledge sharing** C 3.1 Individual expertise provided to group C 3.2 Pro active – willingness to transfer and share individual knowledge	Enablers
Interview 14 TL Interior Simulation	Components know how relies on individuals: Mr. Instrument panel or Mr. Door panel, says a lot how personified such a knowledge is. (C3.1). To leverage this knowledge and provide it to junior engineers would be a very important activity in the vehicle development process. (C3.2)	**C 3 Personal knowledge sharing** C 3.1 Individual expertise provided to group C 3.2 Pro active – willingness to transfer and share individual knowledge	Enablers

A successful product development process needs the application of created knowledge; teams involved in the knowledge creation process create a common understanding of the essential considerations and constraint of all aspects of the vehicle development project.

The creation and management of different knowledge groupings avoids the overloading of the design process. Picking the right expertise for design solution is a gateway to make product design right first time. All parties involved in the vehicle development must have a basic knowledge base for the whole system. This creates a common understanding between different functions, supports the allocation of individual skills and generates a broad participation of team members. It therefore links the expertise of different functional levels to a collective knowledge base about the product.

Pertaining to this, Nonaka and Takeuchi (1995, p. 237) say, "the essence of knowledge creation is deeply rooted in the process of building and managing synthesis". In relation to this perspective, the project engineers must have power over practical assets, be capable of working in a problem-definition and task-oriented manner and possess skills for both analysis and combination.

2.4.3 Case example: Tacit design domain in relation to inhibitors of knowledge transfer

On the surface, engineering design knowledge appears to be concrete and declarable. Such knowledge is expressed in tables of data, formulae in handbooks, standards, company documents and so on (the *explicit* domain of design knowledge), but in reality we know that this externalised knowledge is not sufficient. Engineers have problems articulating their past experience or describing in detail why they chose a particular decision and the basis for some of their justifications. (This is the *tacit* domain of design knowledge.)

In summary, the engineers pull all these different types of experience together, determine what is applicable, select the appropriate mechanism and justify the selection.

The understanding of what knowledge to use, why it was used, how to use it, which selection was more appropriate for the present application and why engineers know what they know is difficult to express in writing or speech and for that reason very difficult to transfer.

In the research project (figure P1.4), we see that vehicle development contains different engineering disciplines, like chassis, drive train, engine, body in white, interior and electronics, and engineers of these specific disciplines are specialists in their fields. They posses a high portion of domain-specific knowledge, which is so complicated that it is barely understood by other engineering disciplines. This generates the perception that functional knowledge has to stick in their domain specific silos of functional expertise (table P1.6).

If we take the virtual car, everybody has the same source of knowledge but the interpretation is completely different within differing engineering teams.

Even, where engineers have an overlapping context of expertise, like front end with bumpers or drive train and chassis, it cannot be taken for granted, that engineers have a common understanding and talk the same language. For example it is not guaranteed that the chassis engineer understands the needs of the drive train engineer or vice versa, Based on this knowledge gaps, engineers have problems identifying and combining valuable knowledge. One engineer stated, “A big source for failures or delays in the process, which cause additional design loops, is created because each party doesn’t understand the other one”.

Table P1.6: Example research interviews

	Interviewees Statements	Codes	Categories
Interview Question 3: Were there different types of knowledge that were transferred?			
Interview 10 TL Front Area Simulation	Everybody as a team member has the virtual car, so theoretically everybody has the same source of knowledge, but the interpretation is completely differing in the groups (C5.3). Even in modules like front end with bumpers, integration of power train, suspension etc., is not a confirmed understanding established to create successful decision processes where the suspension engineer understands the needs of the drive train engineer, so we are starting with trade-offs based on vague understanding. (C 5.1 + C 5.4). A big source of failures or delays in the processes one parties' lack of understanding of the other. (C 5.4 + C 5.3 + C 5.2)	**C5 Barriers of knowledge transfer** C 5.1 Functional knowledge stick in silos C 5.2 Unawareness of valuable knowledge C 5.3 Difficult to articulate C 5.4 Uncertainty	Inhibitor
Interview Question 5: How did the knowledge groupings differ from those that that could not be transferred?			
Interview 8 TL Body Side engineering	Expertise solves by itself design specific tasks and provides the solution to the sub-teams or module-teams. Mostly these teams have to rely on these solutions, because decision based on domain specific expertise is a grey area and hard to quantify for module-teams. (C5.2+C5.3+C 5.4)	**C5 Barriers of knowledge transfer** C 5.1 Functional knowledge stick in silos C 5.2 Unawareness of valuable knowledge C 5.3 Difficult to articulate C 5.4 Uncertainty	Inhibitor
Interview 7 PM Interior Simulation	Innovative know-how and expertise is difficult to describe and explain as it is mostly dedicated to functional expertise. (C 5.1)	**C5 Barriers of knowledge transfer** C 5.1 Functional knowledge stick in silos C 5.2 Unawareness of valuable knowledge C 5.3 Difficult to articulate C 5.4 Uncertainty	Inhibitor
Interview 3 PM BIW HOP Engineering	The vehicle as a whole is a development process combining modules out of sub-systems and they are created out of components, which are generated under an ongoing design processes, and continuous change processes. This complexity creates a barrier for sharing knowledge between cross-functional disciplines. Knowledge gaps (C 5.1) are the problem; all parties involved do not always understand the expertise. (C 5.3). In the teams understanding is good but between cross functions it is very specific and difficult – a different world of expertise. (C 5.1)	**C5 Barriers of knowledge transfer** C 5.1 Functional knowledge stick in silos C 5.2 Unawareness of valuable knowledge C 5.3 Difficult to articulate C 5.4 Uncertainty	Inhibitor

In the light of current vehicle development processes, sharing all knowledge between all individuals would be inefficient, not to say impossible. Even if the exact knowledge required is transferred to the engineers, there are still numerous potential barriers to the receivers' correct interpretation. As noted in many decision-making studies, decision-makers often face the trade-offs between quality information and accessible information. When there is time pressure, the decision-makers tend to accept lower quality information that is more accessible (O'Reilly, 1982; Todd and Benbasat, 1991; Ahituv, Igbaria and Sella, 1998).

One of the appropriate goals of knowledge management in vehicle development processes would be to provide rapid access to quality knowledge, which is achievable if a reasonable "*knowledge base of the product"* (figure P1.9), exists and it is understood by all decision makers engaged in the product development process.

2.4.4 Case example: Explicit design domain in relation to enablers of knowledge transfer

A typical vehicle must be engineered to endure 10 years of useful life and / or over 160,000 km of normal driving, to achieve general durability design targets. To secure this lifetime performance, the structural integrity of new vehicles is a basic requirement for a complete vehicle engineering and development program. The results of a vehicle's performance directly affect its marketability, profitability, and, most importantly, the existence of the automobile manufacturer. A set of design criteria and performance targets must be established at the beginning of the engineering and development stage of any product development program.

Phase one of the vehicle development process (figure P1.3), concepts and technology, and phase two, product and process, covers the complete design cycle, with a duration of thirty-two to thirty eight months for most vehicle programs, which industries continually strive to reduce.

CAD and CAE tools are used during the vehicle development process to create a virtual car (figure P1.6), which is used to integrate new ideas, failure analysis, optimisation process and, based on several design criteria and performance targets, the product performance is assessed before the physical prototype enters the proving ground and testing phase.

In the concept phase the styling is defined. The next step is to conduct a feasibility study and form the design concept. The typical sections and major dimensions are defined in this stage of the vehicle development process.

As soon as the major dimension are defined, the focus moves on to crashworthiness and occupant safety related issues, as they are the most critical and the most difficult to modify once the feasibility concept is established. CAE appears to be the most effective approach in achieving the safety-related criteria at this stage. The virtual car (figure P1.6) contains, electronically, the production design intent structure, which is also used to evaluate vehicle structure, crashworthiness, occupant protection and development of integrated subsystems.

Table P1.7: Engineering tasks, engineering activities, and knowledge transfer

Engineering tasks: Crashworthiness studies	Engineering activities	Knowledge transfer
Frontal Barrier Impact Rear End Barrier Impact Dynamic Side Impact Roof Crush Load Bearing Capacity Knee Bolster Energy Absorbing Free Motion Head Form Impact Seat Belt Pull	The vehicle crashworthiness simulations strictly conform to the test procedures defined by the legislation of various governments. The performance simulations are usually dictated by legislation, the insurance industry, and consumer groups. These groups affect the manufacturer's design criteria and performance targets for a given vehicle. The most common safety standard used for design targets and performance guidelines is the Federal Motor Vehicle Safety Standards (FMVSS) established in the USA. The performance criteria are usually measured in terms of load/energy bearing capacity (door intrusion and roof crush), crash distance (frontal impact), injury index (HIC and Chest G), and fuel leakage (rear end impact). Safety requirements for the EEC (European Economic Community) are established in the same manner as the FMVSS.	**C1 Transfer methods** C 1.1 IT infrastructure, C 1.2 Network CAD – CAE → CAx world C 1.3 Storage and retrieve of project data in CAx world C 1.4 CAD data, CATIA files, C 1.5 Lotus notes, for meetings schedule and short memos C 1.6 Intranet C 1.7 DMU – Component matrix C 1.8 Phone C 1.9 Reports provided C 1. 10 Design reviews C 1. 11 Technical specification for quality standards **C 6 Explicit knowledge transfer** C 6.1 Project structure C 6.2 Communication channels C 6.3 Categories and Standardisation of knowledge groups C 6.4 Routines

The vehicle structural integrity can be confirmed after the above stated safety criteria are passed (table P1.7). Some of the major automobile manufacturers have established higher standards than those defined in the EEC and FMVSS, to satisfy the insurance industry and consumer group requirements, because many educated buyers are making purchasing decisions based on the published crashworthiness performance of vehicles.

In terms of vehicle engineering this requires a consistent virtual product development process. The electronic drawings generated by three-dimensional wire and surface structures and then a digital-mock-up in short called DMU, describe the whole vehicle in a digital form, and this can be used for crash investigations, assembly analysis and structural analysis. This geometric representation of the whole vehicle, containing information such as the materials used, physical properties, space information and joint technologies and tolerances, is captured in several software tools, in short summarised as the CAx – world. This information is available in explicit form for all engineers, and it is communicated electronically.

As soon as this product knowledge base of the virtual car is available in a codified form, it is very efficiently used in the product development teams.

Table P1.8: Example research interviews

Question 1: In what ways was knowledge transferred between engineering team and product simulation team during the vehicle development process?			
	Interviewees Statements	**Codes**	**Categories**
Interview 13 TL Interior Engineering	Very good results in phase two with CAx world – digitised knowledge transfer Lotus notes, Word, Excel, Power point PDM Tools, DMU – Component matrix Part lists Technical Specifications Phone Fax	**C1 Transfer methods** C 1.1 IT infrastructure, C 1.2 Network CAD – CAE → CAx world C 1.3 Storage and retrieve of project data in CAx world C 1.4 CAD data, CATIA files, C 1.5 Lotus notes, for meetings schedule and short memos C 1.6 Intranet C 1.7 DMU – Component matrix C 1.8 Phone C 1.9 Reports provided C 1. 10 Design reviews C 1. 11 Technical specification for quality standards	Enablers

In the research project, if the vehicle development process reaches phase two, where most of the interfaces are clear defined, the virtual car is in a very detailed model containing all relevant parts and the knowledge transfer is very efficient and process orientated (table P1.8).

In this phase the main focus is on product and process engineering, which requires a detailed existence of CAD and CAE models with clearly defined interfaces to bundle all information about the whole vehicle, to make intensive reflections of manufacturing and assembly aspects. Still the vehicle is under an optimisation process containing several design parameters such as materials quality, thickness of several components, joining techniques and assembly procedures, but major geometrical changes are not common in this phase of the product development process. The knowledge base about the product is broadly known and shared by all engineers; single modules are defined and combined to a functional system.

In this phase engineers can base their judgement on a sufficient knowledge base about the product as the vehicle at least exists in electronic form, components, systems and modules are defined, product descriptions for components exist and a high context of the vehicle is available in codified form.

This explicit knowledge is transferred very efficiently in the vehicle development process.

2.4.5 Case example: Explicit design domain in relation to inhibitors of knowledge transfer

In vehicle development projects engineers need to tackle a large amount of information about technical details of the vehicle development and manufacturing processes, which is unavailable at the beginning of the vehicle project. Due to the complex design tasks and knowledge gaps between several functional departments, knowledge exchange is time consuming and is constrained by cost and time (table P1.9).

Table P1.9: Example research interviews

Question 2: What influenced the transfer of knowledge during the project?			
	Interviewees Statements	**Codes**	**Categories**
Interview 11 TL Front Area Engineering	Vehicle development is strongly aligned to the development schedule through stage gate processes, to secure product quality regarding technical specifications and strict budget control; this creates a constraint for intensive knowledge sharing. (C7)	**C7 Economical constraints** C 7.1 Time C 7.2 Financial resources	Inhibitors
Interview Question 3: Were there different types of knowledge that were transferred?			
Interview 2 Head BIW Simulation	Many different solutions are given no chance to come to fruition because of constraints regarding budget and timeframe, which is a constraint for knowledge sharing, People are communicating on a task performing basis with little space for new ideas. (C 7)	**C7 Economical constraints** C 7.1 Time C 7.2 Financial resources	Inhibitors
Interview Question 8: Does the transfer of knowledge within your group differs from that transferred between the different functional engineering groups?			
Interview 19 TL Cockpit Engineering	The squeezed time schedule is seen as a barrier for many engineers to integrate innovation in the development process, (C7) For that reason knowledge creation is not integrated, as it should be.	**C7 Economical constraints** C 7.1 Time C 7.2 Financial resources	Inhibitors

Many vehicle projects are on overly tight schedules, driving out the time needed to allow the engineers to learn. While the pace of activity under time pressure may increase, research suggests that time pressure can be motivating only up to a point (Andrews and Farris, 1972; Kelly and McGrath, 1985). Rather than squeezing each project over tight schedules, automotive manufacturers are better off creating a sufficient knowledge base about the modules to be integrated into future vehicle lines. This would slash the development time for the vehicle development projects they follow.

Knowledge creation involves making tacit knowledge explicit. The same principle relies on a sufficient knowledge base to define, for components, current capabilities and current constraints of applications. It helps to show how the components will perform in new design solutions.

To create such a product knowledge base takes time up-front to explore and document feasible solutions from design and manufacturing perspectives, but leads to tremendous gains in efficiency and product integration later in the vehicle development process. It acts as a kind of design library for future vehicle projects, which helps to determine feasibility of several design solutions at an early stage and avoids applying many design loops until the solution meets the design objectives.

This investment of time up-front may require a cultural shift by European and American vehicle manufacturers, with regard to how they steer and allocate resources to future vehicle development programmes.

European companies are good at creating and using knowledge, which is easily communicated as information. In Japan, according to Nonaka and Takeuchi (1995), tacit knowledge is emphasised for the innovation process. If it is possible to make tacit, unarticulated knowledge explicable, then we could speed up learning-, transfer-, and innovation-processes within organisations.

In order to create knowledge for new product development processes we have to organise the process to make tacit knowledge available to people engaged in the vehicle development process.

The creation of a sufficient knowledge base of vehicle modules would make tacit knowledge, unknown knowledge and unarticulated knowledge, explicable in some way, so that it can be transferred between people.

2.5 Product knowledge base to create and transfer knowledge

A reasonable knowledge base about the product creates a great potential to enhance knowledge creation and knowledge transfer in product development teams, so that as soon as knowledge is articulated, product development teams can share it.

This finding is aligned with the work by Takeuchi and Nonaka (1995), who proposed the SECI modes, which explore knowledge creation through conversion between tacit and explicit knowledge. The SECI modes consist of socialisation (S), externalisation (E), combination (C), and internalisation (I). Socialisation converts new tacit knowledge such as shared mental models, technical skills, and shared experience. Typically, it occurs from an apprenticeship rather than documents or manuals. Externalisation transfers tacit knowledge into explicit concepts. Externalisation can be seen in the process of concept creation and triggered by dialogue or collective reflection. Combination converts explicit knowledge into more systematic sets. Internalisation embodies explicit knowledge into tacit knowledge. Explicit knowledge can be internalised into individuals' tacit knowledge. These four modes of knowledge conversion are aligned with the activities engineers have to perform (table P1.10) if they create a product knowledge base, which is a process of knowledge creation and knowledge transfer. A product development process involves different engineering disciplines, with different backgrounds and expertise. A product knowledge base supports the exchange of individuals' explicit and tacit knowledge into a common understanding and a shared vision of the new product characteristics and product development processes.

Table P1.10: Knowledge combination to create a product knowledge base

Engineering activities	**Knowledge combination**	**Example of product knowledge base, which is transferred and shared**
For example a product plan (figure P1. 8) articulates the needs and customer wants regarding the appeal of an instrument panel - sporty versus comfortable. Engineers used it as a gateway to bridge different fields of expertise; marketing, styling, product engineering, to discuss the feasibility of different styles and trends. This is a piece of technical context, which is able to create an understanding between different functions, and helps to be implement the final shape of a new instrument panel. Here we see that even before the product comes alive, it must be shaped in people minds and communicated through all functional levels involved.	**Socialisation** converts new tacit knowledge such as shared mental models, technical skills, and shared experience.	The creation of the product plan contains intensive face-to-face contact, and shoulder-to-shoulder working processes between different engineering disciplines. It is not a piece paper, it is a common understanding in knowledge groups, and this expertise combined in knowledge patterns is made descriptive, and thus communicable.

Continuous table P1.10: Knowledge combination to create a knowledge base

Engineering activities	Knowledge combination	Example of product knowledge base, which is transferred and shared
To create a common knowledge base about the new product, an identification of knowledge takes place: what is the right expertise; who posses the expertise; and how should we combine this expertise so that we can develop a new product? Very often the expertise relies in individuals and therefore it is important in product development activities that individual expertise is provide to the product development group, and shared between different functions. The complexity of vehicle development activities makes it obvious that a single person cannot perform this activity, and not even a single department is able to develop a car. Therefore engineers of several engineering disciplines must create a common understanding and shared vision to develop a new vehicle.	**Externalisation** transfers tacit knowledge into explicit concepts. Externalisation can be seen in the process of concept creation and triggered by dialogue or collective reflection.	Knowledge must be prepared for the transfer. This activity can be seen as a pre-knowledge creation activity, it needs some energy and time, but as soon as the product knowledge is available in a visual context, embedded in a presentation or CAD model, it is able to be transferred and shared between different parties. A real challenge for all engineers involved in this activity is to create group expertise out of individual expertise and make this group expertise descriptive, so that it can be transferred.
In the research project, if the vehicle development process reaches phase two, where most of the interfaces are clear defined, the virtual car is in a very detailed model containing all relevant parts and the knowledge transfer is very efficient and process orientated, In this phase the main focus is on product and process engineering, which requires a detailed existence of CAD and CAE models with clearly defined interfaces to bundle all information about the whole vehicle, to make intensive reflections of manufacturing and assembly aspects.	**Conversion** converts explicit knowledge into more systematic sets.	The knowledge base about the product is broadly known and shared by all engineers; single modules are defined and combined to a functional system. In this phase engineers have a sufficient knowledge base about the product; the vehicle exists at least in electronic form. Components, systems and modules are defined, product descriptions of components exist and a high context of the vehicle is available in codified form. This portion of knowledge, called explicit dimension of design knowledge, is transferred very efficiently in the vehicle development process.
Knowledge creation involves making tacit knowledge explicit and vice versa, The same principle relies on a sufficient knowledge base to define, for components, current capabilities and current constraints of applications. It helps to show how the components will perform in new design solutions. To create such a knowledge base takes time up-front to explore and document feasible solutions from design and manufacturing perspectives, but leads to tremendous gains in efficiency and product integration later in the vehicle development process.	**Internalisation** embodies explicit knowledge into tacit knowledge. Explicit knowledge can be internalised into individuals' tacit knowledge. "Learning by doing and on past experience"	The knowledge base acts as a kind of design library for future vehicle projects, which helps to determine feasibility of several design solutions at an early stage and avoids applying many design loops until the solution meets the design objectives. So it gives engineers a guideline regarding what they can learn on past experience and creates a new expertise combining past experience with new technologies.

This knowledge combination between engineers creates a common understanding of the product, which gives them the ability to define current capabilities and constraints of a product related to several engineering disciplines.

For example, body exterior panels defining the appeal of a vehicle are sophisticated styling solutions and are challenging in the manufacturing process. A knowledge conversion between styling, body engineers and manufacturing engineers, helps to define the constraints of a body shape.

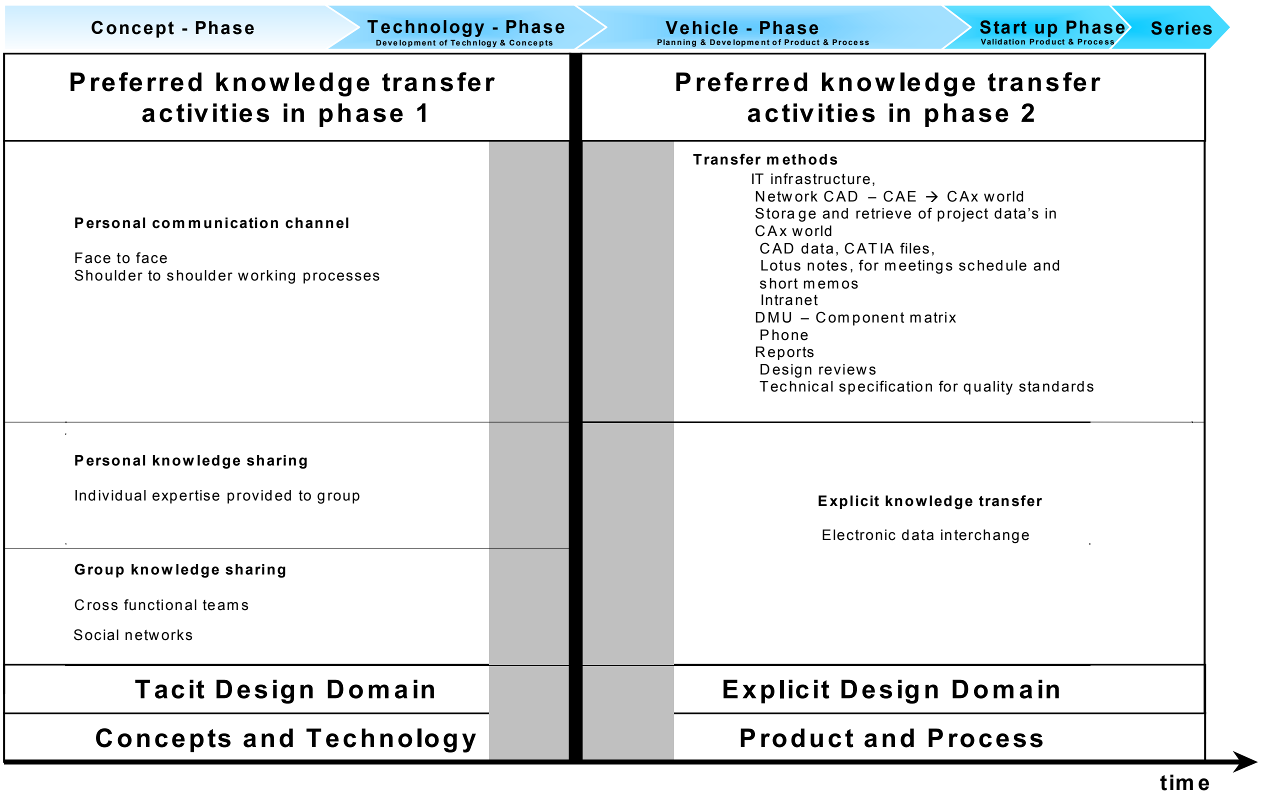
A generated product knowledge base can be a document, for example, which contains the range of flange angles that produce a good part, what kinds of interfaces avoid assembly problems, how to design slip joints for a robust fit, what areas of the part tend to have formability issues, and quick calculations on the risks of curvatures and deformations. It supports decisions between several functions and helps to define product feasibility for engineering and manufacturing.

Engineers abstract their experience with each design step and add on the new findings into the product knowledge base, so it is a continuous description of the product, facilitating a common understanding between different engineering disciplines and creating the opportunity to create and share domain-specific knowledge between several functions.

2.6 Findings and contribution

The research demonstrates that the methods by which knowledge is transferred change during the vehicle development process.

Figure P1.10: Tacit and explicit design domain and knowledge transfer



As shown in (figure P1.10), in the concept and technology phase of the product development process, where engineers are engaged with the product concept and new technologies (referred to as the tacit design domain in my research); tacit knowledge transfer dominates and so the key enablers of tacit transfer and the activities to foster tacit knowledge exchange are the resources for a value creation potential in the product development process. Certainly there is no clear borderline between the tacit domain and explicit domain of design knowledge, as it is shown simplified in the figure above, but a clear outcome of the research is that, in the tacit domain, engineers strongly favour shoulder-to-shoulder working processes, face-to-face communication as the most efficient approaches to make tacit knowledge available to other team members and transferring it, as a next step, between different functional teams.

In this phase of the product development process an environment for tacit knowledge sharing would enhance the product development process; the key is to facilitate knowledge transformation across different engineering disciplines identified as enablers of knowledge transfer in the research project (table P1.1). The research shows that if the vehicle development process reaches phase two, where most of the interfaces are clear defined, knowledge transfer is very efficient and process orientated (table P1.8). In this phase the main focus is on product and process engineering. An environment that creates an optimised exchange of explicit knowledge, which is supported by advanced information technology to store and accumulate explicit knowledge between product development teams, will be the source for a value creation potential in the product development process.

From a managerial perspective, the finding suggests to create for phase one (figure P1.10) a project structure, which facilitates real time interaction, flexibility for new design solutions and space for improvisation to give birth to new concepts. Engineers should have the possibility to develop multiple alternatives and should be able to communicate different sets of possibilities between different technical functions to seek conceptual robustness for several solutions. Knowledge used during this phase of the product development process is mainly embedded in the tacit design domain and therefore product developers should be aware that a rigid project structure limits the potential to implement new technologies into new products. On the other hand if the vehicle development process reaches phase two, where most of the interfaces are clear defined, the product development process is a predictable process, one that can be planned out as a series of discrete steps. By overlapping this defined steps more tasks can be accomplished in parallel, because the knowledge necessary to perform each is step is in explicit form available and therefore easier to transfer between different engineering disciplines.

From a theoretical perspective the research finding is in line with the theory of Takeuchi and Nonaka (1995), which explores knowledge creation through conversion between tacit and explicit knowledge. Group knowledge is created through individual knowledge exchange, which is facilitated if product development teams generate a product knowledge base (figure P1.9 and table P1.10), which is communicated between different engineering disciplines.

The way we make knowledge descriptive, “the product knowledge base”, and how we link this expertise together needs a deep understanding of how people share different domain-specific knowledge and how they bundle it together in cross-functional activities.

To create a product knowledge base of a vehicle, and keep it alive, requires continues updating of the knowledge base from project to project. This means there is a need invest financial resources and time upfront. This may require a cultural shift by European and American vehicle manufacturers with regard to how they steer and allocate resources to future vehicle development programmes. The concept of front loading and problem solving on product development performance is intensively discussed in previous research studies

(Thomke and Fujimoto 2000; Clark and Fujimoto, 1989), and it is also broadly accepted in the product development processes of all automotive manufacturers. On the other hand, the term pre-knowledge creation is widely ignored in the vehicle development process. In vehicle development, non-routine tasks are high on complexity and to solve such complex design tasks, a high degree of task interdependence between technical disciplines is necessary to evaluate and investigate proper design solutions. This requires that team members have an understanding of the complete product system architecture. To create such an understanding, engineers need to identify, access, combine and design relevant knowledge. This activity can be seen as a pre-knowledge creation, the result is a shared product knowledge base, which makes it possible for people engaged in the vehicle development process to use different kinds of knowledge to capture and link new technologies into innovative products. The research supports the opinion that a shared product knowledge base combined from different functions, has an enormous potential to link innovation and functionality into new vehicle development programmes.

Title page project two

Title of DBA Research:

An explorative study of knowledge transfer processes in new product development in the automotive industry

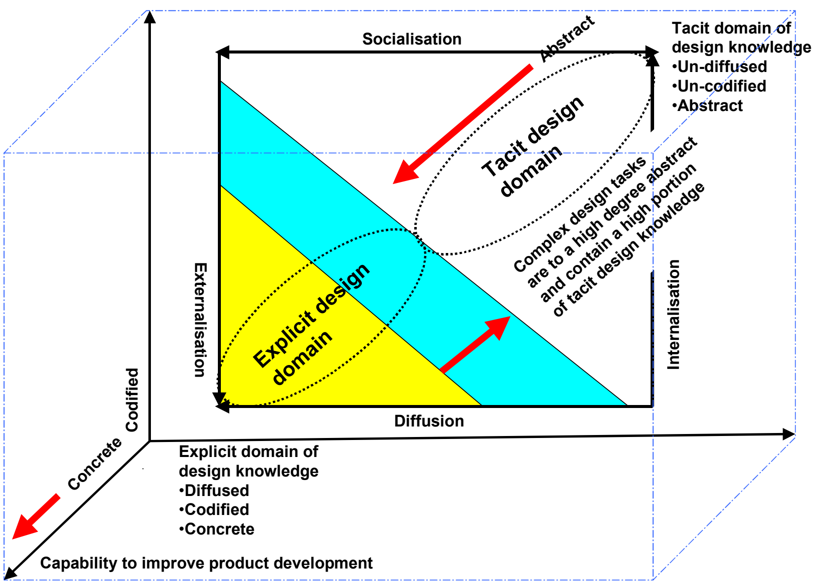
Abstract: project two

The study focuses on levels of knowledge transfer between business units engaged in a new product development project.

From a theoretical perspective, the first challenge was how to illustrate the value creation potential of successful knowledge transfer and to establish how realistic it is to claim that successful knowledge transfer increases the capabilities of integrating innovation into new products.

The second challenge was how to demonstrate the power of enablers and inhibitors, and to put on view their positive or negative effect on the knowledge transfer process.

Based on my research findings, I was able to develop a theoretical framework, which distinguishes between tacit and explicit design domains and integrates the dynamics of enablers and inhibitors of knowledge transfer. It demonstrates the importance of knowledge transfer as a tool to combine new technologies (mainly embedded in the tacit design domain) with existing technologies (mainly embedded in the explicit design domain) to generate new knowledge, and as such it assists the strategic aim to improve product development.



3. Background and theoretical perspective - project two

The research focus in project two is how intra-firm knowledge flow between business units takes place. To identify how relevant knowledge is produced in subsidiaries and made available to those units that need it, it should be possible to determine what enables or inhibits knowledge transfer between business units. From a theoretical perspective, knowledge transfer has developed out of studies focused on how firms could best accomplish international technology transfers to facilitate the pursuit of Vernon's (1966) product life cycle. Early studies found that transfer costs decrease with experience (Mansfield, 1979; Teece, 1976, 1977) and showed that the time taken to transfer innovations to subsidiaries decreased with experience. (Mansfield and Romeo, 1980; Davidson, 1980).

The objective of any knowledge transfer project is to create a successful knowledge exchange between sender and receiver. Researchers have used different approaches to define transfer success as a dependent variable. At the most basic level, transfer success was defined as the number of knowledge transfers engaged in during a certain period of time (Hakanson and Nobel, 1998). A second approach defined a successful transfer as one that is on time, on budget, and produces a satisfied recipient (Szulanski, 1996).

Another research stream focus on companies ability to put product designs, manufacturing processes, and organisational designs that are new to them into practice (Nelson, 1993), and knowledge transfer is seen as occurring through a dynamic learning process where organisations continually interact with customers and suppliers to innovate or creatively imitate (Kim and Nelson, 2000). From this perspective, knowledge transfer involves the recreation of a sender's knowledge package in the receiver. Since it is often difficult to know which elements, (people, tools and routines), comprise a sender's knowledge package (Spender and Grant, 1996), assessing replication is difficult. Thus, even if the elements of the knowledge package can be clearly identified, they may be hard to discern in their adapted forms within the recipient. Another perspective of successful knowledge transfer is to define success as the degree to which a recipient obtains ownership of, commitment to, and satisfaction with the transferred knowledge (Meyer and Rowan, 1977). The intensity of the recipient's association with the knowledge, and the number of interactions involving the knowledge, can affect his feeling of ownership.

Lastly, knowledge ownership also relates to the degree that an individual invests energy, time, effort, and attention in the knowledge. Additionally, individuals develop knowledge commitment to the extent that they see the value of the knowledge, develop competence in using the knowledge (Leonard-Barton, 1995), and maintain a working relationship or interaction with the knowledge, and are willing to put in extra effort to work with the knowledge (Mowday, 1979).

From a management perspective, companies acting on a global scale must create and possess the ability to provide and manage resources and expertise of different business units. How to identify and link the knowledge sources with needs is one of the major points I established during the research in project two. If knowledge has to be transferred between different business units, including the different cultures and different kinds of expertise each unit possess, a clear identification of resource allocation supports the transfer of knowledge.

Normally, each organisational unit pursues a dual task: It sends knowledge to others (source unit) and it receives knowledge from others (target unit). In order to support a free flow of knowledge, the company has to develop a certain organisational architecture; i.e. cross-functional, flexible structures (Nevis, DiBella, and Gould, 1995), open communication (Argyris, 1994) and a learning culture (Slater and Narver, 1995). Sharing and accessing knowledge across the organisation extends the knowledge available to product developers, and this can be applied to the problems they seek to solve. This sharing may occur in a number of ways, such as electronically, by drawing on personal network contacts or calling on company experts, and/or through task-oriented exchange in the course of participating in teams and groups.

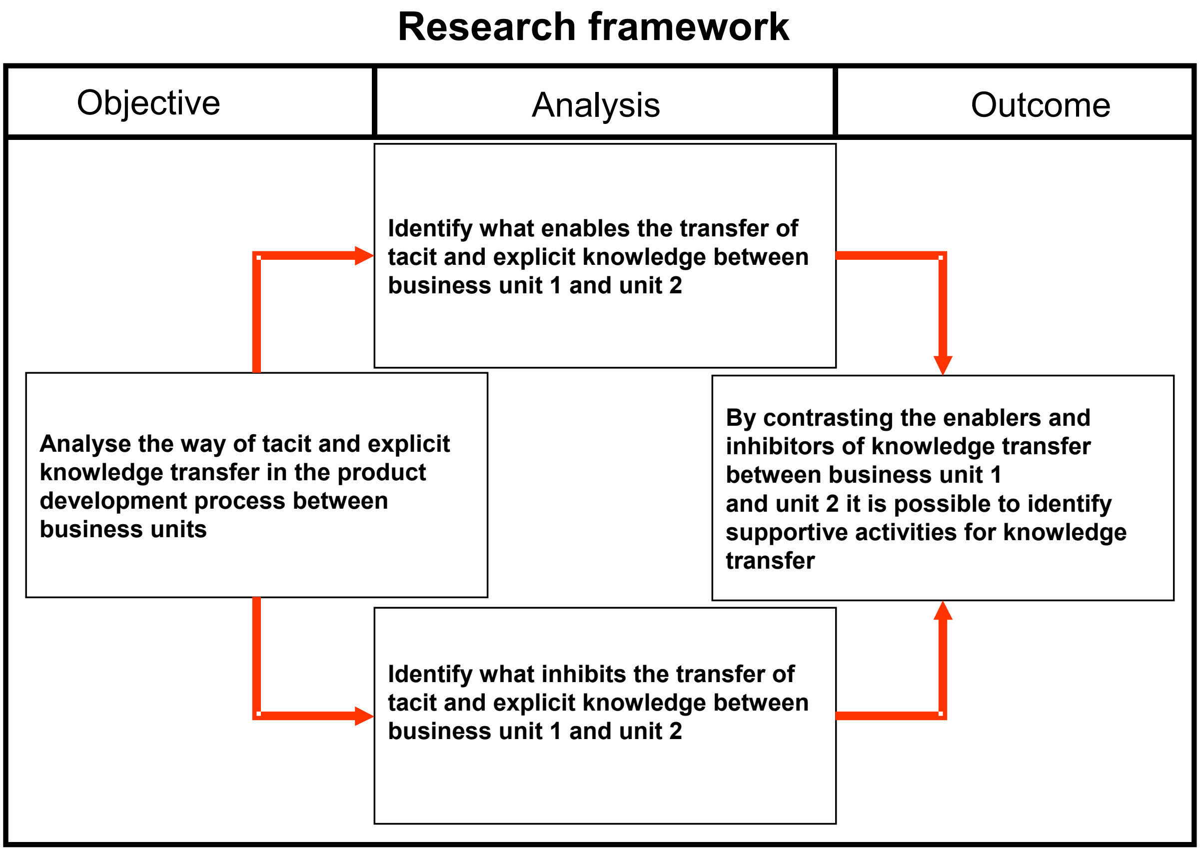
To identify in more detail how knowledge is transferred, the research focuses on an advanced engineering project, which is being carried out between a Swiss and an Italian business unit of a tier one supplier in the automotive industry. The main focus is to investigate the knowledge transfer between these two business units and how they transfer and work together in an advanced engineering project to develop a floor module for future vehicle generations.

The focus of this research is not the technical context of developing a new floor module; it is how two subsidiaries transfer knowledge to achieve a defined project outcome.
Within the research, I examine what supports the knowledge transfer between business units, and how the participants used the enablers of knowledge transfer and tried to overcome the inhibitors during the project.

3.1 Research framework project two

The research concentrates on the transfer of tacit and explicit knowledge between two business units to create a new product, which integrates new technologies, so far not tested on the market or even in a pre-production phase. To explore the transfer of knowledge between these two business units, possessing different pools of expertise, I draw down following research framework:

Figure P2.1: Research framework



I used the framework shown above to identify and analyse the transfer of tacit and explicit knowledge in the product development process between business units.

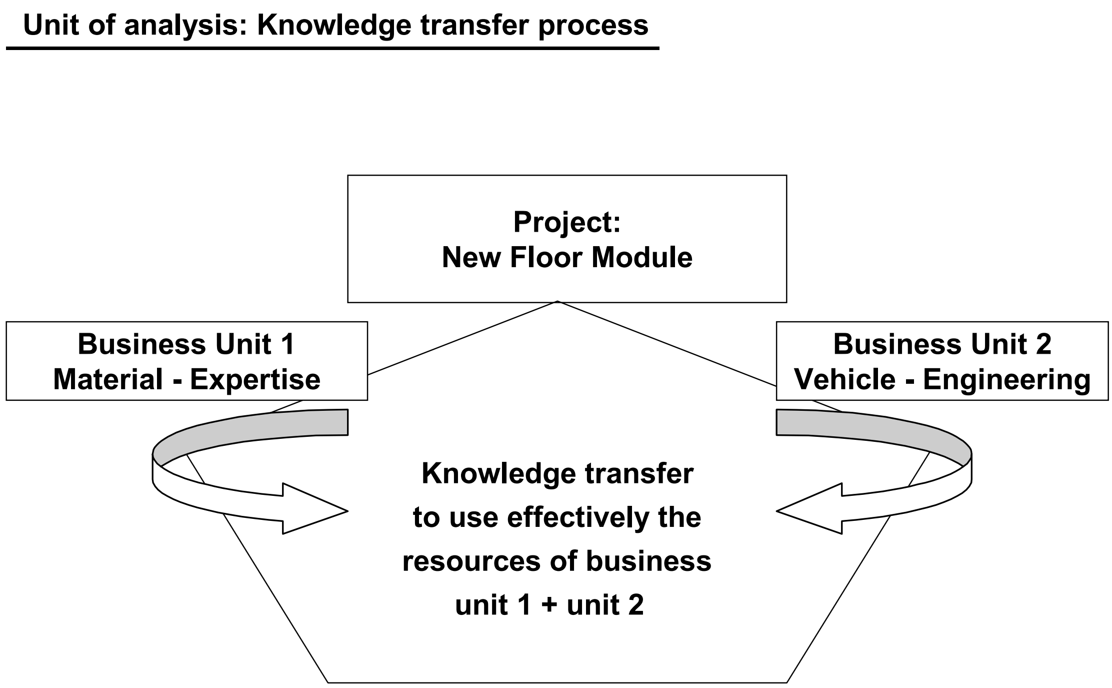
The project itself had two major phases. The concept and resource allocation phase at the beginning and during the life cycle of the project, and the project orientated perspective between the business units. This perspective meant that people engaged in the project effectively belonged to one team created out of two business units.

By contrasting the enablers and inhibitors of knowledge transfer through the life cycle of the project, it was possible to identify major enablers and inhibitors of knowledge transfer.

3.1.1 Methods project two

Similarly to project one, I have used the case study method for data collection and subsequent validation. The unit of analysis shown in the figure below is the knowledge transfer process between business units belonging to the same parent company, (a tier one supplier in the automotive industry). The team, which was created out of both business units, is engaged with the task of developing a vehicle floor module, which should have the advantage of extending the platform variable in length and width, and additionally improve the integration of functionality, such as channels for wire and harness, carpet and acoustic systems already integrated in the floor module. All these features would enhance the functionality and also reduce costs, in comparison to a conventional vehicle floor system.

Figure P2.2: Unit of analysis



The teams engaged in this product development project had a core team, which was responsible for the progress. Additionally during the project, other different team members, possessing different kinds of expertise relating to problems occurring during the development process, also participated. With a contemporary study of the project, I have the opportunity to evaluate ongoing activities of the engineers engaged in this project, to see how knowledge was transferred between business units. By contrasting the inhibitors and enablers of knowledge transfer, I am able to express the way in which people deal with the uncertainty of knowledge transfer to create, from different kinds of expertise found in different business units, a capability of linking emerging technologies into innovative products.

3.1.2 Data collection and coding - project two

To investigate the dynamics of knowledge transfer, I collected data for this study from several sources; interviews, e-mail communication, minutes of meetings and my own participation in the project. Interviews commonly lasted from 60 to 90 minutes.

I interviewed 8 engineers and I used a structured interview with open-ended questions (described in appendix two) to allow the participants to respond of their own volition, free of the potential influence of preconceived answers. The participants were engineers engaged in the new floor module project and part of the core team, so from this point they were responsible for the project's progress, and regularly engaged with the project and parts of both business units. All 8 engineers were very experienced and were tasked with tracking the project to the agreed technical specification, which was defined at the concept and resource allocation phase. The interview questions focused on developing an overall understanding of the process of knowledge transfer between business units engaged with new product development activities.

In later interviews, I asked more specific questions to refine and elaborate themes that emerged from the analysis of earlier interviews and the analysis of factual data. I encouraged informants to illustrate their statements with specific events and examples from the project: *To investigate how knowledge transfer should be organised to harness product development knowledge effectively to generate innovative products.*

As a second significant data source, I used also e-mail communication related to the new floor module and minutes of meetings.

To identify the right case examples of major design tasks, I used additional to interviews e-mail communication and minutes of meetings. The major purpose to use this additional source of information was to select relevant examples of knowledge transfer during the product development process in relation to the technical complexity.

The minutes of meetings were a valuable source to identify the major design steps and objectives from a technical context. In project two the main objective was to substitute the conventional floor pan of a car with a sheet moulding floor module to reduce number of parts and allow vehicle platforms to vary in length and width. To understand and explore why several enablers and inhibitors played a significant role it was important to select and compare design tasks containing simple and complex product development steps. To frame and describe specific design tasks, I used in project two twelve minutes of meetings of design reviews and scanned approximately hundred e-mails related to the design reviews in detail described in (chapter 3.2.2 – chapter 3.2.4).

A third source, was my own participation in the project, which included meetings, videoconferences and review of design documents, as well as informal discussions with engineering team members.

My personal engagement with the project was over a year, so that observations at any time during the course of the project were likely to be witnessed due to my active role in the project.

During the data analysis I read interview transcripts, created notes out of e-mail conversations and meeting minutes, and scanned through documents of design reviews looking for themes and patterns (Milles and Hubermann, 1994). Critical data from different resources were coded using typical content analysis procedures (Strauss 1987).

First, I coded all data into a number of categories according to the proposed theoretical model (Yin, 1994). These categories are enablers and inhibitors of knowledge transfer. Then I created subcategories using classifications identified in project one, and which also emerged in project two from informant descriptions. For example, time and financial resources were grouped into economical constraints and were identified as inhibitor in the case study.

Figure P2.3: Example of data coding and categories

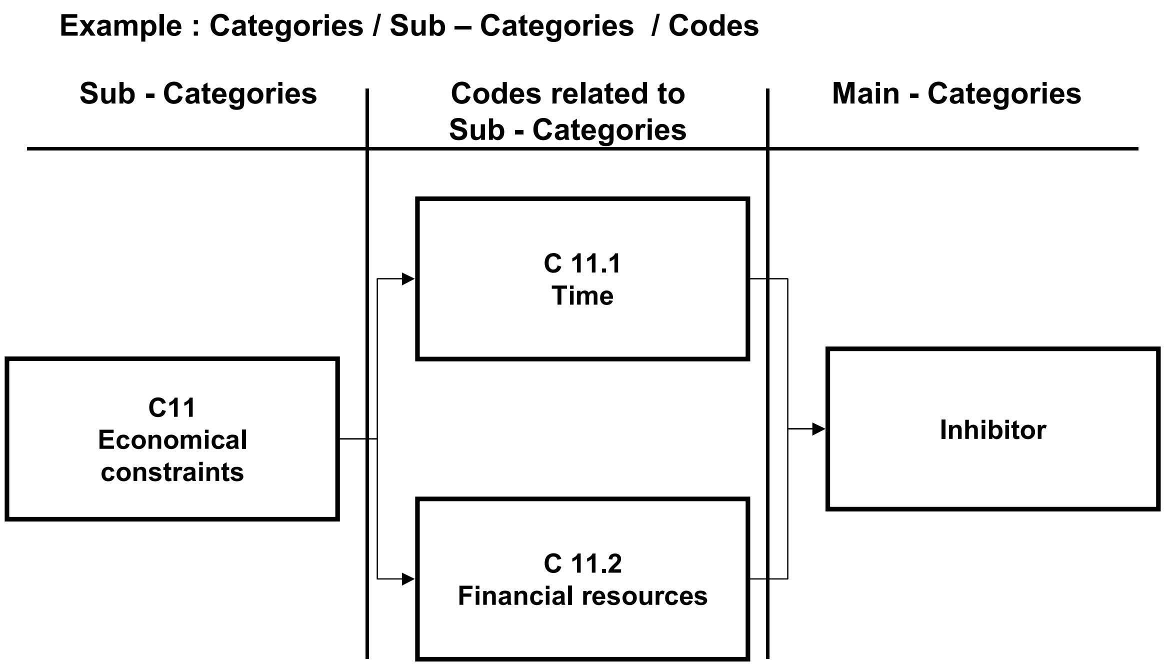


Figure P2.3, combined with following description, explains how the interview transcriptions were used to identify codes related to subcategories and classified them into the main categories of enabler or inhibitor of knowledge transfer.

Interview question: In what ways was knowledge transferred between business unit one and business unit two?

Interviewee's statement:

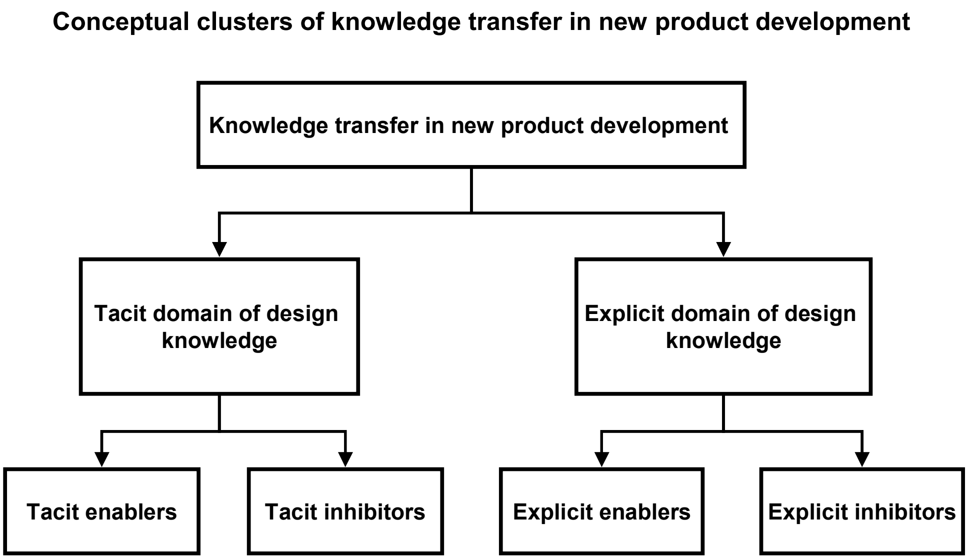
Several management meetings are essential, to determine the expertise possessed in the business units and to align resources to project objectives. In this phase, we found out how difficult it is to reapply team and individuals knowledge at distance. Time consuming (C11.1) co-ordination of management meetings, taking into account that many key players are engaged in several projects of their parenting unit as well. Also financial resources put an upper limit (C11.2) on what you can expect from the knowledge transfer processes. Management Meeting (face-to-face) are perceived as one of the strongest activities to transfer expertise, but to create a knowledge flow based only on face-to-face contact would increase the project costs to a level, no one likes to pay. (C11.2)

As shown in (figure P2.3), engineers perceived time consuming activities and limited financial resources as inhibitors of knowledge transfer. These expressions are classified in main categories, subcategories and codes related to subcategories. Table P2.1 provides an overview of categories, subcategories and codes related to subcategories.

As the study progressed, I sorted these statements (available in detail in appendix two) and grouped them to arrive at conceptual clusters (Berg, 1989). Conceptual clusters are sets of closely related analytical ideas.

In project two, I identified two streams of knowledge transfer in new product development projects. Firstly, complex design tasks rely more on a tacit domain of design knowledge and are therefore more strongly influenced by tacit enablers and inhibitors. On the other hand basic design tasks, for example described in technical specifications, rely more on an explicit domain of design knowledge and therefore they are more influenced by explicit enabler and inhibitors.

Figure P2.4: Conceptual cluster of knowledge transfer



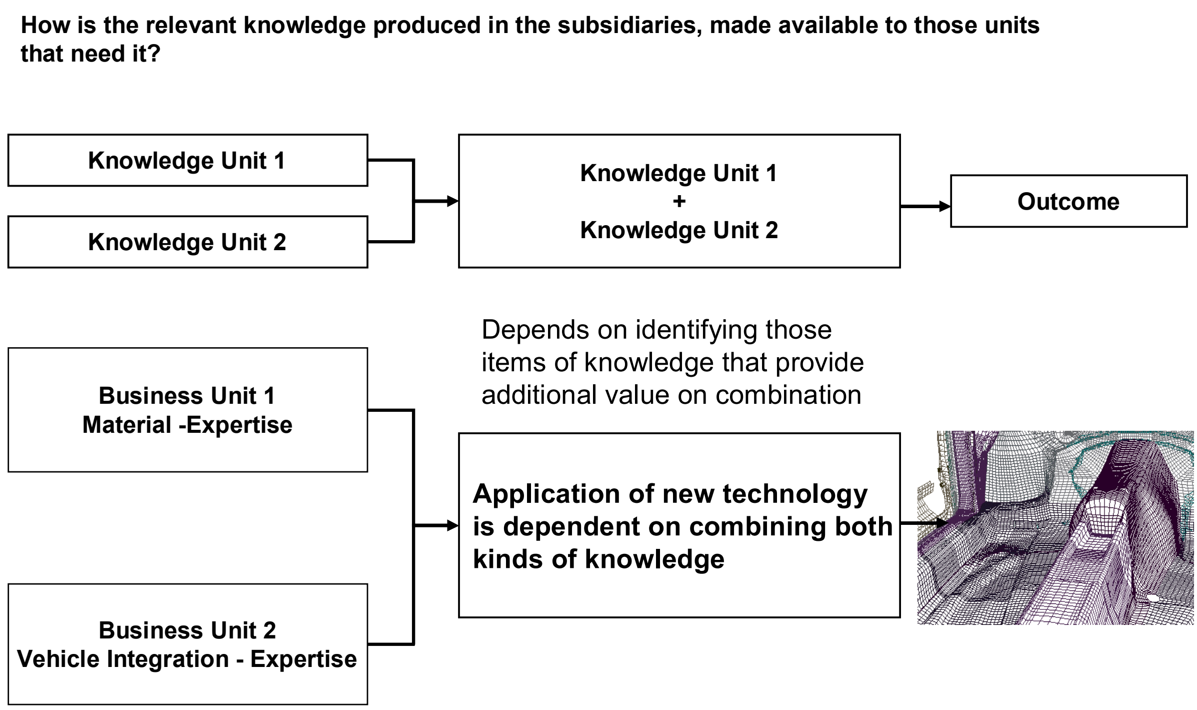
I systematically compared the emergent theoretical interpretations contained in codes and categories with the evidence from several case examples investigated in project two, in order to assess how well or poorly they fit the case data (Eisenhardt, 1989).

This iterative process of comparing theory and data led to a detailed description of the dynamics of knowledge transfer in new product development projects. To test the credibility of my findings, I checked my emerging insights on an ongoing basis with my informants, through several meetings and informal face-to-face discussions (Hirschmann, 1986; Lincoln und Guba, 1985). These member checks served to revise and sharpen the findings discussed in following chapters.

3.1.3 Surfacing and articulating key themes project two

For companies acting on a global scale, one of the key activities is to provide and manage the resources and expertise of different business units, to capture innovation in relation to financial efficiency. The major focus is how the relevant knowledge, produced in the subsidiaries, made available to those units that need it.

Figure P2.5: Combination of knowledge between business units



The figure above shows that the knowledge owned in business unit one (material expertise) and the knowledge owned in business unit two (vehicle integration expertise) is quite different. In order to develop a new floor module, it is important to combine material expertise located in business unit one with vehicle integration expertise located in business unit two to create feasibility and application for the new product.

The knowledge combination and knowledge transfer processes are influenced constructively (by means of enablers), or destructively (by means of inhibitors). To understand the impact of enablers and inhibitors and their interdependence in relation to the knowledge transfer process, it is important to investigate them within major engineering tasks and objectives, to see when and why they come to light and what role they played in the product development process.

The challenge, in general, is that the crucial product design knowledge is usually not available in a readily retrievable format. It is often held in the minds of a handful of key persons and it combines different types of knowledge.

- Design knowledge is necessary to track a new product development process; the expertise involved contains explicit theories and formulae.
- Application knowledge requires the understanding of design theories as well articulating components of estimation/judgement and “best trade”, what and how to apply when and where.

Knowledge with both explicit and tacit elements is required. The advanced floor module project strongly depends on the knowledge transfer between business units, how multicultural teams work together and manage the exchange of expertise to create a product that integrates new and sophisticated technologies.

A second challenge was that we recognised from the start of the project that there was no previous experience to draw on within the team, with regard to how unit one and unit two should work together.

These quote represent how engineers were confronted with a lack of experience to transfer knowledge:

> *In general it was, for all parties involved, doing something new. So we had to learn to do something new, strongly based on communication of information between business units. The key was to identify knowledge and to organise the exchange of knowledge transfer between the units. It was difficult, in the beginning, to locate knowledge; for example, who possessed the right source of expertise for specific design tasks. Obviously we knew that our Swiss unit owned material know-how and our Italian unit owned the vehicle integration know-how, but that is not enough to develop a new floor module. These are only the basic resources to carry out such a complex project. How should we work together, who has the helm in the project and how to share responsibility are open issues, if we start such a project.*

The start phase created a number of questions about project management techniques and management styles. Just of few of these were: how should the business unit’s work together;

how to define the resources; how to define and assign the work packages and responsibilities for development steps; How to track the product development process?

The uncertainty created out of new technologies and identifying how to estimate costs at the concept stage, could be seen as critical factors. In this phase, team members could become frustrated by a lack of a common understanding, which creates a knowledge gap between unit one and unit two.

In project one, we had the same experience: one of the key enablers in knowledge transfer is a common understanding of the objectives and goals in the product development process. In project two, this argument surfaced again: a lack of common understanding has a negative impact into the overall performance of the project.

A clear definition of the targets, and the right organisational process to allow teams to work together effectively, are key issues from a management perspective. A clear identification of expertise is key; in other words, the managers had to define what relevant knowledge each unit posses and what activities were necessary to combine the knowledge of unit 1 and unit 2 to perform the requested task. See following quote for instance:

> *The identification of the people who possess the knowledge that is needed to perform the required task is very difficult, due the fact that the team members know quit well the brains of their own units. But it was difficult to identify the right person to talk to in the other unit, how is the relevant knowledge available or what functional department is the best to ask for specific solutions. This was very time consuming in the beginning. From this point it was very helpful to get more familiar with the Swiss unit, creating a personnel contact helps to understand whom to ask and this supported the knowledge exchange.*

The research project illustrated, that project managers should establish a structured knowledge transfer process. This procedure should, identify, assess, collect and combine knowledge, which is a course of actions to structure knowledge and express it a way that is appropriate to the receivers' needs.

We observed that this systematic approach of knowledge transfer is, in a broader context, influenced by several factors. During the research we found that successful knowledge transfer requires that both parties develop an understanding of where the desired knowledge resides within the source, and that both business units participate in the processes by which the knowledge is made accessible. The importance of a common understanding is also shown in this statement:

> *The knowledge that we transferred during the project is strongly dependent on the participation of the people involved. A more successful transfer can be achieved if the degree of interdependence is*

> *higher, so unit one relies on the expertise of unit two and vice versa. If the transferring unit is strongly reliant on the outcome of the receiving unit, the incentive and interest to foster and track the process is much higher. Within the life cycle of the project, engineers got more familiar with each other's expertise, so the development process improved. Engineers started combining each other's knowledge; a very important fact to explore new material combination and implement them into the car. For example if unit one sent only their material know-how, but they didn't explain how it would perform under dynamic conditions, the expertise provided is worth nothing. If the receiver doesn't understand the knowledge provided, the application would be zero. To create social networks to understand each other's expertise is a major challenge for our success in developing a new floor module.*

As we completed the project, we found that interdependence of the business units had, by itself, an active influence on the frequency of knowledge transfer. As a result, people involved created social networks, where a combination of new knowledge was shared and actively used to develop a new product. These social networks were essential to move the development process forward. Decisions, new joint technologies and new material combinations were a result of this created knowledge base.

On the other hand, the knowledge transfer process was complicated by the fact that the knowledge owned in each business unit was quite different. It is very difficult to create a common understanding if sender and receiver expertise differs widely in context, as is stated in the following quote:

> *The units needed each other's expertise, material expertise versus vehicle expertise, so the exchange of expertise was strongly based on communication of information, usually from one unit to the other. However, it was very difficult to implement the transferred knowledge into the design process. To be really transferred, knowledge must be understood by the receiving partner. In general, engineers are able to share competencies only in their own discipline. To transfer domain-specific knowledge between different engineering disciplines is very complex because it is located in individuals and they are members of different functional departments. Additionally the knowledge of engineers is a combination scientific expertise and experience and as such very hard to explain between different functions. I would say it is only transferable over face-to-face exchange.*

So people engaged in this process get the feeling that knowledge sticks in functional departments of the business units and cannot be transferred. Overlapping areas of expertise are easier to transfer than expertise where sender and receiver do not understand the domain specific knowledge of each other. If knowledge is combined and transferred, it cannot be guaranteed that this knowledge is recreated in the receiver unit. Even if the elements of the knowledge package are identified, collected and combined, it is not by itself integrated into the development process of the receiver. Knowledge received is part of the practices integrated into the product development process.

To be useful, transferred knowledge must be integrated into an operation, as it is stated in following quote:

> *To be really transferred, knowledge must be embodied in an actual operation of a certain design stage; this can be either transfer from more basic knowledge into technology, or adaptation of an existing technology to a new use. For example, to work out smart joining technologies between body frame and floor module, in order to reduce the number parts, you create many ideas in the beginning. You have to judge them and therefore you need the expertise of several specialists. To create multi-functional parts you need a lot of interaction between engineers, discussions, and meetings, As a result you have many interactions until a solution, which fulfils crash requirements, production feasibility and cost targets, (to name a few of the objectives of product development) is found. Through interaction you are able to combine expertise and compare it with targets, which is necessary to create products with technical feasibility.*

In this project, I tried to analyse, what it means to integrate a systematic approach of knowledge transfer; how engineers try to implement a methodology to break down complex knowledge requirement into receiver needs. This involved tackling the challenge of transferring knowledge containing explicit and tacit elements, and how engineers combine knowledge to create a new knowledge base. This activity is a knowledge creation process and goes hand in hand with the knowledge transfer process, and therefore it should be considered as one integrated set of activities.

Knowledge transfer is not a pure task-orientated approach: various enablers influence it and inhibitors that affect the knowledge transfer process. From the research strategy it is important to identify enablers and inhibitors of knowledge transfer and their impact on the knowledge transfer process, in order to investigate their positive impact and negative constraints for knowledge exchange and knowledge creation between business units.

3.1.4 Identifying the key enablers and inhibitors of knowledge transfer between business units

The main research strategy was to identify the enablers of knowledge transfer, to support knowledge transfer between business units. It is obvious that a successful product development process must be capable of transferring intangible ideas and findings as well, so it needs a procedure to manipulate enablers and inhibitors of knowledge transfer. If the proportion of explicit knowledge is high, the transfer can be seen as a task-orientated approach, which is aligned with the theory, of several knowledge management frameworks, (table P2.7). With increasing project complexity, decisions of engineers are based more on experience and design trade offs, which means that the transfer of knowledge is more influenced by tacit enablers and tacit inhibitors of knowledge transfer.

To investigate the relationship of enablers and inhibitors and their influence on knowledge transfer process, I used following questions to identify key enabler and inhibitors of knowledge transfer between business units.

Interview questions to analyse the knowledge transfer process between business units:

1. In what ways was knowledge transferred between business unit one and business unit two?
2. How is relevant knowledge, produced in the business units, made available to those units that need it?
3. How does communication occur between those units that need the knowledge and those units who possess it?
4. Were there different types of knowledge that were transferred between the business units?
5. Were there any types of knowledge that could not be transferred between the business units?
6. Was there anything about the organisational structure that hindered the transfer of knowledge between the business units?

With these interview questions I tried to identify a pattern of relationships, to explain and describe how engineers engaged in the project tracked the knowledge transfer process of a new product development activity. To identify patterns of relationships, I identified main codes, which were assembled out of several sub-codes based on their relationship to the main codes. In (table P2.1), there is an overview of significant codes and sub-codes, and categories of the knowledge transfer activities in project two.

Table P2.1: Research results; Enabler and Inhibitors of knowledge transfer

Sub - Categories	**Codes related to Sub - Categories**	**Main - Categories**	**Frequency of occurrence [%]**
C1 Core process of knowledge transfer	C 1.1 Identifying knowledge C 1.2 Assessing knowledge C 1.3 Collecting knowledge C 1.4 Combining knowledge	Enabler	14,8
C2 Transfer methods	C 2.1 Management Meeting C 2.2 Video Conferences C 2.3 Intranet C 2.4 Lotus Notes - E- Mail C 2.5 CAD Files C 2.6 Phone, Memos C 2.7 CAx World	Enabler	7,4
C3 Personal communication channel	C 3.1 Face-to-face C 3.2 Personal engagement	Enabler	11,1
C4 Wrong media	C 4 Wrong media to transfer knowledge	Inhibitor	3,7
C5 Personal knowledge sharing	C 5.1 Individual expertise provided to group C 5.2 Pro active – willingness to transfer	Enabler	8,3
C6 Receiver reproduction	C 6.1 Transfer creates not automatically replication	Inhibitor	6,5
C7 Sender receiver exchange	C 7.1 Sender – Receiver Interdependence C 7.2 Frequency of transfer	Enabler	12
C8 Group knowledge sharing	C 8.1 Teams C 8.2 Relationship	Enabler	9,3
C9 Barriers of knowledge transfer	C 9.1 Functional knowledge stuck in silos C 9.2 Unawareness of valuable knowledge C 9.3 Difficult to articulate C 9.4 Uncertainty	Inhibitor	11,1
C10 Explicit knowledge transfer	C 10.1 Project structure C 10.2 Communication channels C 10.3 Categories and Standardisation C 10.4 Routines	Enabler	10,2
C11 Economical constraints	C 11.1 Time C 11.2 Financial resources	Inhibitor	5,6

As we see in (table P2.1), I used the transcription of interviews, (appendix two), to identify the main codes and sub-codes, and classify them in categories, in order to identify the importance of enablers and inhibitors, depending on the role they played during the project and whether they were perceived by the engineers as more or less important for the efficiency of the knowledge transfer process.

The frequency of occurrence is not directly related to the importance of enablers and inhibitors. Therefore the research outcome gives more weight to some enablers and inhibitors, related to their role they played in the project.

This is an advantage of case study: the main questions of *what* is going on and *how* things are proceeding call for a description of the phenomena observed. As Bernard (1998, p. 317) puts it, such analysis “makes complicated things understandable by reducing them to their component parts”.

To understand why several codes and categories were perceived by engineers as significant, it is also important to understand the dynamics and situations of the product development process. This is a task and a problem solving process, with different situations arising during the life cycle of the project. For several situations during the project, I have described case examples *(design tasks),* in terms of enablers and inhibitors. Different conditions and interactions of activities help to show how certain inhibitors and enablers were perceived as more important than others in the product development process.

From this analysis, there is potential to implement findings to improve product development processes. Several business units are confronted with constraints like limited co-location, expensive face-to-face contacts and the need to overcome such constraints to create a successful sender receiver exchange of expertise.

Further, the combination of different pools of expertise is also a knowledge creation process, and if managers pay attention to this fact, and ensure that knowledge created is not lost, an organisation can thereby gain competitiveness.

In the following chapter, I will give a detailed description of the role of enablers and inhibitors of knowledge transfer in the project.

3.2 Identifying the core process of knowledge transfer between business units

The project team, combined from both business units, was engaged to develop a new concept for a vehicle floor module. This module would allow vehicle platforms to vary in length and width, and should integrate channels for wire and harness and aircon systems.

The new floor module integrates additional insulation and carpet and therefore it supports the objective to improve the acoustic in the vehicle cockpit. All these features would enhance the functionality and reduce cost, because the number of single components would be reduced in comparison to a conventional vehicle floor system. To create a new floor module, and to secure functionality in a new vehicle, involves many resources and technical disciplines. The concept phase and the integration of this floor module in the car was supported by a massive use of virtual simulation to estimate how it will influence the overall performance of the body in white structure. There are two major challenges for the new module technology. The first is, is the new system able to fulfil the criteria of the crash test and are we able to secure the required stiffness of the car body? To allocate the right resources and identify the expertise required for the project, a structured outline of the major steps in the project was created.

Figure P2.6: Milestones; Floor module development

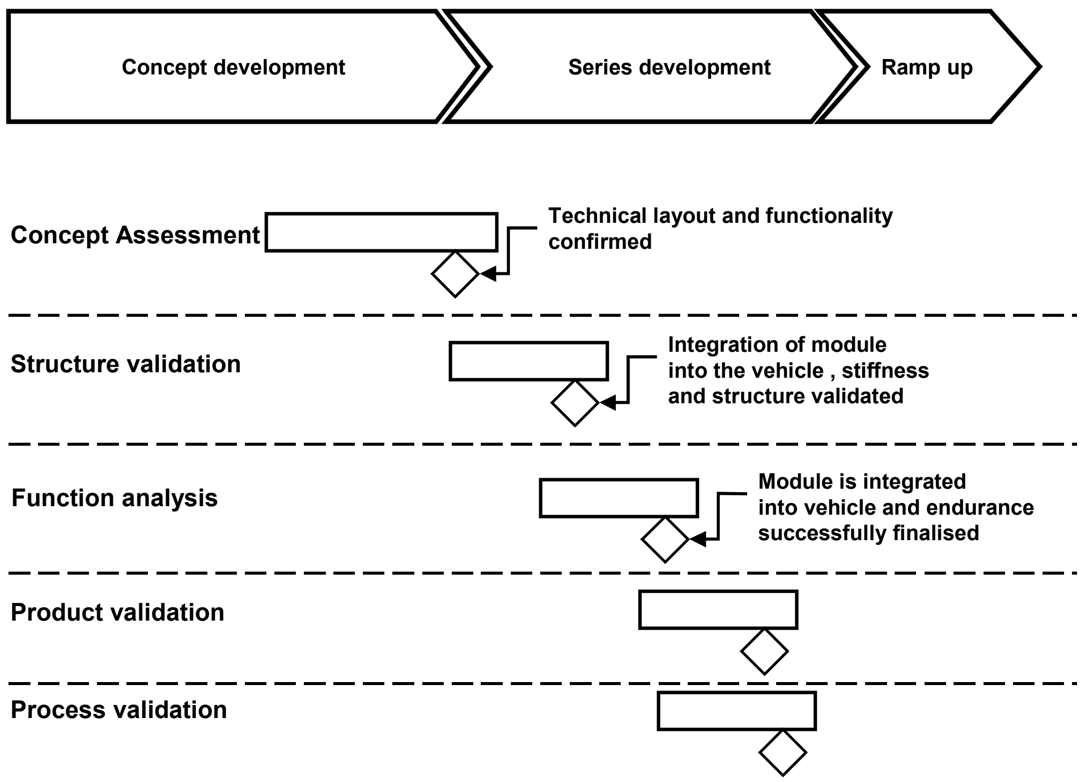


Figure P2.6 illustrates the major steps of the project. To define the overall budget volume and how it is divided, the amount of money provided to each unit is aligned to the amount of activity each unit has to perform. How much resources must be allocated to the project to create feasibility for new technologies? Are we able to define, on virtual simulation, the concept approval, structure validation and functional analysis? Product and process validation will strongly rely on the results of the first three steps, shown in (figure P2.6).

Project one identified similar knowledge patterns, creation of plans and guidelines that supported the transfer of knowledge. This application made expertise more transparent, and people were able to understand knowledge being created at different levels and disciplines.

In project two the geographical distance created a more challenging role in identifying, assessing, collecting and combine the necessary expertise. Knowledge was exchanged between different units and between different functional departments, which makes the process more complex than in project one.

People soon requested a more organised approach to define and allocate the required resources. While in project one it was quite clear where to find the expertise required, in project two this was a significant issue. Thus I had already identified a major enabler of knowledge transfer. Geographical distance, different cultures and different languages, mean that it should be as simple as possible to implement knowledge transfer.

Table P2.2: Example research interviews

Question 2:
How is relevant knowledge produced in the business units, made available to those units that need it?

	Interviewees Statements	**Codes**	**Categories**
Interview 4 – unit 1	Resource definition (C1.1) and allocation (C1.2) plays a significant role in effective knowledge transfer	C 1.1 Identifying knowledge C 1.2 Assessing knowledge C 1.3 Collecting knowledge C 1.4 Combining knowledge	Enabler
Interview 7 – unit 2	Identification (C1.1) of the people who possess the knowledge is the fact to allocate (C1.2) the expertise	C 1.1 Identifying knowledge C 1.2 Assessing knowledge C 1.3 Collecting knowledge C 1.4 Combining knowledge	Enabler
Interview 7 – unit 2	Whom and where to ask (C 1.1) in a more effective way, targeting (C1.2) the right resources the first time.	C 1.1 Identifying knowledge C 1.2 Assessing knowledge C 1.3 Collecting knowledge C 1.4 Combining knowledge	Enabler
Interview 7 – unit 2	Storage and retrieval of project data, is a possible source to codify expertise, which is retrievable again, is a way to collect (C1.3) and combine (C1.4) knowledge	C 1.1 Identifying knowledge C 1.2 Assessing knowledge C 1.3 Collecting knowledge C 1.4 Combining knowledge	Enabler
Interview 8 – unit 1	A driver for knowledge transfer is, that the new technology of the project needs the combination (C1.4) of expertise out of both units.	C 1.1 Identifying knowledge C 1.2 Assessing knowledge C 1.3 Collecting knowledge C 1.4 Combining knowledge	Enabler

From the interview questions it can be seen that the identification of knowledge was perceived as a major aspect of effective knowledge transfer.

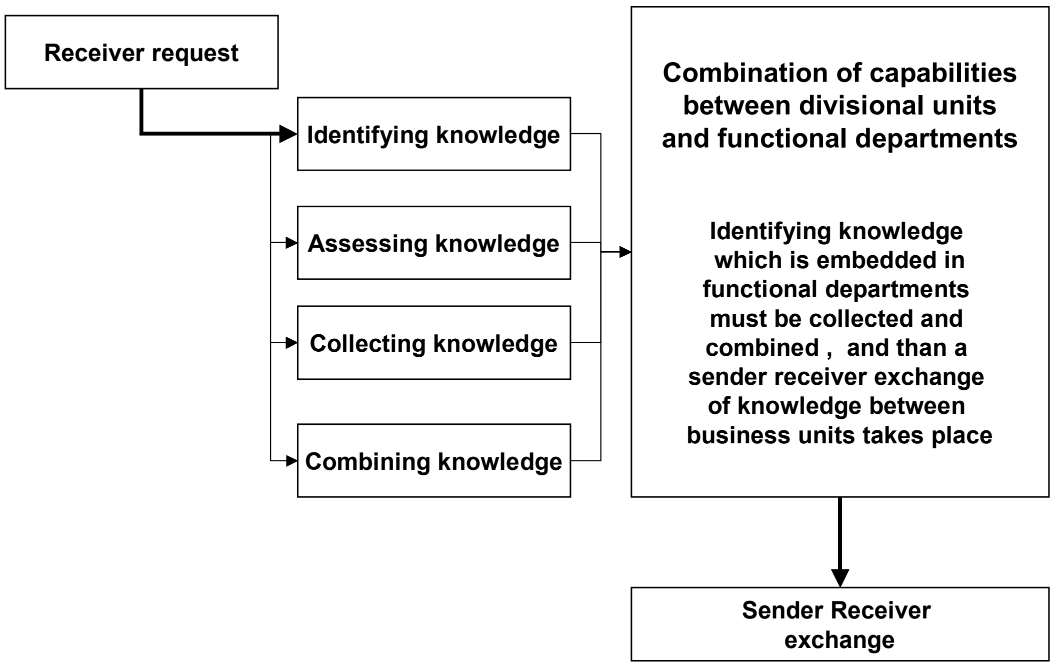
The person to ask, in a team transfer is not such a critical issue as it is in the transfer between business units. Here, a face-to-face contact is very cost intensive and people involved rely more on communication channels like e-mail, phone and CAD files. Under these conditions, information channels play a significant role in knowledge transfer between business units.

For instance as an engineer stated:

> *As soon as we had established a link between project groups, an organised approach to collect and transfer knowledge was created. People belonging to different business units are not familiar, so it can be challenging to know who to ask in the project. Sometimes we even have difficulty in identifying where the expertise resides in our own business unit. But what I really want to say is that knowledge transfer needs an organised process - right media, and clear identification of the right person to ask is key to transferring design specific knowledge.*

Before a sender can provide the receiver with the requested expertise, knowledge must be identified and a collection process must take place. As a next step, combination takes place, with the strategic aim of matching receiver request and sender provided expertise that it is understood and implemented correctly in the receiving business unit.

Figure P2.7: Surfacing the key process of knowledge transfer



The knowledge of companies is embedded in functional departments. Multinational companies with a divisional structure have a functional structure in their headquarters, and a leaner functional structure in their units.

An effective sender/receiver exchange takes place only if engineers are able to identify, assess, collect and combine existing knowledge. This may be embedded in several functional departments and different business units.

The following example describes how engineers identified and assessed material expertise and collected and combined it to transfer it from one business unit to the other. It helps also to understand what engineers understand with the terms shown in (figure P2.7) and how they used this approach to evaluate and combine knowledge.

To identify relevant plastic materials for the floor module, engineers needed to compare the properties of various natural and synthetic fibres and sheet moulding compounds to support the virtual product development process. Material expertise combined with the vehicle development expertise of unit two, created the opportunity to combine different sources of domain-specific knowledge to support the product development process.

From this perspective we see that the success of the project relies on the performance of both units in identifying and combining different domain-specific knowledge, and in developing a forward-thinking product for future vehicle generations.

In practice we found that it is very helpful for each business unit to nominate a person who is familiar with the overall knowledge held by his business unit. From a practical perspective, it is an administrative position; we call it a gatekeeper, a person who identifies sources of knowledge, and who plays an active role in setting in motion the knowledge exchange process. For example, in order to decide what material is appropriate to be used for a new advanced floor module, engineers in the unit with material expertise have to exchange their expertise with engineers in the unit with vehicle engineering knowledge. Therefore they must be able to make their domain-specific expertise communicable. This approach is described in following case example, which looks in detail at how engineers transferred knowledge to solve complex design tasks. Assessing knowledge means matching existing expertise to requested requirements.

Table P2.3: Physical properties
Comparison of various natural and synthetic fibres

Fibre	Specific gravity [g.cm-3]	Tensile strength [GPa]	Specific strength [GPa/g.cm-3]	Tensile modulus [GPa]	Specific modulus [GPa/g.cm-3]	Cost ratio
Sisal	1.2	2.00	1.60	85	71	0.5
E-Glass	2.60	3.50	1.35	72	28	1
Kevlar 49	1.44	3.90	2.71	131	91	6
Carbon	1.75	3.00	1.71	235	134	10

In (table P2.3) we see kevlar and carbon fibre are the most promising materials to substitute a metal in the floor pan. But if we take the steep increase in cost into account, we can see that this technology is not affordable for high-volume cars.

Here we see that the sender of knowledge can influence how useable the expertise is for the concept as a whole.

The third action is to collect knowledge, which means selecting solutions. These help the product development processes, in relation to outcomes of the activities performed during the procedure to identify and assess knowledge.

Table P2.4: Material properties of Sheet Moulding Compounds

SMC	**Glass SMC 20% cont. Vf = 15%**	**Glass SMC 40% cont. Vf = 30%**
E- modules [GPa]	8.5	10.5
Tensile strength [MPa]	95	130
Flexural modulus [GPa]	10	13.5
Flexural strength [MPa]	125	240
Impact strength [KJ / m^2]	50	85

Decisions on parameters important to the whole process, such as composite strength and modulus, cost, process and production feasibility, must be considered, if the expertise available is going to be of value to the receiver.

As the next step, it is very important to tailor the selected solution to receiver requirements, giving them the expertise they need rather than everything you possess. It is necessary to pinpoint the essential data to them (table P2.4). For example, a technical explanation with a sophisticated technical description of material properties would be created by the engineers of unit two with only low level of certainty.

As one engineer of business unit two stated:

> *Frankly, I have neither the time nor the interest to study plastic engineering, to understand the information provided by unit one. I only need five parameters of the suggested material to simulate the behaviour of the SMC floor pan in relation to the metal floor pan.*

In (table P2.5) I have summarised the main steps of a successful knowledge transfer process between business units. The interpretations of engineers in terms of what activities and thoughts they link to these actions are included.

Table P2.5: Core process of knowledge transfer linked to management activities

Codes	Management activities and thoughts	Categories
C 1.1 Identifying knowledge	Whom and where to ask	Enabler
C 1.2 Assessing knowledge	Match the existing expertise to requested requirements	Enabler
C 1.3 Collecting knowledge	Give them the expertise they need, not everything you possess	Enabler
C 1.4 Combining knowledge	Tailor the selected solution to knowledge transfer requirements	Enabler

Identifying knowledge refers to the activity of spotting, within business units, existing knowledge resources needing knowledge, and to provide that knowledge in an appropriate representation to receiver requirements.

Assessing knowledge is similar to identification. The main distinction is that it manipulates knowledge resources already existing in the organisation. An engineer describing this practice used the phrase "matching the existing expertise to requested requirements".

Collecting knowledge is the activity of selecting and categorising from existing knowledge. Senders need to "give them [receivers] the expertise they need, not everything you possess".

Combining knowledge is a course of action to structure knowledge and express it a way that is appropriate to receiver needs. In other words, "to tailor the selected solution to knowledge transfer requirements".

As indicated in (table P2.5), there are enablers of knowledge transfer between business units. But we have seen in the project that systematic knowledge transfer is a broader context that is influenced by several factors. During the research, we found that successful knowledge transfer requires that both parties should develop an understanding of where desired knowledge resides within a given source, and that both business units participate in the processes by which knowledge is made accessible. This is shown also in following quote:

> *Within the life time of the project, engineers learned of each others expertise, which supported the aim of creating a common understanding of the floor module as a system; so unit one got an understanding about vehicle engineering and unit two got an understanding about material expertise.*

Frequency of transfer and willingness to transfer plays a significant role in improving knowledge flow between business units.

Knowledge flow between organisations is fundamentally driven by communication processes and information flows. Analysing communication theories, Krone, Jablin and Putnam (1987) observe that all communication systems consist of a sender (source), a message, a receiver, a channel, and coding/decoding schemes.

Many researchers have noted the difficulties of knowledge transfer under conditions of weak co-location (Cohen and Levinthal, 1990; Gupta and Govindaraja, 1991; Appleyard, 1996). Co-location means sharing of place. Sharing of working place implies a high probability of face-to-face contact and frequent responses to actions. In a co-location environment, individuals meet each other relatively easily and often purposefully, and enjoy face-to-face communications. As a result of this interactive communication process, individuals can understand each other's actions and the background relatively easily. Through shared context, co-location implies common language (verbal and non-verbal) and achieves high levels of understanding (Dougherty, 1992; Brown and Duguid, 1991).

As a result of project one, we saw that a co-location and shoulder-to-shoulder working processes create a common understanding. This is aligned with the theory of Dougherty, Brown and Duguid.

In project two, where there are two separate business units and geographical distance must be taken into account, we see that team members depend heavily on communication channels. It is apparent that development of communication channels does not guarantee a full understanding of knowledge.

Previous research shows that assessing and creating replication is difficult. There is significant evidence that effective re-creation also requires that the knowledge package is made accessible to or de-conceptualised for the recipient, so that the recipient can convert it, adapt it or reconfigure it to its specific needs (Devadas and Argote, 1995; Dixon, 1994; Leonard-Barton, 1988; Moreland, 1996).

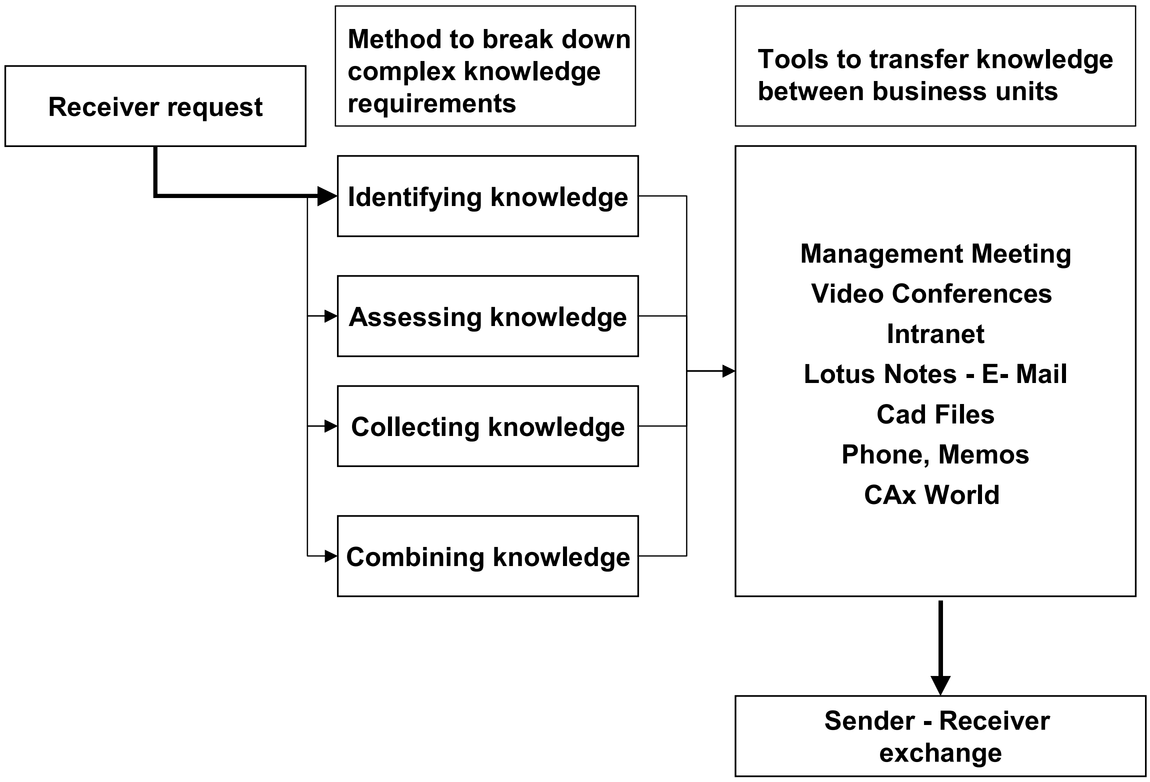
Based on this finding, I would argue that successful knowledge transfer takes place if the receiver is assumed to understand the provided knowledge and is able to use it for technical applications.

As we have seen in this project, transfer does not automatically create replication. There is no guarantee that recipients' and senders' interpretations of knowledge would be the same (Brannen and Wilson III, 1996).

To minimise the risk arising from context-dependent knowledge, a formal methodology should be implemented in order to match knowledge with recipient requirements, thus increasing the probability of a correct interpretation.

In this project the product development team illustrated in (figure 14), used a method to break down complex knowledge requirements and transfer knowledge over communication channels from the unit that owns the expertise to the unit needing the expertise (figure P2.8). It was not simply about networking, but about use of information tools like product data and document management systems to provide the capability to store, retrieve, share, and maintain data related to the product development process.

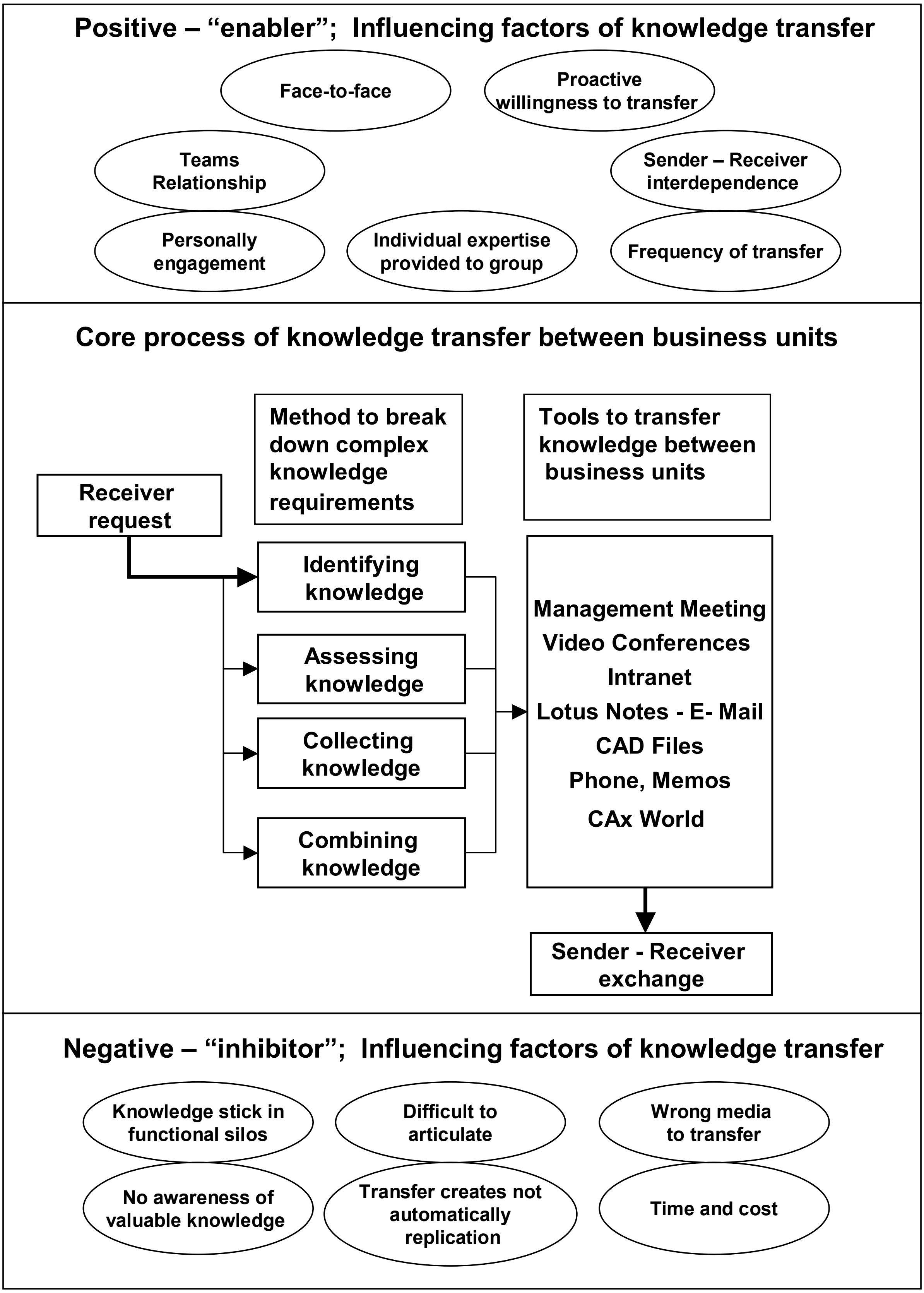
Figure P2.8: Core process of knowledge transfer between business units



Each category of communication tool supports the acquisition and development of knowledge through interaction with team members or linking experts located in different units.

As a research outcome we identified that the knowledge transfer process depends on several influencing factors, which I described as inhibitors and enablers of knowledge transfer, summarised in (figure P2.9) on following page.

Figure P2.9: Core process of knowledge transfer between business units and influencing factors of knowledge transfer in project two



As we can see in (figure P2.9), a successful knowledge transfer strongly depends on the implementation of enabling factors of knowledge transfer. On the other hand, recognition of negative influencing factors helps to define project structures and procedures, and so reduces their negative weight in the knowledge transfer process. Due to the environment in which this project took place, the knowledge transfer process was focused on the project objective.

Engineers were forced to combine expertise to develop a new product, so they collected and manipulated knowledge and transferred knowledge between business units. From this perspective, product development activities can be seen as transactions that are integrated into an overall system of identifying, assessing, collecting and combining knowledge. The main output of this complex processing scheme is not so much a physical product, it is more a knowledge base about the new product.

To transfer knowledge between business units, it is no surprise that engineers engaged in virtual product development for the advanced floor module needed a systematic framework to collect and combine expertise that was essential for the new product development process. The product development team called this the core process of knowledge transfer between business units, shown in (figure P2.9). This core process of knowledge transfer between business units is, of course, influenced by enablers and inhibitors.

Table P2.6: Overview Enabler & Inhibitors of the knowledge transfer process

Positive – "enabler"; Influencing factors of knowledge transfer	**Negative – "inhibitor"; Influencing factors of knowledge transfer**
Face-to-face	Knowledge stick in functional silos
Proactive, willingness to transfer	Difficult to articulate
Teams Relationship	Wrong media to transfer
Sender / Receiver interdependence	No awareness of valuable knowledge
Personal engagement	Transfer does not automatically create replication
Individual expertise provided to group	Time and cost
Frequency of transfer	

As a research outcome, I identified enablers and inhibitors of knowledge transfer, summarised in (table P2.6). Each has either a positive or a negative impact on the knowledge transfer process.

The knowledge transfer process includes more than just the core process of identifying, assessing, collecting and combining knowledge. This systematic approach is to create a knowledge flow between business units or organisations.

We should recognise, that this flow is strongly influenced by the task environment within which people share and communicate the knowledge they possess. Obviously, people and organisations have already developed frameworks for knowledge management. The effectiveness of these frameworks is heavily dependant on the attention people and organisations give to the influencing factors of knowledge transfer.

Today's frameworks, (examples are shown in table P2.7) can be classified as either prescriptive, descriptive, or a combination of the two.

Prescriptive frameworks provide direction on the types of knowledge management procedures without providing specific details of how those procedures can or should be accomplished. In essence, they prescribe different ways to engage in knowledge management activities.

In contrast, descriptive frameworks characterise or describe knowledge management. These frameworks identify attributes of knowledge management important for their influence on the success or failure of knowledge management initiatives. The majority of frameworks presented in the literature to date are prescriptive frameworks. As such, they tend to be task-oriented (Rubenstein-Montano, 2001).

Table P2.7: Example of knowledge management frameworks

Framework	Description	Classification
Liebowitz (1999)	{1} Identify, {2} Capture, {3} Store, {4} Share, {5} Apply and {6} Sell	Prescriptive
Marquardt (1996)	{1} Acquisition, {2} Creation, {3} Transfer and Utilisation, {4} Storage	Prescriptive
Buckley and Carter (1998)	Key knowledge processes are identified: {1} Knowledge Characteristics, {2} Value Added from Knowledge Combination, {3} Participants, {4} Knowledge Transfer Methods, {5} Governance and {6} Performance	Descriptive
Nonaka and Takeuchi (1995)	{1} Socialisation, {2} Externalisation, {3} Combination, {4} Internalisation	Combination of both
Holsapple and Joshi (1998)	{1} Managerial Influences including Leadership, Coordination, Control, Measurement, {2} Resource Influences including Human, Knowledge, Financial, Material, {3} Environmental Influences including Fashion, Markets, Competitors, Technology, Time, Climate, {4} Activities including Acquire, Select, Internalise, Use, {5} Learning and Projection as Outcomes	Combination of both

Many of the knowledge management frameworks focus only on the knowledge cycle process or tasks, the movement of knowledge through the organisation and the tasks required for facilitating such movement.

Other critical elements of knowledge management such as integration of knowledge management with the strategic goals of the organisation, the people involved in knowledge management activities, and the cultural context within which knowledge management is developed are not really included in the task orientated approach.

According to Drucker (1993), knowledge workers will tend to operate more in taskforces involving specialists from various functions to work together to accomplish some tasks, but selecting qualified employees to participate in a product development team is regarded as a non-technological example of knowledge selection.

Forming a team is essentially an act of knowledge selection in which employees possessing appropriate knowledge are identified and assigned to the team. Each employee has knowledge in explicit and tacit modes, and the way in which they bring this knowledge to bear on the product development work is a dynamic process of interactions between these individuals.

In the research project, the core process of knowledge transfer in general adopts a task orientated approach, but the effectiveness of this process strongly depends on influencing factors, which are classified in the research project in enablers and inhibitors. For a new product development project, the pure task orientated approach, in reality faces many constraints. Moreover, knowledge transfer packages are not comprised of written documents and codified information alone. We found that it is very difficult to transfer domain-specific knowledge, which relies on functional departments or individuals.

A pure task-orientated approach is effective at facilitating the transfer of codified knowledge, but it is unable to include design-relevant expertise. Such expertise is embedded in individuals, experience created in management meetings, feelings, engineers' perception of new ideas and problem solving activities. But this expertise is essential for a successful product development process.

To generate knowledge transfer where knowledge is provided and tailored to receiver requirements needs as a backbone a task-oriented approach.

In this project this is defined as the core process of knowledge transfer between business units. It is obvious that a successful product development process must be able to transfer intangible ideas and findings. It therefore needs a networking structure to manipulate the enablers and inhibitors of knowledge transfer.

This creates a dynamic process of knowledge flow, strongly driven by individuals and their willingness to share their domain specific expertise. There is no best practice approach defined so far, in spite of the fact that we talk about a high portion of tacit knowledge embedded in functional departments and individuals. For that reason, I don't expect a best practice solution to emerge in the near future. However, based on the research outcome, I propose a number of key factors that support knowledge transfer processes for new product development projects, releasing expertise stored in different business units.

3.2.1 Enablers and inhibitors and their influence on the core process of knowledge transfer between business units

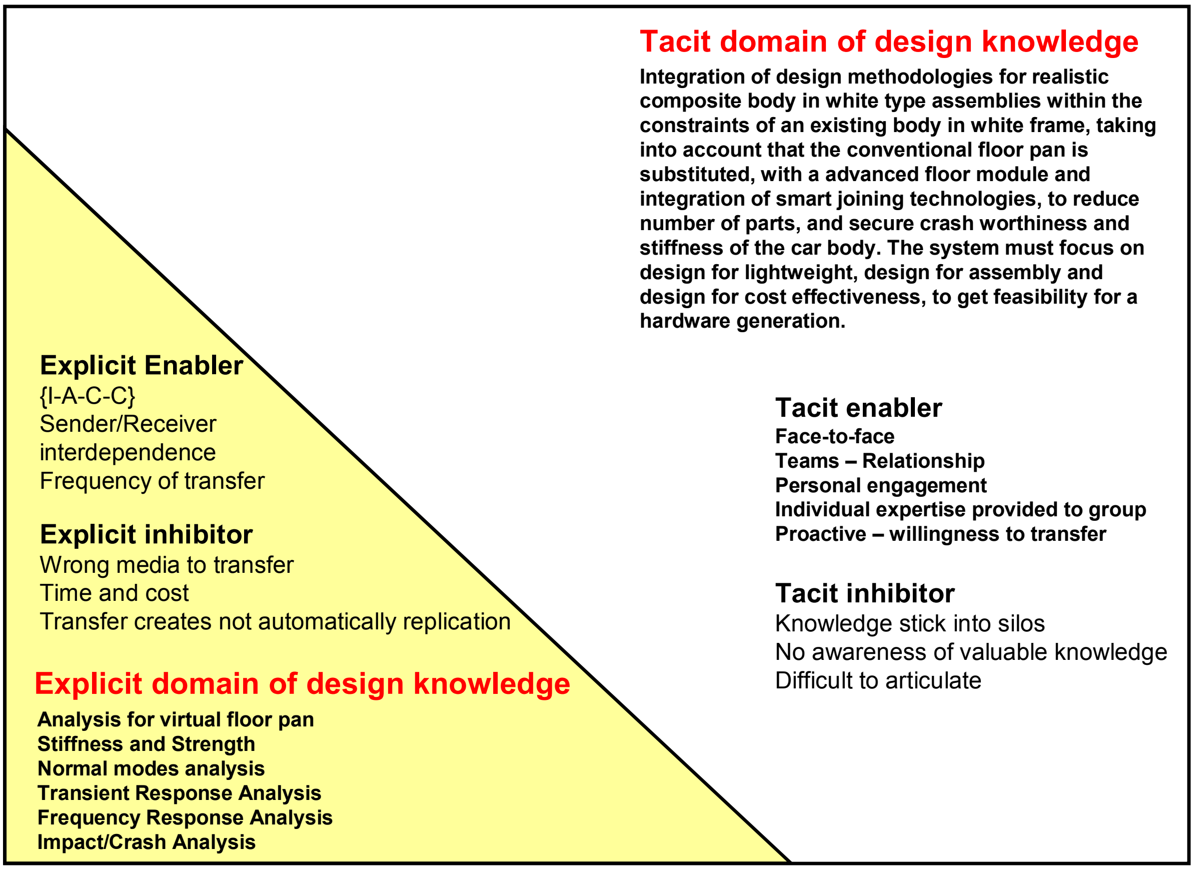
To understand the impact of enablers and inhibitors and their interdependence in relation to the core process of knowledge transfer (figure P2.9), it is important when and why they come to light, with regard to major engineering tasks and objectives, and what role they played in the product development process in relation to the knowledge transfer process.

The challenge, in general, is that the crucial product design knowledge is usually not available in a readily retrievable format. It is often held in the minds of a handful of key persons and it combines different types of knowledge; for example the design knowledge necessary to track a new product development process requires that the expertise involved contains explicit theories and formulae on the one hand, while on the other, the knowledge of applying such theories requires the understanding of the theories as well as expressing the components of estimation/judgement and, "best trade", on what and how to apply when and where. Knowledge with both explicit and tacit elements is required.

I propose to divide design tasks into two domains depending on their level of explicitness and tacitness (figure P2.10). This builds on the finding of project one which demonstrates that the methods by which knowledge is transferred change during the vehicle development process. As shown in (figure P1.10), in the concept and technology phase of the product development process, where engineers are engaged with the product concept and new technologies, tacit knowledge transfer dominates and so the key enablers of tacit transfer and the activities to foster tacit knowledge exchange are the resources for a value creation potential in the product development process. The research shows that if the vehicle development process reaches phase two, where most of the interfaces are clear defined, knowledge transfer is very efficient and process orientated. An environment that creates an optimised exchange of explicit knowledge, which is supported by advanced information technology to store and accumulate explicit knowledge between product development teams, will be the source for a value creation potential in the product development process.

From a theoretical perspective, to divide design tasks into explicit and tacit domains is in line with the theory of Takeuchi and Nonaka (1995), which explores knowledge creation through conversion between tacit and explicit knowledge.

Figure P2.10: Tacit and explicit domains of design knowledge



In (figure P2.10), I propose that knowledge can be represented in tacit or in explicit domains. There is no strict boarder line between these domains of design knowledge but we know that some engineering tasks rely more on judgement and estimation and depend on individual's expertise on how to apply a proper solution.

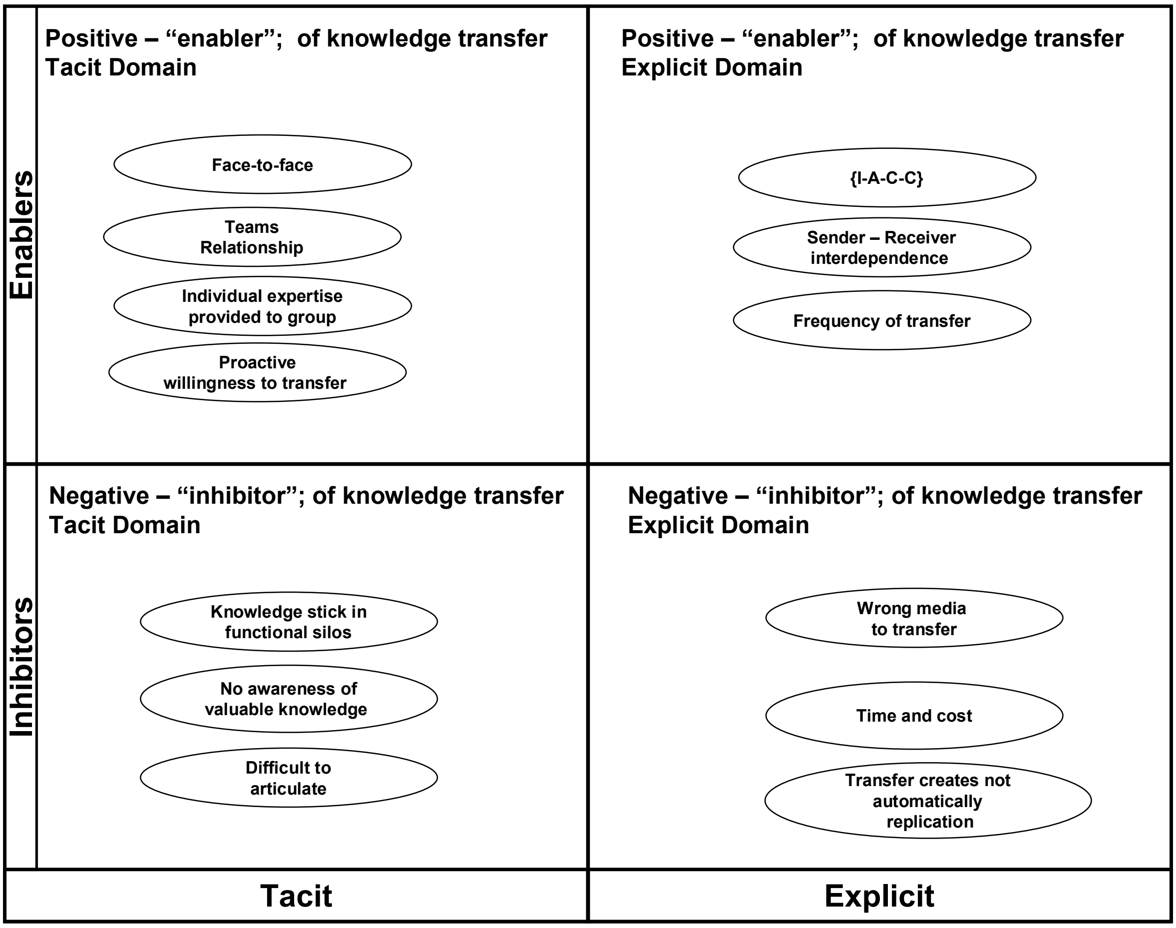
In contrast, we have design tasks appearing to be concrete and definable, expressed in tables of data, formulae in handbooks, standards, company documents and so on. The essence of design is to select the appropriate information and put it together to make the product work in the required manner. The designer needs to know what to do, when and how.

It is sometimes easily to explain why particular information / knowledge is used and how it can be applied to achieve the design objectives. It is usually related to physical principles or properties of material behaviour. However, some design tasks require some form of estimation or judgement, which can hardly expressed in plain language.

Additional evidence comes from the major finding of project one, which was that engineers strongly preferred to transfer tacit knowledge in shoulder-to-shoulder working processes, face-to-face meetings and creation of plans and reports to draw down knowledge patterns.

This enabled them to articulate and make their tacit knowledge visible to other team members, and to transfer it between different functional teams. The way knowledge was transferred in project one changed significantly when the product development process moved into phase two. Here engineers were mainly engaged with product engineering and process technology. For the most part, engineers strongly used the IT infrastructure and CAx World for explicit knowledge transfer.

Figure P2.11: Tacit and explicit domains of inhibitors and enablers of knowledge transfer



Based on these findings, we should be aware that some kind of enablers and inhibitors of knowledge transfer have a stronger influence on tacit design tasks. There are also some enablers and inhibitors which have a stronger influence on explicit design tasks.

Examples of engineering tasks from the research project can help to illustrate how tacit and explicit enablers and inhibitors support or prevent knowledge transfer between business units. While (figure P2.11) attempts to classify enablers and inhibitors, in reality we know there is not such a strict demonstration. But (figure P2.11) helps to explain why engineers perceived certain enablers as very important for specific design tasks, while others were perceived as less important to accomplish these tasks.

Also there is a relationship between enablers and inhibitors; for example face-to-face meeting were seen, as an important process to transfer tacit knowledge, but this process is relatively expensive, so it is influenced by cost and time. This is classified as an inhibitor, because it influences a tacit enabler negatively. It can be measured by travel expenses, time consuming scheduling for management meetings, and the opportunity cost of different management priorities within business units.

3.2.2 Case example: Primary design task and objectives and the relation to inhibitors and enablers of knowledge transfer

To understand the dynamics of knowledge transfer, we need to take a deeper look into the major design task, what challenge the engineers faced and how they handled it.

Table P2.8: Primary design task and objective:

Develop a vehicle floor module, which should integrate the advantage of extending the platform variable in length and width and additionally create an advantage through integration of functionality, like channels for wire and harness, carpet and acoustic systems already integrated in the floor module. All these features would enhance the functionality and reduce cost in comparison to a conventional vehicle floor. system.	
Tacit enabler Face-to-face Teams – Relationship Personal engagement Individual expertise provided Proactive – willingness to transfer	**Explicit Enabler** Sender/Receiver interdependence Frequency of transfer
Tacit inhibitor Knowledge stuck in silos No awareness of valuable knowledge Difficult to articulate	**Explicit inhibitor** Wrong media to transfer Time and cost Transfer creates not automatically replication

As described in (table P2.8), the primary task is to develop a new product, using the expertise of two different business units. This activity includes the core process of knowledge transfer between business units, sender receiver exchange, shown in (figure P2.9), and is influenced by enablers and inhibitors of knowledge transfer.

At the beginning of the project, we defined objectives and targets aligned to a time schedule. Several management meetings are essential to determine the expertise possessed in the business

units and to align resources to project objectives. In this phase, it become apparent that it is very difficult to apply team and individual knowledge at a distance.
As one engineer stated:

> *The success of knowledge transfer strongly depends on what kind of knowledge is transferred. Knowledge codified in technical specification and CAD models, like the digital car, are easy to transfer. The difficulty is how to use this knowledge base about the car, how to organise development steps, providing new solutions containing new technologies. Knowledge is very difficult to transfer between units, if it should contain intangible domains like expertise of engineers, a combination of different ideas to form innovation. How realistic is it to transfer this kind of knowledge between business units using electronic exchange methods?*

As already stated, management meetings creating face-to-face contact are perceived as one of the strongest activities to transfer expertise, but to create knowledge flow based only on face-to-face contact would increase the project costs to an unacceptable level. For that reason, the product development team used videoconferences as a means of transferring knowledge. After a few such meetings it became apparent that it was not possible to transfer design-relevant knowledge with this communication tool because it created a disruption of the design process. Engineers used a more aggressive style in discussions to support their opinions. Design is not a sequential process: multiple options and conflicting decisions need to be debated to carry forward promising solutions. This design trade off includes discussions, additional resources like drawing, CAD files and analysis of simulation data to evaluate different material properties under different conditions. This argues against to use of videoconferences, because an efficient transfer of multiple data sets through one communication channel is very difficult to achieve.
As one engineer stated:

> *Real design knowledge, which integrates a high portion of tacit and informal knowledge, is transferred mainly by face-to-face interactions. Very disappointing outcome with videoconferences; there was no way to articulate relevant knowledge to develop a new floor module. Even if you see your partners on the screen, how can you explain a technical idea sketched on a drawing; how can you draw down the thoughts and comments of your development partners on the other side to frame this new idea into a solution? Most of the time we agreed to meet each other in a few days, to discuss this personally to sort out the next design steps.*

A successful knowledge transfer process needs the right medium for transfer and a method to break down complex knowledge requirements, to transform intangible ideas and findings into an explicit form and create a valuable sender / receiver exchange. A systematic approach to break down complex requirements, and the right transfer medium, creates the backbone of successful knowledge transfer (figure P2.9).

3.2.3 Case example: Pure explicit design task and objectives and the relation to inhibitors and enablers of knowledge transfer

Table P2.9: Pure explicit design task and objective:

	Tacit	Explicit
Component durability for series is in general, 15 years, (130,000 hours), it is assumed that the car will be actually operated between 3,000 and 5,000 hours. The design temperature range is assumed to vary from 40 degrees Celsius to a maximum of 120 degrees Celsius.		X

Here we see an example of a pure explicit design task and objective. This information is provided to engineers involved by means of e-mail, word documents, and also in verbal form, at design meetings. The following quote is an example:

> *Codified and articulated knowledge, for example technical specifications, are very effectively provided to all team members by e-mail; also CAD-files are exchanged without any problems. All these are available in a descriptive form. But how do you describe an idea in a plain text document, which contains a judgement of several concepts? How do you explain to others why you think this solution is the best one, without discussion? I think successful product development containing new technologies needs an interaction of experts. Meetings and face-to-face contacts are necessary to integrate new technologies into new products.*

We can classify explicit design tasks as easy to transfer: it is clearly coded, and has its origin in objectives and data tables.

In the following design tasks, we see the real challenge of a product development process. A lot of expertise is needed, to form intangible ideas and solutions based on findings from an ongoing development process, so that the product development outcome is aligned to the objectives.

3.2.4 Case example: Complex design tasks and objectives and the relation to inhibitors and enablers of knowledge transfer

Table P2.10: Complex design tasks and objectives

	Tacit	**Explicit**
Design task one: Integration of design methodologies for realistic composite body in white type assemblies within the constraints of an existing body in white frame, taking into account that the conventional floor pan is substituted with a advanced floor module and integration of smart joining technologies, to reduce number of parts and secure crash worthiness and stiffness of the car body. The system must focus on design for lightweight, design for assembly and design for cost effectiveness, to get feasibility for a hardware generation.	X	X
Design task two: Using complex shaped multi-functional parts and smart joining technologies to reduce number of parts.	X	X
Design task three: CAE Simulation technologies of static / crash behaviour to translate performance requirements into feasible part concepts using these virtual development technologies	X	X
Design task four: Simulation tools that allow us to predict the performance of a composite finished floor module of an assembly, using materials parameters and simulation technologies to predict static, fatigue and crash performance and strength and stiffness of the body	X	X
Design task five: Comparison of test results of conventional body and simulation data of developed floor module concepts, to evaluate performance and to create a knowledge base for further design activities.	X	X

Design tasks one to five are strongly interdependent. The activities are an ongoing process including tacit and explicit knowledge. Here there is clear evidence that engineers rely on their expertise to find solutions and define further activities.

The challenge is to combine domain-specific knowledge, embedded in individuals and different functional departments, and make it available at a distance to team members located in different geographical locations.

Here we see the challenge for knowledge transfer. The extent of knowledge needed to solve such a complex design tasks must be individually developed to cope with specific design needs. For that reason the identification and combination of knowledge and presentation of knowledge is an active process, that depends on the willingness of the engineers involved. The following statement indicates this:

> *Experience of senior engineers is very important to form solutions, but is strongly dependent on the individual willingness to share his expertise with engineers of different disciplines, which is also negatively influenced by the fact that project teams are divided and placed in different units. Members are not in touch on a daily basis, and that means more effort is necessary to share knowledge. It is not enough, to walk from one door to the next - business*

trips are on the agenda and who enjoys staying in boring hotels over night, by the way? Proactively and willingness to provide expertise to the project group can be very exhausting for people engaged in international product development projects.

Figure P2.12 illustrates the expertise needed to solve this type of design task. It shows how complex it is to combine different domain specific expertise to create a new product.

Figure P2.12: Combining tacit and explicit expertise

Complex design tasks are a combination of tacit and explicit design knowledge

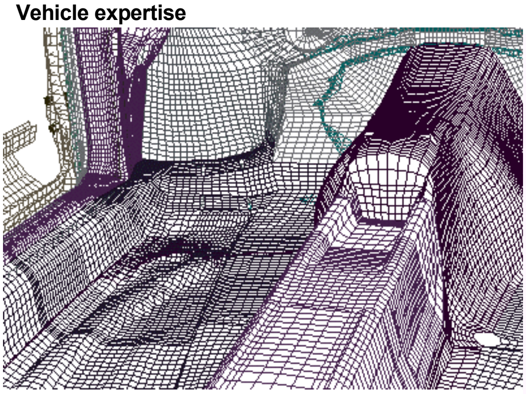
Conventional floor pan is substituted, with a advanced floor module and integration of multi-functional parts and smart joining technologies, to reduce number of parts.

Outcome:

Creation of knowledge

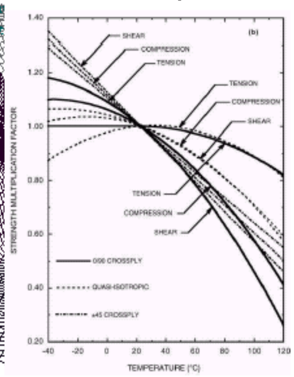
Knowledge Unit 2

Vehicle expertise



Knowledge Unit 1

Material expertise



Comparison of test results of conventional body and simulation data of developed floor module concepts, to evaluate performance and to create a knowledge base for further design activities.

CAE simulation technologies of static / crash behavior to translate performance requirements into feasible part concepts using these virtual development technologies

To tackle such a complex design tasks, it is essential to use a method to break down complex design requirements so that a path to transfer the expertise between engineers and business units is created. Complex design tasks are not purely tacit or explicit, but are usually a combination of both.

A method for breaking down complex design requirements can be seen as a knowledge preparation phase. Such a process involves multiple presentations, discussions and dialogues about the knowledge needed and should involve sender and receiver. This helps to make tacit design knowledge more accessible by means of conversions into a more descriptive form.

3.2.5 Case example: Complex design tasks and objectives and the core process of knowledge transfer in relation to inhibitors and enablers of knowledge transfer

The effectiveness of the knowledge transfer process is related to the fit between available tools for knowledge transfer and the communication patterns used by engineers involved in complex design tasks. Integration of design methodologies for realistic composite body in white type assemblies within the constraints of an existing body in white frame, taking into account that the conventional floor pan is substituted with a advanced floor module.
Design teams must select the right piece of information and expertise out of functional departments and business units and use it in the right way, at a right time and place. This set of skills includes a task orientated approach to identify, assess, collect and combine knowledge to create innovative products. This process can be described by tacit characteristics.

Combining the understanding process and the possession of this expertise creates the ability to transfer knowledge over communication channels. This can be face-to-face, verbal or process driven - for example data exchange, CAD files or e-mail conversation. Engineers engaged in these processes need a systematic approach to knowledge transfer, which I call the "core process of knowledge transfer". If we take the broad spectrum of expertise needed to solve the complex design tasks into account, we can see that many intangible factors influence the knowledge transfer process.

The process of selecting explicit and tacit knowledge is seen as an engineer's action in performing problem-solving functions. This requires the understanding of explicit theories, described in technical specification and also embedded in engineering tools, like stiffness/ strength analysis with MSC/NASTRAN or ABAQUS, noise & vibration with MSC/NASTRAN and crashworthiness with LS/DYNA or PAM/Crash. To use such engineering tools in a proper manner in order to create advanced design solutions can be seen as a tacit dimension of design knowledge.

Additional knowledge transfer success is also affected by its articulability, or the extent to which knowledge can be verbalised, written, drawn or otherwise articulated (Bresman 1999). As Polanyi (1966) noted, individuals know more than they can explain, since individuals possess tacit knowledge that is non-verbalised, intuitive, and unarticulated. Tacit knowledge is hard to communicate and is deeply rooted in action, involvement and commitment within a specific context: It is “a continuous activity of knowing” (Nonaka, 1994, p. 16). In this research project, a central activity is to identify related knowledge elements and combine them to make them easily transferable (table P2.11).

Table P2.11: Management activities and thoughts to combine knowledge

Codes	**Management activities and thoughts**	**Findings**
		Material expertise, for example, which can be codified, is much better to transfer than complete vehicle engineering expertise, which occupies a combination of many engineering disciplines.
C 1.1 Identifying knowledge	Whom and where to ask	
C 1.2 Assessing knowledge	Match the existing expertise to requested requirements	
C 1.3 Collecting knowledge	Give them the expertise they need, not everything you possess	
C 1.4 Combining knowledge	Tailor the selected solution to knowledge transfer requirements	

The knowledge required for complex design tasks is embedded in people, tools and routines. The issue is, how many knowledge elements and related networks must be created to be transferred to the receiving unit?

From a technical perspective the greatest challenge in this research project is to integrate an advanced floor module in a conventional body frame, using multi-functional parts and smart joining technologies and using materials parameters and simulation technologies to predict static, fatigue and crash performance and strength and stiffness of the body.

Table P2.12: Engineering activities, needed expertise and sub – codes

Engineering activities	**Expertise**	**Sub - Categories**
Using multi-functional parts and smart joining technologies	Complete vehicle engineering expertise, embedded in different engineering disciplines and functional departments, strongly depending on material behaviour, integrates a large portion of the knowledge, which is difficult to articulate.	C 2.1 Management Meeting C 3.1 Face-to-face C 3.2 Personal engagement C 5.1 Individual expertise provided to group C 5.2 Proactive – willingness to transfer C 8.1 Team C 8.2 Relationship
Using materials parameters and simulation technologies to predict static, fatigue and crash performance and strength and stiffness of the body.	Expertise that contains more an explicit dimension; formulae, table with material properties, CAE Simulation tools, CAD files for the virtual car. Implementation of these models in PAMCRASH software to study technique for crash prediction behaviour of joint areas conventional body and advanced floor pan	C 2.1 Management Meeting C 2.2 Video Conferences C 2.3 Intranet C 2.4 Lotus Notes - E- Mail C 2.5 Cad Files C 2.6 Phone, Memos C 2.7 CAx World

Continuous table P2.12: Engineering activities, needed expertise and sub – codes

Engineering activities	Expertise	Sub - Categories
Comparison of test results of conventional body and simulation data of developed floor module concepts, to evaluate performance and to create a knowledge base for further design activities.	Expertise, relies on judgment of results and decisions, for further steps, next loops, what sort of material, reinforcement for areas failed. These are based on explicit results, new investigations and decisions based tacit expertise. A combination of different domain-specific knowledge creates the opportunity to develop solutions with feasibility for implementation.	C 2.1 Management Meeting C 3.1 Face-to-face C 3.2 Personal engagement C 5.1 Individual expertise provided to group C 5.2 Pro active – willingness to transfer C 8.1 Team C 8.2 Relationship

Table P2.12 shows that engineers prefer knowledge transfer to take place as a personal exchange of design relevant expertise. This helps to build a knowledge base for judgement and decision processes. From a research perspective the difficulty, time requirement and expense of communication to create a regular face-to-face knowledge transfer between business units was recognised. The geographical distance between business units was an additional constraint for face-to-face activities and therefore the difficulties in articulating and transferring design relevant knowledge are much more challenging.

The design teams in both units improved their relationship to facilitate good communication during the life cycle of the project. For example during the product simulation process, if a design solution fails, a new solution is required.

So the teams go through a learning process, a product improvement loop whereby new routines and knowledge transfer is created. Face-to-face meetings create a personal engagement and help to create a common understanding of essential activities to achieve design objectives.

During the kick off phase of a new product development project, it is best to have few management meetings where key players get familiar with each other and develop an understanding of the knowledge elements needing to be transferred.

The objective of this knowledge-preparation process is to identify, assess, collect and combine knowledge, and must involve both sender and receiver parties.

For example, we faced the major challenge that composite materials modelling technology lagged behind modelling of metallic materials. So we needed project engineers who were able to make a judgment based on their experience to permit design and evaluation of polymer composite structures under dynamic conditions to facilitate preliminary design and sizing and crash critical behaviour.

A clear articulation and definition of existing and required expertise helped to identify knowledge gaps. As soon as they were identified, teams could act to close the gap.

With the information in hand, an administrative process can be defined to share and transfer knowledge between business units. This administrative process, described as the core process of knowledge transfer. With the increased number of knowledge transfer activities, the success of knowledge transfer improved. Table P2.13 gives examples of statements from interviews.

Table P2.13: Example of research interviews

Question 6: Was there anything about the organisational structure that hindered the transfer of knowledge between the business units?			
	Interviewees Statements	**Codes**	**Categories**
Interview 3 – unit 2	During the project, engineers got more used with the knowledge exchange procedures, which helped to improve the outcome (7.2), social networks were emerging, engineers, know each other, even though they were located in different countries	C 7.1 Sender/Receiver Interdependence C 7.2 Frequency of transfer	Enabler
Interview 4 – unit 1	If the transferring unit is strongly relying on the outcome of the receiving unit with the knowledge provided, the desire to foster and track the process is much greater. (7.1	C 7.1 Sender/ Receiver Interdependence C 7.2 Frequency of transfer	Enabler

In the research project, the unit in need of expertise to move forward in development is more proactive in requesting the required knowledge. So the interdependence of the business units by itself had an active influence on the frequency of knowledge transfer. As a result, the people involved created social networks where a combination of new knowledge is shared and actively used. These networks proved to be essential in order to move the development process forward.

The knowledge transfer process is very challenging because the knowledge owned in each business unit was quite different. For the knowledge transfer process, it is very difficult to create a common understanding if the sender and receiver expertise differs very much in context. People are not able to allocate valuable knowledge, because the requirements of the receiving parties are poorly understood. So people engaged in this process get the feeling that knowledge sticks in functional departments of the business units and cannot be transferred.

In the project, we have seen that the right choice of material combination depends on engineers understanding the dynamic conditions of materials in automotive structural applications. Superior material know-how alone does not create the ability to estimate how a new material will perform when it is integrated into the car. To implement a new material combination into the structural body frame of a new vehicle involves the use of multiple presentations, discussions, and dialogues about the advantage and risks and technical feasibility of this new solution.

Knowledge across multiple teams is communicated and judged within both business units. This active interaction diffuses the functional silos of expertise and new knowledge is created and shared in a broader context between engineers. During this process of new knowledge creation, engineers rely very much on face-to-face contact and management meetings. The following quote demonstrates this:

> *In the beginning of a project you start to define what you want to achieve with a new product. We have defined, by the start, that to be accepted by our customers, our new floor module must focus on design for lightweight, design for assembly and design for cost effectiveness. There are many ideas, but how does one form this idea into a tangible product? That is the challenge. The combination of new technologies creates new products, therefore you must learn from other disciplines to combine knowledge. This needs communication between several engineering disciplines. For example to develop a smart joint technology for the floor pan with the lower A-pillar, B-pillar and C-pillar, where are the tricky areas to secure side crash worthiness? This shows how complex it is to find a proper solution. Engineers need virtual analysis tools and several feedback loops, redesign of reinforcement components, new material combinations … and don't forget the manufacturing aspects to create production feasibility. You need informal meetings to run improvement loops and design reviews with many experts. For example, if your finding has a major impact on the concept, for example a material combination fails, you need to combine all resources available to search for a new solution. You are not able to transcribe all your findings and provide them to all team members. No not at all, you discuss with team members, using drawings and presentations in meetings, to sort out how to organise the next development steps to create a proper solution.*

The project showed that knowledge required for complex design tasks is embedded in people, tools and routines.

The issue is, how many knowledge elements and related networks must be created to transfer knowledge containing tacit and explicit domains of design knowledge?

Table P2.14 on following page gives additional examples of how demanding it is to transfer tacit design knowledge between business units.

Table P2.14: Example of research interviews

Question 4: Were there different types of knowledge that were transferred between the business units?			
	Interviewees Statements	**Codes**	**Categories**
Interview 4 – unit 1	Very often people don't know how to allocate valuable knowledge, (C 9.2) in other business units. Frankly, how should they?	C 9.1 Functional knowledge stick in silos C 9.2 Unawareness of valuable knowledge C 9.3 Difficult to articulate	Inhibitors
Interview 5 – unit 2	Engineers sticking too much to their own field of expertise. (C9.1) Others expertise is hardly understood. Only intensive discussions help to understand the value of expertise that comes out of several engineering disciplines. (C 9.2)	C 9.1 Functional knowledge stick in silos C 9.2 Unawareness of valuable knowledge C 9.3 Difficult to articulate	Inhibitors

The project demonstrated that tacit design knowledge is very difficult to transfer in a systematic way between business units.

In previous research it is noted that *difficulty in codification and transfer* is a central attribute of tacit knowledge (Grant, 1996; Nonaka, 1994; von Hippel, 1994; Zander and Kogut, 1995).

From a product development perspective we know that tacit knowledge is only capable of codification to some degree, and even it is codified and transferred, it cannot be taken for granted, that knowledge is recreated in the receiver unit. Successful transfer does not automatically create replication of knowledge. This is because knowledge is embedded in many engineering disciplines and intensive communication between engineers creates combination, and as such it is to some extent integrated into the product development process. Table P2.15 gives an example of an interviewee statement in relation to replication.

Table P2.15: Example of research interview

Question 5: Were there any types of knowledge that could be transferred between the business units?			
	Interviewees Statements	**Codes**	**Categories**
Interview 2- unit 2	The units needed each other expertise, material expertise versus vehicle expertise, so the exchange of expertise was strongly based on communication of information, usually from unit to the other. But it was very difficult to implement the transferred knowledge into the design process. (C6) First we had to learn to implement and trust in the information provided. Additionally, if you read through a technical specification and as a next step you come to the application, you immediately face several questions. Again you need communication to use the knowledge provided, even it exits in explicit form.	C6 Transfer does not automatically create replication	Inhibitor

New knowledge for product development can be traced as a progression along the knowledge spectrum from tacit (un-codified) to explicit (codified) knowledge. The advantage of codifying tacit knowledge is that it could be distributed to a large numbers of employees over large distances and applied to a wide range of applications. In perfect form it would create the opportunity to replicate knowledge and make it available to all members of the product development process. In reality we know that creating replication is difficult. There is significant evidence that effective re-creation also requires that the knowledge package is made accessible to or de-conceptualised for the recipient so that the recipient can convert it, adapt it or reconfigure it to its specific needs (Devadas and Argote, 1995; Dixon, 1994; Leonard-Barton, 1988; Moreland, 1996). In project two, we found that knowledge received is part of practices integrated in the product development process; it is subject to negotiation and arguments and as such it is to some extent integrated into the product development process.

Transferring and combining design knowledge is a continuous and cross-functional process involving and integrating a growing number of different technological capabilities between parties involved. As a result of this activities we can assume that the capabilities to improve product development has increased.

In other words, capability to improve product development is the process of combining new technologies with existing technologies to generate new applications for tangible products.

Figure P2.13: Capabilities to improve product development

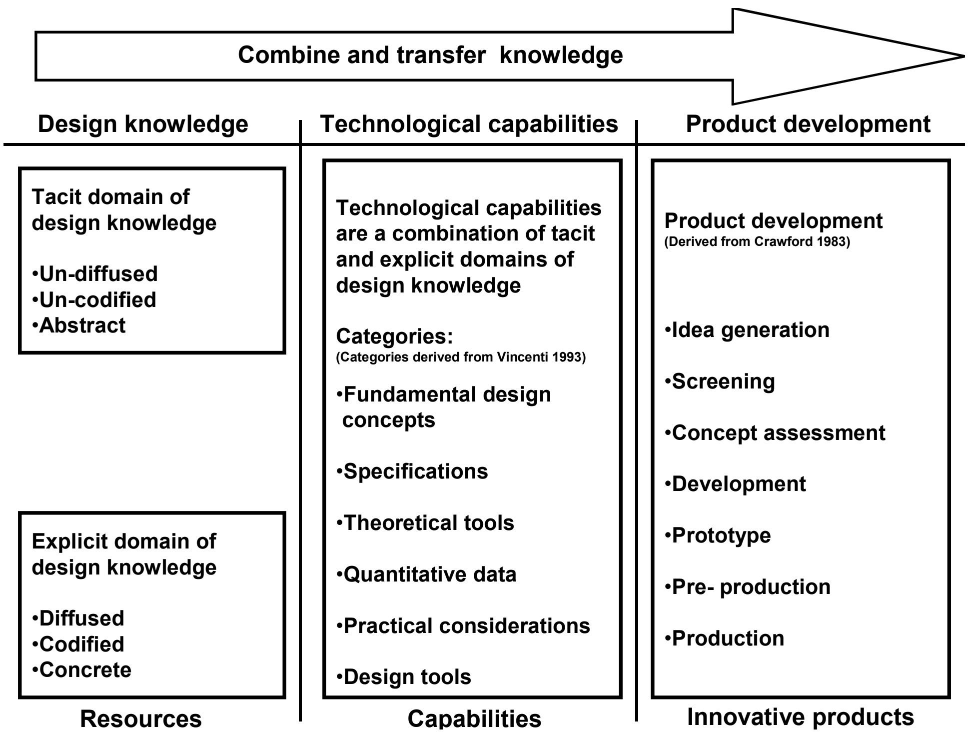


Figure P2.13 illustrates, that knowledge transfer combines technological capabilities to improve product development. For example recent studies suggest that the key to success for an organisation is embodied in its ability to implement and appropriate new technology (Willmann, 1991). The answer to how this might be achieved is described in terms of the knowledge transfer capability within the organisation. This argument is developed by Cohen and Levinthal (1990), who suggest that knowledge transfer is a critical factor in the ability of a firm to innovate.

The process of new product development and technological innovation embraces a wide range of activities that contributes to the generation of new technological knowledge and/or improved use of the knowledge available. It has been recognised that the technological innovation process has had varying effects both at macro *"society, economic system, and industry"* (Schumpeter, 1942; Hall 1986, 1994) and at micro level *"firm"*(Burgelman and Maidique, 2001; Wheelwright and Clark, 1992; Tidd, Bessant and Pavitt, 2001; Tushmann and Anderson 1997; Spender, 1996).

At the macro level, the technological innovation process: (1) modifies the structure of industries, (2) changes the composition of demand in the labour market, (3) alters the competitive position of nations, (4) stimulates economic growth, and (5) increases the well-being of society as a whole. At micro level, the technological innovation process goes on within organisations.

From a business management point of view, using disaggregated units of analysis, studies have been undertaken of the problems arising from management and organisation of innovatory activities. From a firm perspective the main features studied are integrating technology into strategy and organising innovation (Kantrow 1980; Pavitt 1990; Porter 1983; Quinn, 1985).

The second main area focused on organisation of R &D departments with a perspective on management of technical personnel and transmitting technological information (Leonard-Barton, 1992; Nonaka and Takeuchi, 1995; Teece, 2000; Tushman and O'Reilly, 1997; Katz, 1997; Nonaka and Teece, 2001).

The third research stream concentrates on planning and managing R&D projects (Allen 1997, Twiss 1986, Teece 1977).

The fourth area of studies explored the process of developing new products, with specific areas such as exploiting technological capabilities, product platforms, success factors in developing new products and reducing development times (Clark and Fujimoto, 1991; Wheelwright and Clark, 1992; Meyer and Lehnerd, 1997; Cooper, 1998; Boisot, 1998). All studies on technological innovation embrace a wide range of activities that contribute to the same assumption: innovation begins with the construction of a new kind of knowledge within the firm.

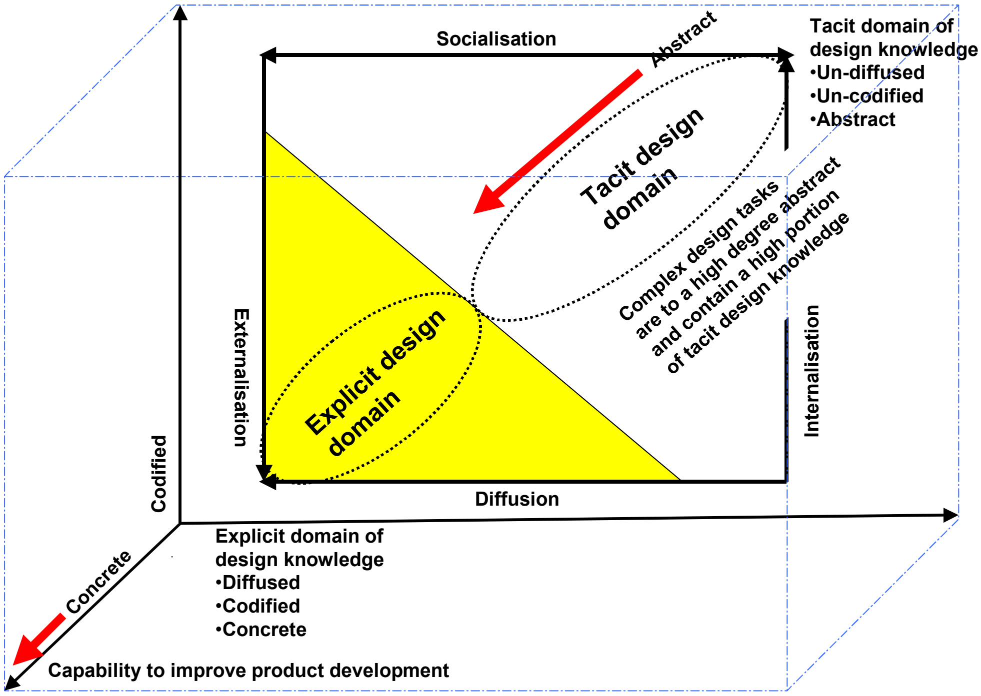
From a product development perspective, as time based competition becomes the norm, particularly for the development and introduction of new products, companies must create the capabilities to create quickly and efficiently new products. Knowledge on which product development is based comes from inside a firm, and the way in which that knowledge is combined and transferred fastest to the product development teams is key to generate a process of continuous improvement in products. Product development teams increase their capabilities to improve product development by turning tacit knowledge into explicit knowledge and by passing tacit knowledge on to others (Nonaka and Takeuchi, 1995). To turn tacit knowledge into explicit knowledge, externalisation takes place. This externalisation describes the codification of tacit knowledge. To pass tacit knowledge on to others socialisation takes place. This describes the process of communicating and enhancing tacit knowledge.

Additionally I would say that innovative products hold a higher degree of tacit design knowledge than commodity products. Based on these definitions and the research findings, I am able to draw down a conceptual framework for knowledge transfer in new product development projects, to show that successful knowledge transfer increases the capability to improve the product development process.

3.3 From complex design tasks to a conceptual framework of knowledge transfer in new product development

As in (figure P2.10) illustrated, I propose that knowledge can be represented in tacit or explicit domains. Complex design tasks are a combination of both domains but to be successful completed, they rely more on the tacit domain of design knowledge. To structure in a conceptual framework around why successful knowledge transfer increases the capabilities of a firm to improve product development, I defined the position of tacit design knowledge and explicit design knowledge in the knowledge space. The knowledge space model, as is shown in (figure P2.14), is derived from Boisot (1998) and Nonaka and Takeuchi (1995).

Figure P2.14: Position of tacit and explicit design knowledge in the knowledge space



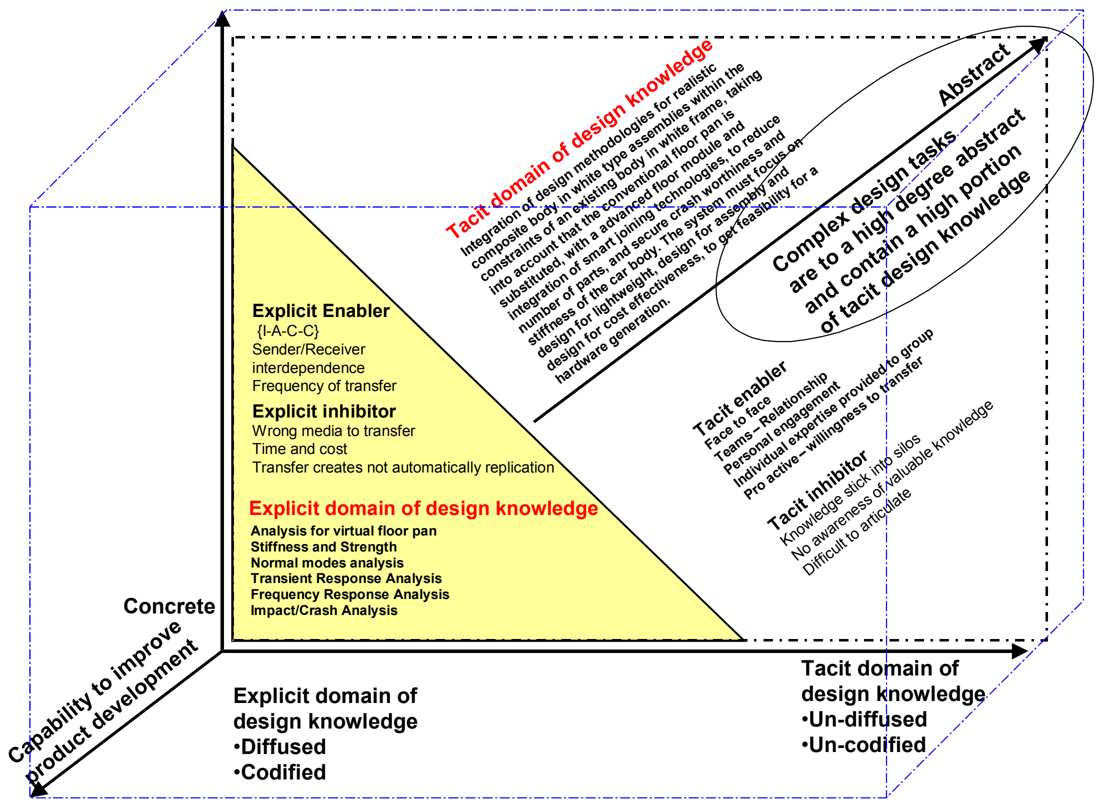
The primary characteristics of the tacit design domain are that it is un-diffused, un-codified and abstract. On the other hand the explicit design domain is diffused, codified and concrete.

- *Externalisation* describes the codification of tacit knowledge, it is one way to transform tacit into explicit knowledge.
- *Socialisation* describes the process to pass tacit knowledge on to others, for example face-to-face contact and shoulder-to-shoulder working processes are effective facilitators of tacit knowledge transfer. If tacit knowledge is transferred to others, a kind of codification and externalisation occurs. Additionally, this knowledge is available for new applications. Engineers use this knowledge to form new ideas and explicit knowledge becomes the platform for new tacit knowledge - internalisation takes place.

Therefore socialisation takes place in both directions it transforms tacit knowledge into explicit knowledge and on the other hand explicit knowledge can be the basis for new thoughts and builds new tacit knowledge in the product development process.

- *Internalisation* describes learning by doing, and documented knowledge can play a helpful role in this process. For example technical specifications or design guidelines are useful to support the product development process.
- *Diffusion* identifies the degree to which the knowledge has been communicated. A particular act of diffusion may have many potential audiences: in a product development project your audience is on a cross-functional level, owning different fields of expertise.
- *Abstract – Concrete axis* identifies the degree of improvement potential. If you achieve a common understanding over socialisation and diffusion, abstract design tasks are transformed into concrete design tasks and therefore they are understood by a broader audience, which helps to increase the capabilities to improve product development.

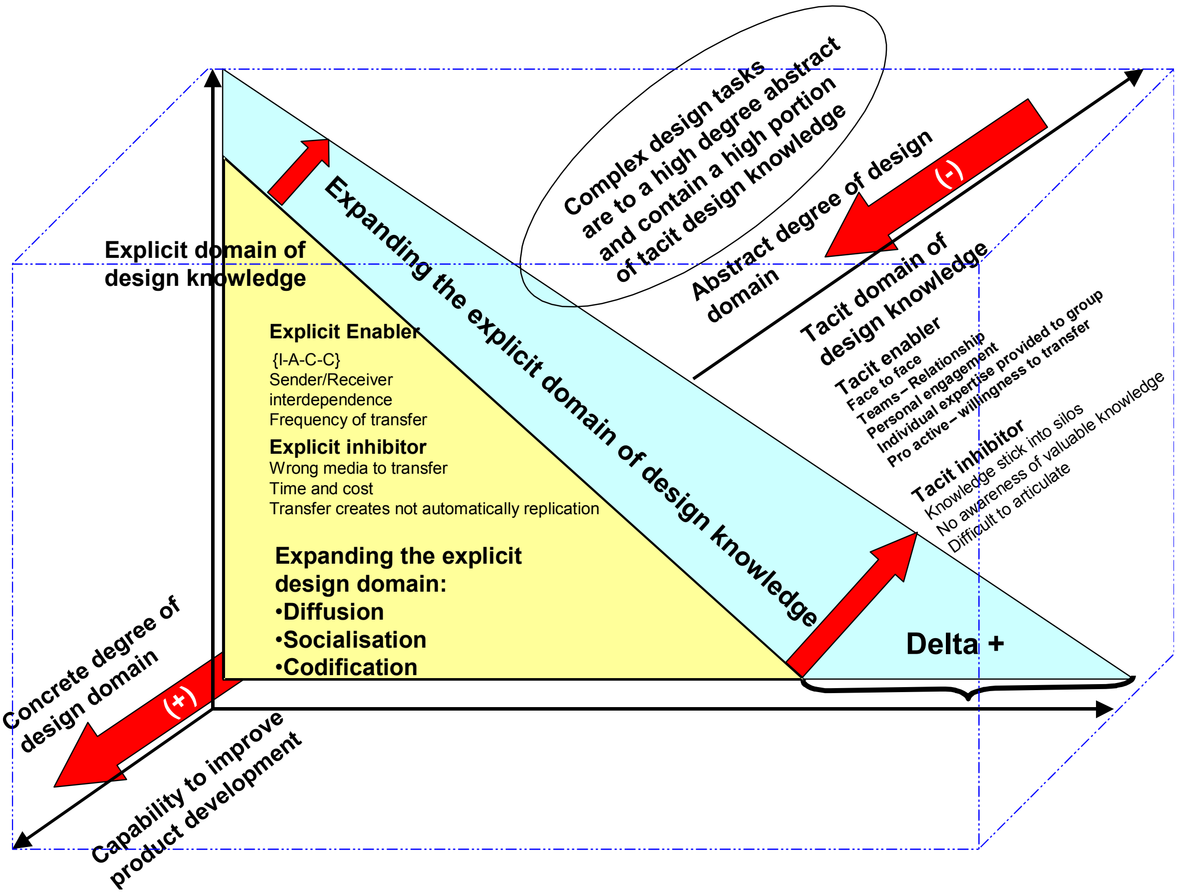
Figure P2.15: Complex design task: "Advanced floor module", in the knowledge space



Based on the conceptual framework, we have three ways to increase the capabilities to improve product development with the use of knowledge transfer. Firstly diffusion of tacit design knowledge would increase the space of the explicit design domain, therefore the design task is understood in a broader audience and therefore it is, to same degree, more concrete. The second force to enhance the explicit design domain is socialisation, which is the process of passing tacit knowledge on to others, from a product development perspective, experience of senior engineers from different fields of expertise, would be shared in broader context.

The third force is externalisation. It also increases the explicit design domain and due to this fact, the knowledge is easier to transfer in a systematic way and therefore it can be distributed to a large number of team members over large distances and applied to a wide range of applications. Diffusion, socialisation and externalisation, as a result, decrease the abstract degree of design task and the concrete degree of design task therefore increases, which means complexity of new technologies decreases. As a result of this, capabilities to improve product development processes increase. Figure P2.16 illustrates the relationship between abstract / concrete design domain and the capability to improve product development.

Figure P2.16: Expanding the explicit design domain shifts the degree of abstract design to concrete design, which increase the capabilities to improve product development



The dynamics of enablers and inhibitors of knowledge transfer, depending what activity is chosen to expand the explicit design domain, influence this conceptual framework. To expand the explicit design domain, tacit knowledge must be transferred and “come to live” in the product development team. Recognising this objective, it is obvious that the right use of enabling factors will enhance the knowledge transfer process.

On the other hand, knowing what role the inhibitors played for particular procedures, in the product development process helps to minimise their negative weight on the processes. To link the conceptual framework, (figure P2.16), to the research findings, I classify enablers and inhibitors in relation to their positive or negative effect in the knowledge space, to analyse what facilitates knowledge transfer and knowledge creation. To expand the explicit design domain, engineers must identify, assess, collect and combine knowledge, which results in knowledge creation and transfer. Both go hand in hand and should be considered as one activity.

Table P2.16: Enabler and inhibitors of knowledge transfer and their effect in the knowledge space

Tacit design domain: “ Enablers” of knowledge transfer and their effect in the knowledge space		
Project findings: enablers	**Effect in knowledge space**	**Example of previous research findings**
Face-to-face: Face-to-face increases the frequency of rich communication, necessary for resolving the ambiguous situation, which is natural if you start with a new project.	**(+) Diffusion** **(+) Socialisation**	Face-to-face and shoulder-to-shoulder working processes imply a common language and achieve a high level of understanding. (Dougherty, 1992; Brown & Duguid, 1991)
Teams- Relationship: The knowledge required for complex design tasks is embedded in people, tools and routines. The issue is how many knowledge elements and related networks must be created to be transferred to the receiving unit.	**(+) Diffusion** **(+) Socialisation** **(+) Externalisation**	Knowledge transfer and creation of new knowledge is a dynamic process, and is dependent on the ability to create, transfer and utilise knowledge assets, as Teece (2000, p. 35), puts it*:* “the value creation potential of knowledge assets strongly depends on the extent, to which knowledge is transferable and usable in the firm.” Product development teams increase innovation by turning tacit knowledge into explicit knowledge and by passing tacit knowledge on to others (Nonaka and Takeuchi, 1995). To turn tacit knowledge into explicit knowledge externalisation takes place; it describes the codification of tacit knowledge.
Individual expertise provided to group: The degree of knowledge needed to solve complex design tasks must be individually developed to cope with specific design needs. For that reason the identification and combination of knowledge and presentation of knowledge is an active process, that depends on the willingness of the engineers involved.	**(+) Diffusion** **(+) Socialisation**	Knowledge ownership also relates to the degree that an individual invests energy, time, effort, and attention in the knowledge. Additionally, individuals develop knowledge commitment to the extent that they see the value of the knowledge, develop competence in using the knowledge (Leonard-Barton, 1995), maintain a working relationship or interaction with the knowledge, and are willing to put in extra effort to work with the knowledge (Mowday, 1979).

Continuous table P2.16: Enabler and inhibitors of knowledge transfer and their effect in the knowledge space

<table>
<tr><th colspan="3">Tacit design domain: “ Enablers” of knowledge transfer and their effect in the knowledge space</th></tr>
<tr><th>Project findings:
enablers</th><th>Effect in knowledge space</th><th>Example of previous research findings</th></tr>
<tr><td>Proactive willingness to transfer:

The challenge, in general, is that the crucial product design knowledge is usually not available in a readily retrievable format. It is often held in the minds of a handful of key persons and it combine different types of knowledge. For example the design knowledge necessary to track a new product development process requires that the expertise involved contains explicit theories and formulae on the one hand. On the other, the knowledge of applying such theories requires the understanding of the theories as well as expressing the components of estimation/judgement and, “best trade”, on what and how to apply when and where. Knowledge with both explicit and tacit elements is required.</td><td>(+) Diffusion
(+) Socialisation</td><td>The process model of knowledge creation builds on the crucial presupposition that human knowledge is created and enlarged by means of a social interaction between tacit and explicit knowledge. This interaction is called a knowledge conversion. It is further important to note that this conversion does not take place within individuals but between individuals within an organisation (Nonaka and Takeuchi, 1995)</td></tr>
<tr><th colspan="3">Tacit design domain: “ Inhibitors” of knowledge transfer and their effect in the knowledge space</th></tr>
<tr><th>Project findings:
inhibitors</th><th>Effect in knowledge space</th><th>Example of previous research findings</th></tr>
<tr><td>Knowledge stick into silos:

For the knowledge transfer process, it is very difficult to create a common understanding if the sender and receiver expertise differs greatly in context. People are not able to allocate valuable knowledge, because the requirements of receiving parties are poorly understood. So people engaged in this process get the feeling that knowledge sticks in functional departments of the business units and cannot be transferred.</td><td>(-) Socialisation</td><td>The concept of a knowledge gap has been discussed by a number of researchers with respect to its potential impact on knowledge transfer (Hamel, 1991; Lane and Lubatkin, 1998; Dinur et al., 1998; Nonaka and Takeuchi, 1995).

Additional in previous research it is noted that difficulty in codification and transfer is a central attribute of tacit knowledge (Grant, 1996; Nonaka, 1994; von Hippel, 1994; Zander and Kogut, 1995).</td></tr>
<tr><td>Unawareness of valuable knowledge:

The term represents the difficulty to locate product development knowledge between different engineering disciplines.

For example following quote:

In general it was, for all parties involved, doing something new. So we had to learn to do something new, strongly based on communication of information between business units. Key was to identify knowledge and to organise the exchange of knowledge transfer between the units. It was difficult in the beginning, to locate the knowledge; for example who possesses the right source of expertise for specific design tasks. It was obvious that we know that our Swiss unit owns material know-how and our Italian unit owns the vehicle integration know-how, but that is not enough to develop a new floor module. These are only the basic resources to carry out such a complex project. How should we work together; who has the helm in the project; and how to share responsibility? These are open issues if we start such a project.</td><td>(-) Diffusion</td><td>Stasser (1995) found that group performance increased when everyone in a group was informed of each other member’s expertise. That is, when group members were informed about who knows what (the people–people network), the group’s performance increased (Wegner, 1987).

Moreland (1996) research confirmed that group training about who knows what produces better group performance, and disruptions to a group’s knowledge about who knows what (through the reassignment or turnover of people) hurts group performance.</td></tr>
</table>

Continuous table P2.16: Enablers and inhibitors of knowledge transfer and their effect in the knowledge space

Tacit design domain: " Inhibitors" of knowledge transfer and their effect in the knowledge space		
Project findings: inhibitors	**Effect in knowledge space**	**Example of previous research findings**
Difficult to articulate: Quote: *Domain specific and design relevant knowledge is very hard to explain, for why or why not a particular solution was done cannot always summarised in words. It is a combination of experience and theory and this combination influence the decisions.* Complex design tasks require some form of estimation or judgement, which can hardly be expressed in plain language. This is classified in the research as tacit domain of design knowledge.	**(-) Diffusion** **(-) Socialisation**	Tacit knowledge is hard to communicate and is deeply rooted in action, involvement and commitment within a specific context: It is "a continuous activity of knowing" (Nonaka, 1994, p. 16). To enhance the product development process people must be able to generate new products with existing systems, technologies, and market experiences, and must be able to articulate product concept to all parties involved, so sustained innovation also relies heavily on articulated knowledge (Cooper 1998, Wheelwright and Clark 1992).
Explicit design domain: " Enablers" of knowledge transfer and their effect in the knowledge space		
Project findings: enablers	**Effect in knowledge space**	**Example of previous research findings**
{I-A-C-C} **I=Identifying knowledge** **A=Assessing knowledge** **C=Collecting knowledge** **C=Combining knowledge** The research project illustrated, that project managers should establish a structured knowledge transfer process. This procedure should, identify, assess, collect and combine knowledge, which is a course of actions to structure knowledge and express it a way that it is appropriate to receiver needs. *Identifying knowledge* refers to the activity of spotting within business units, existing knowledge resources requiring knowledge, and to provide that knowledge in an appropriate representation to receiver requirements. *Assessing knowledge* is similar to identification. The main distinction is that it manipulates knowledge resources already existing in the organisation. An engineer described this practice with following words, "*matching the existing expertise to requested requirements".* *Collecting knowledge* is the activity to select and categorise from existing knowledge. Receiver requirements are *"give them the expertise they need, not everything you possess".* *Combining knowledge* is a course of action to structure knowledge and express it a way that is appropriate to receiver needs. In other words, "*to tailor the selected solution to knowledge transfer requirements".* During the research, we found that successful knowledge transfer requires that both parties develop an understanding of where desired knowledge resides within a given source, and that both business units participate in the processes by which knowledge is made accessible.	**(+) Externalisation**	Krone, Jablin and Putnam (1987) observe that all communication systems consist of a sender (source), a message, a receiver, a channel, and coding/decoding schemes. People and organisations have already developed frameworks to organise a systematic knowledge flow in organisations. Today's frameworks*, examples are shown in table P2.7* can be classified as either prescriptive, descriptive, or a combination of the two. Prescriptive frameworks provide direction on the types of knowledge management procedures without providing specific details of how those procedures can or should be accomplished. In contrast, descriptive frameworks identify attributes of knowledge management important for their influence on the success or failure of knowledge management initiatives. (Rubenstein-Montano, 2001). Knowledge transfer success is also affected by its articulability, or the extent to which knowledge can be verbalised, written, drawn or otherwise articulated (Bresman 1999).

Continuous table P2.16: Enabler and inhibitors of knowledge transfer and their effect in the knowledge space

Explicit design domain: "Enablers" of knowledge transfer and their effect in the knowledge space		
Project findings: enablers	**Effect in knowledge space**	**Example of previous research findings**
Sender / Receiver interdependence: A involvement of both parties in the identification and combination of knowledge procedure helps to create an understanding of the knowledge elements needing to be transferred, and the description of knowledge creates a interaction between both parties, and can be seen as a knowledge creation process.	**(+) Externalisation** **(+) Internalisation**	Product development is a knowledge intensive process (Balasubramanian and Tiwana, 1999; Davenport and Prusak, 1998; Drucker, 1993; Nonaka and Takeuchi, 1995). It can be described as an information transformation process where information is gathered, processed and transferred in a creative way. Therefore, communication is a vital and basic necessity for product development activities especially when team members are geographically distributed.
Frequency of transfer: In the research project, the unit in need of expertise to move forward with the development is more proactive in requesting the needed knowledge. So the interdependence of the business units had an active influence by itself on the frequency of knowledge transfer. As a result, the people involved created social networks where a combination of new knowledge is shared and actively used. These networks proved to be essential to move the development process forward.	**(+) Externalisation** **(+) Internalisation**	Knowledge sharing and transfer depends on personal networks and the willingness of individuals to share (Jones and Jordan, 1998; Ruggles, 1998; Ulrich, 1998). Nonaka and Takeuchi (1995) believe that organisations leverage individual talents into collective achievements through networks of people who collaborate.
Explicit design domain: " Inhibitors " of knowledge transfer and their effect in the knowledge space		
Project findings: inhibitors	**Effect in knowledge space**	**Example of previous research findings**
Wrong media to transfer: The constraint of using videoconferences in product development projects is that an efficient transfer of multiple data sets through one communication channel is very difficult to achieve. As one engineer stated: *Real design knowledge, which integrates a high portion of tacit and informal knowledge, is transferred mainly by face-to-face interactions. Very disappointing outcome with videoconference, there was no way to articulate relevant knowledge to develop a new floor module. Even if you see your partners on the screen, how do you explain a technical idea sketched on a drawing; how do you draw down the thoughts and comments of your development partners on the other side to frame this new idea into a solution? Most of the time we agreed to meet each other in a few days, to discuss this personally to sort out the next design steps.* A successful knowledge transfer process needs the right medium for transfer and a method to break down complex knowledge requirements, to transform intangible ideas and findings into an explicit form, to create a valuable sender receiver exchange.	**(-) Externalisation**	A technological approach to knowledge transfer can often be unsatisfactory. In fact, many tools proposed as knowledge transfer applications are actually still designed or used to support just data and information processing, rather than knowledge transfer. (Borghoff and Pareschi, 1999). The natural characteristics of a technology do not absolutely allow one to define it as a knowledge transfer tool: this evaluation is dependent on the context of its use (Sarvary, 1999).

Continuous table P2.16: Enabler and inhibitors of knowledge transfer and their effect in the knowledge space

Explicit design domain: " Inhibitors " of knowledge transfer and their effect in the knowledge space		
Project findings: inhibitors	**Effect in knowledge space**	**Example of previous research findings**
Time and cost: Interviewees statement: *Several management meetings are essential, to determine the expertise possessed in the business units and to align resources to project objectives. In this phase, we discovered, how difficult it is to reapply team and individuals knowledge at distance. Time consuming co-ordination of management meetings, taking into account that many key players are engaged in several projects of their parenting unit as well. Also financial resources put an upper limit, on what you can expect from the knowledge transfer processes.* *Management Meetings and, face-to-face meeting are perceived as one of the strongest activities to transfer expertise, but to create a knowledge flow based only on face-to-face contact, would increase the project costs to a level, no one likes to pay.* Face-to-face meetings are possible if the team is physically dispersed, but be aware they are time consuming and expensive but there is no chance to keep them from the agenda.	**(-) Diffusion** **(-) Socialisation** **(-) Externalisation** **(-) Internalisation**	The radicalness of a new product and the newness of the technologies that it embodies will increase the level of development uncertainty. A team con-confronted with high uncertainty will have to process additional technical and conceptual information and develop new ways of performing the task at hand (Brown and Utterback, 1985; Dewar and Dutton, 1986). Implementing the technology abroad is more costly, due to technology transfer costs. More complex technology demands larger resources for technology transfer. Teece (1977) provides strong evidence for the existence of such technology transfer costs.
Transfer does not automatically creates replication: From a product development perspective, we know that tacit knowledge is only capable of codification to some degree, and even it is codified and transferred, it cannot be taken for granted that knowledge is recreated in the receiver unit. Knowledge exists but is not embedded in networks and routines to be successful implicated.	**(-) Diffusion** **(-) Socialisation**	Previous research shows that assessing and creating replication is difficult. There is significant evidence that effective re-creation also requires that the knowledge package is made accessible to or de-conceptualised for the recipient, so that the recipient can convert it, adapt it or reconfigure it to its specific needs (Devadas and Argote, 1995; Dixon, 1994; Leonard-Barton, 1988; Moreland, 1996).

In (table P2.16), I have classified and deeply discussed the dynamics of enablers and inhibitors of knowledge transfer and their negative or positive effect in the knowledge space.

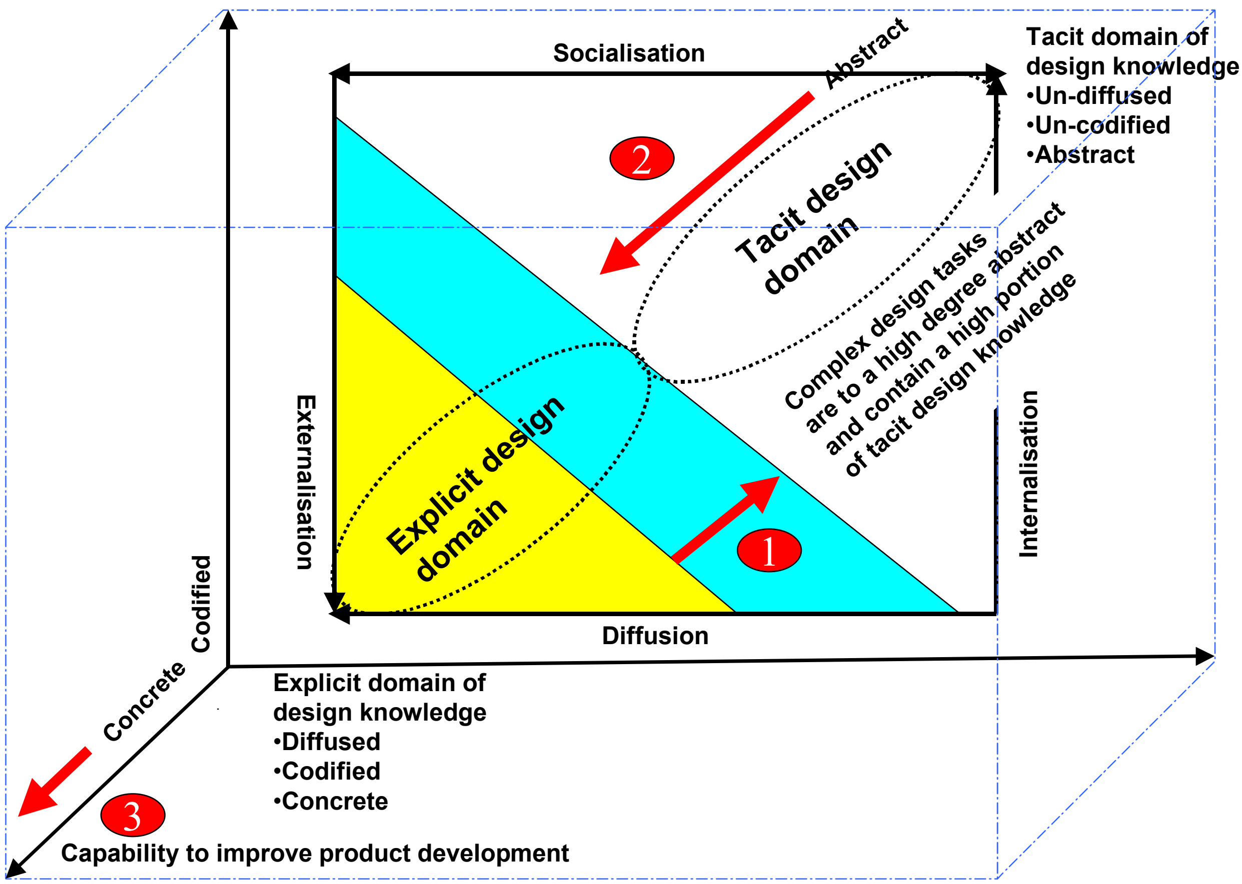
To create and transfer knowledge, we can employ diffusion, socialisation, externalisation and internalisation.

To extend the capabilities to improve the product development process we can see that diffusion and socialisation are important activities to transfer, share and combine tacit design knowledge. This creates a common understanding of complex design tasks on a cross-functional level and, as a result, abstract design tasks transform into concrete design tasks and therefore they are understood by a broader audience. This helps to increase the capability to improve in the product development process. Kogut and Zander (1992) use the term combinative capabilities to describe organisational processes by which firms synthesise and acquire knowledge resources, and generate new applications from those resources.

This definition of capabilities is similar to the definitions given by other authors. For example, capabilities are the drivers behind the creation, evolution, and recombination of other resources into new sources of competitive advantage (Henderson and Cockburn, 1994; Teece, Pisano and Shuen, 1997; Eisenhardt and Martin 2000).

In (figure P2.17), I illustrate why knowledge transfer creates the capability of reducing the high degree of abstract design knowledge in complex design tasks, which makes the content of tacit design knowledge more concrete. The explicit design domain expands and thus new knowledge is shared in a broader context, between engineers, which enhances the capabilities to improve the product development process.

Figure P2.17: Using knowledge transfer to improve the product development process



There are three pathways to enhance the capability to improve the product development process, using knowledge transfer. The main force to increase the capabilities to improve product development builds on the expansion of the explicit design domain in the knowledge space. To expand the explicit design domain we face following questions:

How to expand the explicit design domain?
What are the limits to expanding the explicit design?
What is the challenge in expanding the explicit design domain?

These three fundamental questions are deeply discussed in (table P2.17) under pathway one. In pathway two and pathway three I discuss why and how the expansion of the explicit design domain, using knowledge transfer, combines and creates new knowledge, and therefore abstract design tasks transform, to some extent, into concrete design tasks, thus increasing capabilities to improve product development.

Table P2.17: Using three pathways to enhance the capabilities to improve product development

Pathway one	Knowledge transfer in knowledge space to expand the explicit design domain: "Diffusion, Socialisation, Externalisation and Internalisation "
1	**How to expand the explicit design domain:** In general, to expand the explicit design domain, you must be able to transfer tacit design knowledge. This knowledge is embedded in people, tools and routines. The issue is how many knowledge elements and related networks must be created to pass on tacit design knowledge to others. Diffusion and socialisation are important activities in transferring, sharing and combining tacit design knowledge, and are embedded in following activities: **Face-to-face:** creates diffusion and socialisation of tacit design knowledge **Shoulder-to-shoulder working processes:** create diffusion and socialisation of tacit design knowledge **Team Relationship:** helped to create a common understanding of knowledge elements and related networks **Individual expertise provided to group:** release the knowledge embedded in experts and can be best transferred over diffusion and socialisation **Proactive willingness to transfer:** The process model of knowledge transfer and creation builds on the crucial presupposition that human knowledge is created and enlarged by means of a social interaction between tacit and explicit knowledge. Diffusion and socialisation are important activities in the transfer, sharing and combination of tacit design knowledge. This creates a common understanding of complex design tasks on a cross-functional level and, as a result, abstract design tasks transform into concrete design tasks and externalisation takes place.

Continuous table P2.17: Using three pathways to enhance the capabilities to improve product development

Pathway one	**Knowledge transfer in knowledge space to expand the explicit design domain: "Diffusion, Socialisation, Externalisation and Internalisation "**
1	**Continuous: How to expand the explicit design domain:** **{I, A, C, C}:** The research project illustrated, that project managers, should establish a structured knowledge transfer process. This procedure should, identify, assess, collect and combine knowledge, which is a course of actions to structure knowledge and express it a way that it is appropriate to receiver needs. Externalisation takes place if knowledge is transformed from the tacit domain into the explicit domain. In the project it is described as the core process of knowledge transfer (figure P2.9). The major constraint of this systematic approach to breaking down complex knowledge requirements is, that not all knowledge existing in the tacit domain is capable of being codified, or the effort of codifying is too high, and therefore the prospective value creation is diminished. But by selecting the right content of tacit knowledge and codifying, pre-knowledge creation takes place, and this approach expands the explicit design domain and so amplifies the potential to improve product development. **Sender / Receiver interdependence:** An involvement of both parties in the identification and combination of knowledge procedures helps to create an understanding of the knowledge elements that need to be transferred, and the description of knowledge creates an interaction between both parties, and can be seen as a knowledge creation process. Externalisation and internalisation created through interaction and, therefore, communication, is a vital and basic necessity for product development activities, especially when team members are geographically distributed. **Frequency of transfer:** The interdependence of the business units on its own had an active influence on the frequency of knowledge transfer. As a result, the people involved created social networks where a combination of new knowledge was shared and actively used. These networks proved to be essential to externalise and internalise knowledge.
1	**What are the limits of expanding the explicit design domain?** **Knowledge stuck in silos:** In product development projects there is a lack of common understanding between different engineering disciplines and active socialisation helps to share different domain-specific knowledge, so that new knowledge is created during the product development process. **No awareness of valuable knowledge:** If you start with a new sophisticated project, combining different technologies, engineers are confronted with a problem in identifying and locating the required knowledge. A diffusion of knowledge, understanding who knows what, helps to identify and locate knowledge needed. **Difficult to articulate:** Tacit design knowledge is hard to communicate, because it is deeply rooted in action, involvement and commitment of the engineers involved in the product development process. It is a continuous activity of knowing (Nonaka, 1994). To create a diffusion of tacit design knowledge, it must be articulated, and socialisation takes place. If knowledge is articulated, it is converted from the tacit design domain into the explicit design domain and this conversion integrates externalisation as well. If we talk about externalisation of knowledge embedded in the tacit design domain, we face the following limitations: not all tacit design knowledge is capable of being codified, and how much effort should be invested in codifying that which can? The creation of social networks and face-to-face contacts fosters diffusion and socialisation and helps to articulate tacit design knowledge, which exists to a high degree in experienced and skilled engineers.

Continuous table P2.17: Using three pathways to enhance the capabilities to improve product development

Pathway one	**Knowledge transfer in knowledge space to expand the explicit design domain: "Diffusion, Socialisation, Externalisation and Internalisation "**
1	**Continuous: What are the limits of expanding the explicit design domain?** **Wrong media to transfer:** A successful knowledge transfer process needs the right medium for transfer, which contains a method of breaking down complex knowledge requirements, to transform intangible ideas and findings into an explicit form. Externalisation and codification takes place, and is used to create a valuable sender receiver exchange. **Time and cost:** Complex technology demands larger resources for technology transfer (Teece 1977). Complex design tasks relate generally to new products and integrating additional new technologies. As a result, the level of development uncertainty increases. Companies engaged in such a process must be aware that engineers need to reduce the degree of uncertainty to perform the task. Therefore they need to create new knowledge. Socialisation, diffusion, externalisation and internalisation takes place to transfer knowledge from people owning the expertise to people in need of expertise. A reasonable time frame and budget is needed to create sophisticated products. **Transfer does not automatically create replication:** Knowledge exists but is not embedded in networks and routines to be successful implicated. To adapt and implement the provided knowledge, engineers need to convert it into their domain-specific needs. Socialisation, and diffusion takes place, to re-create existing knowledge for new applications.
1	**What is the challenge to expand the explicit design domain?** Product development in general is a dynamic process, so knowledge created will change over the life cycle of the product development process; new knowledge is created and must be transferred and shared. Tacit design knowledge is best transferred by face-to-face contact. If you have a product development team dispersed by geographical distance, you must define how to organise face-to-face exchange. In general, I would say face-to-face meetings are possible if the team is physically dispersed, but be aware that although they are time consuming and expensive there is no chance to keep them from the agenda. There are several theories about part time co-location, which integrate the issues, how, whom, where and when should we co-locate. (Kahn and McDonough, III, 1997; Peitrangelo 1993; Ragatz, Handfield and Scannell 1997). This is the concept of front loading and problem solving on product development performance, intensively discussed in previous research studies (Thomke and Fujimoto, 2000; Clark and Fujimoto, 1989; Ward, Sobek and Liker 1995, 1998, 1999), and it is also broadly accepted in the product development processes of all automotive manufacturers. However, the term pre-knowledge creation is widely ignored in the vehicle development process. In vehicle development, non-routine tasks are high on complexity, and to solve such complex design tasks, a high degree of task interdependence between technical disciplines is necessary to evaluate and investigate proper design solutions. This requires that team members have an understanding of the complete product system architecture. To create such an understanding, engineers need to identify, access and combine design relevant knowledge. This activity can be seen as a *pre-knowledge creation* and the result is a shared product knowledge base, which makes it possible for people engaged in the vehicle development process to use different kinds of knowledge, to capture and link new technologies into innovative products. Pre-knowledge creation expands the explicit design-domain over externalisation. If you prepare knowledge to receiver expectations, a kind of codification takes place. Additionally this codified knowledge is a next step, a resource for internalisation. This newly created knowledge is available for new applications and can become second nature. Based on past experience, engineers form new ideas, and explicit knowledge is the basis for new tacit knowledge internalisation to take place.

Continuous table P2.17: Using three pathways to enhance the capabilities to improve product development

Pathway two	**Knowledge transfer in knowledge space to transform abstract design tasks into concrete design tasks: "Diffusion, Socialisation, Externalisation and Internalisation "**
2	In general we can say that complex design tasks are largely abstract and contain a high portion of tacit knowledge (figure P2.17). To illustrate, how effective knowledge transfer creates the opportunity to increase the potential to improve product development process, I developed a conceptual framework. I started to define a tacit and explicit design domain, (figure P2.10) to integrate the dynamics of enablers and inhibitors in relation to the knowledge transfer process. As a second step, I derived from Takeuchi and Nonaka (1995) and Boisot (1998) a new model of the knowledge space with the explicit and tacit design domains and their primary characteristics in the knowledge space (figure P2.14). Figures P2.16 and (figure P2.17) illustrate why knowledge transfer builds on diffusion, socialisation, externalisation and internalisation, and how they facilitate in expanding the explicit design domain, resulting in a decrease in the abstract degree of design tasks and a commensurate increase in the concrete design tasks. This means that the complexity of new technologies involved in the product development process decreases, and as a result the potential to improve product development increase. If we increase the explicit design domain, knowledge is bundled in a common understanding, which facilitates knowledge sharing, and as a result knowledge is shared and understood between several functions. (*Abstract degree of design task decrease.)* Different domain specific knowledge is combined and a construction of new knowledge takes place, which is essential in implementing new technologies into new products.
Pathway three	**Knowledge transfer in knowledge space to enhance the capabilities of integrating innovation in new product development**
3	All studies on technological innovation embrace a wide range of activities that contribute to the same assumption: innovation begins with the construction of a new kind of knowledge within the firm. Knowledge on which innovation is based comes from inside a firm and how that knowledge is combined and transferred fastest to the product development teams is key to generating a process of continuous innovation in products. Additionally I would say that innovative products hold a higher degree of tacit design knowledge than commodity products. Based on these findings, it is it is apparent that successful knowledge transfer helps to pass on tacit design knowledge to others, which makes complex design tasks more concrete. Engineers of several functions are able to understand the requirements in a broader context. This creates the basis for implementing new technologies into products and additionally, this shared knowledge base gives birth to new findings. In other words the potential to improve the product development process has increased. In a similar sense to my finding, Nonaka and Takeuchi (1995) showed that product development teams increase innovation by turning tacit knowledge into explicit knowledge and by passing tacit knowledge onto to others. Additionally, recent studies suggest that the key to success for an organisation is embodied in its ability to implement and appropriate new technology (Willmann, 1991). The answer to how this might be achieved is described in terms of the knowledge transfer capability within the organisation. This argument is developed by Cohen and Levinthal (1990), who suggest that knowledge transfer is a critical factor in the ability of a firm to innovate.

The conceptual framework of knowledge transfer in new product development (figure P2.14) helps to describe the dynamics of enablers and inhibitors of knowledge transfer. I discussed in depth the power of enablers and inhibitors of knowledge transfer and their effect in the knowledge space. If engineers understand their positive and negative effect in the knowledge space, they are able to draw down several tactics to enhance knowledge transfer. Based on the conceptual framework, we have three paths to increase capability to improve product development over knowledge transfer (figure P2.17.)

Firstly, to expand the explicit design domain, tacit knowledge must be transferred and "come to live" in the product development team. Recognising this objective, it is obvious that the right use of enabling factors will enhance the knowledge transfer process.

On the other hand knowing, for particular procedures, what role the inhibitors played in the product development process, helps to minimise their negative weight on knowledge transfer processes. Using the effects of enablers and inhibitors of knowledge transfer in the knowledge space to expand the explicit design domain is intensively discussed in (table P2.17).

Figure P2.16 and (figure P2.17) illustrate why knowledge transfer builds on diffusion, socialisation, externalisation and internalisation, and how they facilitate in expanding the explicit design domain. Innovative products hold a higher degree of tacit design knowledge than commodity products. Based on this assumption, it is apparent how important it is to transfer tacit design knowledge to others, thus making complex design tasks more concrete. Engineers of different engineering disciplines are able to understand the requirements in a broader context. This creates the basis to implement new technologies into products and additionally, this shared knowledge base gives birth to new findings.

In other words the potential to improve product development processes has increased, which is illustrated as the third path in the conceptual framework (figure P2.17). I would not claim that this theoretical framework is the recipe for generating successful products. A clear limitation is that complex design knowledge is not static, it is linked to the life cycle of the product development process and therefore it is continuous rebuilt. It is recognised in the research that externalisation of knowledge embedded in the tacit design domain faces following limitations: not all tacit design knowledge is capable of being codified, but the creation of social networks and face-to-face contacts fosters diffusion and socialisation and helps to articulate tacit design knowledge, which exists to a high degree in experienced and skilled engineers.

The project showed that to transfer tacit design knowledge is best performed by face-to-face contact, which is in line with nearly all studies on knowledge management and technological innovation, but it is still not given sufficient weight by product development managers, especially if you have a product development team dispersed by geographical distance.

Under these circumstances it is essential to define how to organise face-to-face knowledge exchange. In general, face-to-face meetings are possible if the team is physically dispersed, but be aware that although they are time consuming and expensive, there is no chance to keep them from the agenda.

In summary, the framework distinguishes between tacit and explicit design domains and integrates the dynamics of enablers and inhibitors of knowledge transfer. It demonstrates the importance of knowledge transfer as a tool to combine new technologies (mainly embedded in the tacit design domain) with existing technologies (mainly embedded in the explicit design domain) to generate new knowledge, and as such it assists the strategic aim to build capabilities to improve product development.

3.4 Findings and contribution

From practical perspective the research project illustrated, that project managers, should establish a structured knowledge transfer process. This procedure should, identify, assess, collect and combine knowledge, which is a course of actions to structure knowledge and express it a way that it is appropriate to receiver needs. Externalisation takes place if knowledge is transformed from the tacit domain into the explicit domain. In the project it is described as the core process of knowledge transfer (figure P2.9). The major constraint of this systematic approach to breaking down complex knowledge requirements is, that not all knowledge existing in the tacit domain is capable of being codified, or the effort of codifying is too high, and therefore the prospective value creation is diminished. But by selecting the right content of tacit knowledge and codifying, pre-knowledge creation takes place, and this approach expands the explicit design domain and so amplifies the potential to improve product development.

In practice, the challenge is that the crucial product design knowledge is usually not available in a readily retrievable format. It is often held in the minds of a handful of key persons and it combine different types of knowledge. The expertise involved contains a mixture of explicit theories and formulae and tacit knowledge. The knowledge of applying such theories requires the understanding of the theories as well as articulation of the components of estimation / judgement. Additional product developers build on past experience, engineers form new ideas, and explicit knowledge is the basis for new tacit knowledge internalisation to take place.

To consolidate this conclusion, I developed a conceptual framework. I started to define a tacit and explicit design domain, (figure P2.10), to integrate the dynamics of enablers and inhibitors in relation to the knowledge transfer process.

As a second step, I derived (from Takeuchi and Nonaka (1995) and Boisot (1998)) a new model of the knowledge space, with the explicit and tacit design domains and their primary characteristics in the knowledge space (figure P2.14).

Figure P2.16 and (figure P2.17) illustrate, why knowledge transfer builds on diffusion, socialisation, externalisation and internalisation, and how they facilitate in expanding the explicit design domain, thus reducing the abstract degree of design tasks and increasing the concrete design tasks. This in turn means that the complexity of new technologies involved in the product development process decreases, and so the capability to improve product development increases.

The conceptual framework, gives product developers a tool to enable them to use several tactics to enhance knowledge transfer.

The framework helps to classify, what knowledge we need to close technological gaps and how realistic it is to transfer this sort of knowledge. The project demonstrated that tacit design knowledge is very difficult to transfer in a systematic way between business units. From a product development perspective we know that tacit knowledge is only capable of codification to some degree, and even it is codified and transferred, it cannot be taken for granted, that knowledge is recreated by the product development partner. Successful transfer does not automatically create replication of knowledge. Therefore product developers must be aware that knowledge is embedded in many engineering disciplines and intensive communication between engineers creates combination, and as such it is to some extent integrated into the product development process.

By classifying the design tasks in explicit and tacit domains, product developers will gain insight as to how, whom, where and when should they co-locate, to implement tacit design knowledge into product development process.

Another important issue is that product decision makers can use the framework to define how, to what extent, they should share product development knowledge with their external partners.

Additional it is also important to classify to what extent they need to share knowledge with their development partner to facilitate product innovation and fast time to market.

In general the research challenges the classical project management techniques, which are heavily aligned to performance targets. I would argue that it is difficult to implement innovation with such a rigid approach. In vehicle development, non-routine tasks are high on complexity and to solve such complex design tasks, a high degree of task interdependence between technical disciplines is necessary to evaluate and investigate proper design solutions. This requires that team members have an understanding of the complete product system architecture. To create such an understanding engineers need to identify, access and combine design relevant knowledge.

This activity can be seen as a *pre-knowledge creation;* the result is a shared product knowledge base, which makes it possible for those engaged in the vehicle development process to use different kinds of knowledge to capture and link new technologies into innovative products.

The concept of front loading on product development performance, intensively discussed in previous research studies (Thomke and Fujimoto, 2000; Clark and Fujimoto, 1989; Ward, Sobek and Liker, 1995, 1998 and 1999), and it is also broadly accepted in the product development processes of all automotive manufacturers. However, the term pre-knowledge creation is widely ignored in the vehicle development process**.**

Pre-knowledge creation expands the explicit design domain over externalisation. If you prepare knowledge to receiver expectations, socialisation takes place. If tacit knowledge is transferred to others, a kind of codification and externalisation occurs. Additionally, this knowledge is available for new applications. Engineers use this knowledge to form new ideas and explicit knowledge becomes the platform for new tacit knowledge - internalisation takes place. Therefore socialisation transforms tacit knowledge into explicit knowledge and on the other hand explicit knowledge can be the basis for new thoughts and builds new tacit knowledge in the product development process.

The research demonstrates that successful knowledge transfer in new product development requires that all parties develop an understanding of where the desired knowledge resides within the source and that all different engineering disciplines participate, in the process by which knowledge is made accessible, which is facilitated through socialisation.

The research findings are supported by several previous developed theories.
For example it is noted that *difficulty in codification and transfer* is a central attribute of tacit knowledge (Grant, 1996; Nonaka, 1994; von Hippel, 1994; Zander and Kogut, 1995).
The importance to distinguish between tacit and explicit design domains to facilitate successful knowledge transfer is aligned with the definition given by previous researchers. For example Kogut and Zander (1992), found in their study, that the nature of the knowledge being transferred, its tacitness versus its articulation, has an important impact on the ease of transfer. In a later study, Zander and Kogut (1995) found that product-based knowledge that is codified and explicit transfers between units more readily than less articulated knowledge.

Additional project two put on view that successful knowledge transfer requires that both parties develop an understanding of where the desired knowledge resides within the source, and that both business units participate in the processes by which the knowledge is made accessible. This is aligned with the definition of Teece, (1990); " Technology transfer differs from ordinary scientific information transfer in the fact that to be really transferred it must be embodied in an actual operation of some kind".

Further this finding is supported by the research of Stasser (1995), where he found that group performance increased when everyone in a group was informed of each other member's expertise.

The finding that knowledge transfer, which facilitates that product knowledge is articulated and provided to all product development partner creates the capability to improve product development is supported by work of (Cooper 1998, Wheelwright and Clark 1992). They found that to enhance the product development process people must be able to generate new products with existing systems, technologies, and market experiences, and must be able to articulate product concept to all parties involved, so sustained innovation also relies heavily on articulated knowledge.

Finally the research demonstrates that product developers, who are able to implement knowledge transfer and knowledge creation as a management disciplines in their development process, are able to create successful products in a efficient way is supported by the study of Cohen and Levinthal (1990), who suggest that knowledge transfer is a critical factor in the ability of a firm to innovate.

Based on the case study research method in project two, I was able to develop a theoretical framework that integrates the power of enablers and inhibitors and their effect related to the knowledge transfer process in new product development projects.

In general I think that the theoretical framework is a valuable tool to create capabilities to improve product development, but on the other hand several limitations of the study should be acknowledged.

First the conceptual framework (figure 15, figure P2.17 and table P2.17) with the three paths to improve product development over knowledge transfer needs further testing on a larger number of product development projects.

Second the research is restricted to automotive product development projects. In other industry sectors with quickly shifting markets and technologies an application of the theoretical framework maybe creates a limited value creation potential.

Finally and there is no limitation to any industry sector, I think future research should pay more attention to the informal aspect of knowledge transfer, identified in my research as enablers and inhibitors of knowledge transfer. To understand the dynamics, how product developers share, combine and create new knowledge to create innovative products has an enormous value creation potential for future product development projects.

Cranfield UNIVERSITY
School of Management

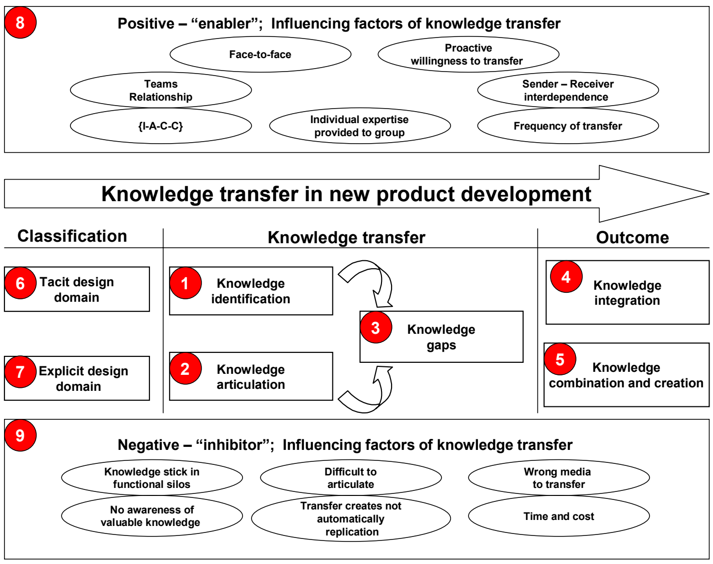
Title page project three

Title of DBA Research:

An explorative study of knowledge transfer processes in new product development in the automotive industry

Abstract: project three

In project one and two, I showed that product development activities can be seen as transactions that are integrated into an overall system of identifying, assessing, collecting and combining knowledge. The main output of this complex process is not a physical product, it is to a certain extent a knowledge base about the new product.



A major challenge for product developers is to transfer intangible ideas and findings, and here we face the difficulty of a successful knowledge transfer process, because the knowledge used in the product development process is not static. Rather it develops under dynamic conditions, due to the fact that product development is a continuous process of improvement, design trade offs and new learning loops. Knowledge is embedded in people and the domain specific expertise they posses. In order to release this expertise and share it among others involved in product development activities, communication tools and social networks are used to transfer and share this expertise. Therefore, I now explore, in project three, how knowledge is identified, articulated and integrated into the vehicle development process between development partners, with the aim to combine and create new knowledge for innovative products.

4. Background and a theoretical perspective project three

This study builds on two previous research projects, where I investigated how knowledge is transferred in automotive product development projects. The focus of project one was to understand knowledge transfer activities in new vehicle development processes. To frame this research I explored what enables knowledge transfer and what inhibits knowledge transfer.
I used project one as a learning project, to understand why engineers used different approaches during the life cycle of the vehicle development process to transfer knowledge and combine knowledge.

As a result of project one, I was able to point out that knowledge transfer is influenced by several factors, which are classified in the research project in enablers positive factors and inhibitors negative factors, affecting the knowledge transfer process. In general complex design tasks are not one hundred per cent tacit or explicit, but rely more on a tacit set of skills or an explicit set of skills, very often a combination of both. Similarly, inhibitors and enablers have more or less importance related to certain activities.

To understand the impact of enablers and inhibitors and their interdependence in relation to the product development process, I investigated major design tasks, when and why they come to light and what role they played in the product development process in relation to the knowledge transfer process. In project one, I identified that the methods whereby how knowledge is transferred change during the vehicle development process. For instance, in project one the major finding was that in phase one of the vehicle development process, where engineers are engaged with the product definition and new technologies, tacit knowledge transfer dominates and thus the key enablers of tacit transfer and the activities to foster tacit knowledge exchange are the resources for a value creation potential in the product development process. In this phase of the product development process an environment for tacit knowledge sharing enhances the product development process. If the vehicle development process reaches the phase two, were most of the interfaces are clearly defined, the virtual car is available in a very detailed form, containing all relevant parts, and the knowledge transfer is very efficient and process orientated. In this phase the main focus is on product and process engineering, which requires a detailed existence of *CAD (computer aided design)* and *CAE (computer aided engineering)* models, clearly defined interfaces to bundle all information about the whole vehicle, to make intensive reflections of manufacturing and assembly aspects. In this phase an environment that creates an optimised exchange of explicit knowledge is the source of value creation potential in the product development process.

I used the findings from project one to frame project two. The main difference in project two was the geographical dispersion of the product development team. Project one was in a single environment, so face-to-face and shoulder to shoulder working processes were much easier to organise.

In project two, teams were geographically dispersed, so that knowledge transfer took place between different business units. This made management meetings and other ways of knowledge transfer more complicated. Therefore engineers soon requested a structured process to transfer knowledge between business units. A typical knowledge transfer then starts with the identification of knowledge to be transferred, in which the potential benefits of the transfer are signalled to the receiving partner or to the sending partner. The next step covers assessing knowledge, collecting knowledge and combining knowledge, in such a way that it is tailored to receiver needs. This helps to enhance the receiver's potential to use the provided knowledge properly. The last step includes an active sender / receiver knowledge exchange in which the transferred knowledge is integrated into the activity of the receiving unit.

In project two, we found that even if the elements of the knowledge package are identified, collected and combined, this does not, of itself, cause integration into the development process of the receiver. The knowledge received forms part of the practices integrated in the product development process, and it is subject to negotiation and arguments, and so it is to some extent integrated into the knowledge base of the receiving unit.

Here again, I faced the challenges of how to visualise the complexity of design knowledge and how to integrate the power of enablers and inhibitors into the knowledge transfer process.

What can engineers do to facilitate knowledge transfer and combination?

From a management perspective, this hinges on using the enablers and reducing the negative impact of inhibitors in the product development process. In addition it is important to integrate and display the value creation potential of knowledge transfer, which is a course of action to combine existing and new knowledge for application in a new product development process.

4.1 Drawing down the hypothesis to test in project three

The first two projects sought to picture how product development teams frame and shape new product knowledge, and how they interpret such knowledge and apply it to the product development process.

To understand the knowledge transfer process and to visualise the power of enablers and inhibitors related to knowledge transfer, I used the case study method for data collection and subsequent validation.

As Harrison (2002, p. 159) puts it, “case study research is of particular value where the theory base is comparatively weak and the environment under study is messy.” Both of these criteria were relevant to my research theme too.

Based on the results out project one, I was able to develop a conceptual framework of the explicit and tacit design domain, to construct a relationship of enablers and inhibitors related to knowledge transfer process.

I derived from Takeuchi and Nonaka (1995) and Boisot (1998) a new model of the knowledge space, where I integrated the explicit and tacit design domains in the knowledge space.

The framework demonstrates why knowledge transfer builds on diffusion, socialisation, externalisation and internalisation, and how these activities facilitate in expanding the explicit design domain, thus decreasing the abstract and increasing the concrete degree of the design task. This means complexity of new technologies involved in the product development process decreases and as a result the capability to improve product development increases.

If we increase the explicit design domain, knowledge is bundled in a common understanding, which facilitates knowledge sharing, and as a result knowledge is shared and understood between several functions.

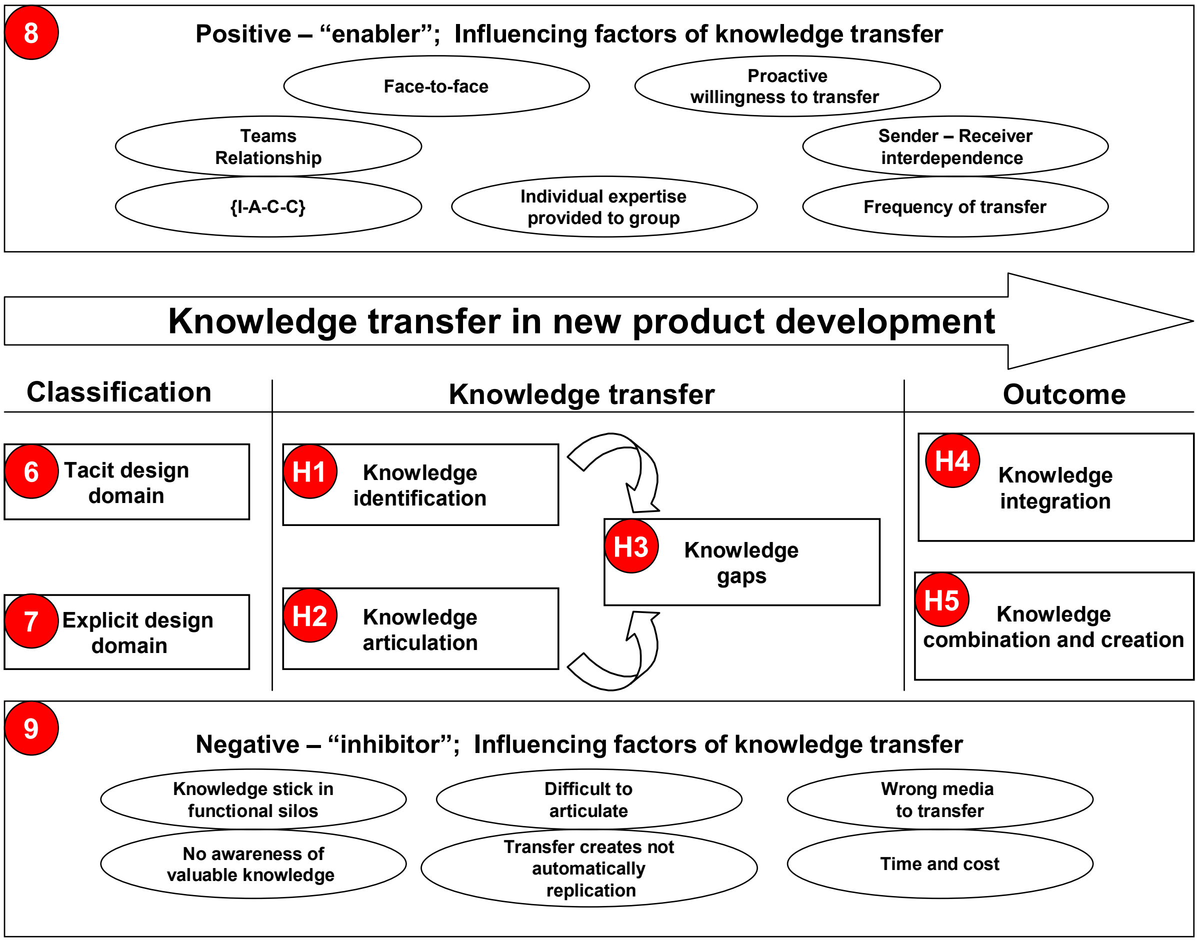
Taking note of the findings from projects one and two, I developed a model of knowledge transfer in new product development (figure P3.1), which integrates enablers and inhibitors related to the process of knowledge transfer in new product development.

The figure illustrates nine key factors affecting knowledge transfer in new product development activities.

Based on projects one and two, it is evident that successful knowledge transfer needs to classify to what degree relevant design knowledge is embedded in the tacit [6] or explicit [7] design domain. This strongly influences how hard it is to identify required knowledge and provide this to your development partners.

Knowledge identification [H1] and knowledge articulation [H2] are domains which are essential to share and combine knowledge for new product development activities. How difficult it is to identify and articulate knowledge can be assessed with a perspective on knowledge gaps [H3] in new product development processes.

Figure P3.1: Knowledge transfer in new product development



The key question here is, is the product development team able to speak a common language in the product development process, or is the knowledge, provided and required, hardly understood between different engineering disciplines? The success of knowledge transfer activities relies very much on how provided knowledge is used and integrated [H4] by the development partner in need of this specific knowledge. Combining provided knowledge with existing knowledge creates new knowledge [H5] and if this specific knowledge is used in a tangible form, innovation in new product development takes place.

The model of knowledge transfer in new product development (figure P3.1) is influenced by many factors identified in research project one and two as enablers [8] and inhibitors [9] of knowledge transfer. In those projects, I found that product development activities can be seen as transactions that are integrated into an overall system of identifying, assessing, collecting and combining knowledge, and the main output of this complex processing scheme is not a physical product, but a knowledge base about the new product.

Knowledge transfer must be able to transfer intangible ideas and findings, and here we see the difficulty of a successful knowledge transfer process, because the knowledge used in the product development process is not a static knowledge base, it is developing under dynamic conditions, due to the fact that product development is a continuous process of improvement, design trade offs and new learning loops. Knowledge is surrounded in people and the domain-specific expertise they posses. To release this expertise and share it among individuals involved in product development activities, engineers use communication tools and social networks.

Therefore, project three sets out to explore, using hypothesis one [H1], how knowledge is identified and integrated into the vehicle development process between development partners. Additionally, knowledge transfer success is also influenced by the extent to which knowledge can be verbalised, written, or otherwise articulated in the product development process. This subject is investigated in hypothesis two [H2] of this project.

The concept of a knowledge gap has been discussed by a number of researchers with respect to its potential impact on knowledge transfer (Hamel, 1991; Lane and Lubatkin, 1998; Dinur, Inkpen and Hamilton 1998; Nonaka and Takeuchi, 1995). Hypothesis three [H3] focus on the impact of knowledge gaps and their influence in the knowledge transfer process for new product development processes.

Successful knowledge transfer takes only place if knowledge provided is integrated and implicated in the new product development project, which is explored in hypothesis four [H4].

Further, I plan to explore, using hypothesis [H5], to what degree generated knowledge is integrated into new product development activities and to what degree it is reused.

Work in other sections shows that knowledge identification and combination for new applications includes knowledge transfer processes such as routines for replication and brokering (Hansen, 1999; Hargadon and Sutton, 1997; Szulanski, 1996). These are used by managers to copy, transfer, and recombine resources, especially knowledge-based ones, within the firm.

If the product development process is a predictable process and engineers are able to build on previous experience in defined design steps product development should improve related to time schedule and quality.

In a simplified form I would say that knowledge combination, and creation and reuse of this knowledge, increase the capabilities of a firm to improve product development.

4.1.1 Knowledge identification in the product development process

To identify the knowledge source, it is important to know where knowledge is located and in what elements, physical assets, human assets, and organisational routines it is embedded. Product- or technology-embedded knowledge has been found to transfer between units more readily than knowledge embedded in other organisational elements (Zander and Kogut, 1995; Galbraith, 1990).

Knowledge is also embedded in organisational routines and best practices (Levitt and March, 1988; Szulanski, 1996). Knowledge can also be embedded in multiple elements and sub-networks. Researchers have pointed out that group performance increased when everyone in a group was informed of each other member's expertise (Stasser, 1995). A group training session explaining who knows about what produces better group performance, and disruptions to a group's knowledge about who knows what (through the reassignment or turnover of people), hurts group performance, (Moreland, 1996).

From a managerial perspective, project two showed that where the product development team was geographically dispersed it was essential to identify the knowledge source. Who and where to ask was an important issue with regard to creating knowledge transfer in the product development team. If knowledge was identified, engineers were able to structure and express the knowledge in a way that was appropriate to the product developers in need of it.

To summarise the research finding, knowledge transfer is positively influenced if both parties have a clear identification of knowledge elements and know where the required knowledge is located and who to ask, for the requested expertise. In formal terms:

Hypothesis 1: *Transfer success increases with a clear identification of available knowledge resources*

4.1.2 Knowledge articulation in the product development process

Knowledge transfer success is also affected by the extent to which knowledge can be verbalised, written, drawn or otherwise articulated (Bresman, 1999).

As, Polanyi (1966) noted, individuals know more than they can explain, since individuals possess tacit knowledge that is non-verbalised, intuitive, and unarticulated. Research has shown that articulated knowledge is more easily transferable than less articulated knowledge.

The nature of the knowledge being transferred, its tacitness versus its articulation, has an important impact on the ease of transfer (Kogut and Zander, 1992). In a later study, Zander and Kogut (1995) found that product-based knowledge that is codified and explicit transfers between units more readily than less articulated knowledge.

The complexity of vehicle development activities makes it obvious that a single person cannot perform this activity: not even a single department is able to develop a car. Therefore engineers of several engineering disciplines must create a common understanding of the new vehicle. In a similar frame of mind, Nonaka and Johansson (1985, p. 183) describe this as involving "...an organisational process where individual knowledge is shared, evaluated and integrated with others in the organisation". From this perspective engineers must identify and articulate knowledge, to facilitate knowledge transfer between different functional areas. Articulating knowledge means deciding what describes the product in a manner that other functional departments can use, and handle, the information provided by domain specific engineering disciplines. If this articulated knowledge is available it is fair to state, that knowledge transfer between product developers should be successful, as it is stated in following hypothesis:

Hypothesis 2: *Transfer success increases, as knowledge is available in an articulated form*

4.1.3 Knowledge gaps in the product development process

For knowledge transfer in new product development a particular difficulty is that the knowledge context of the source and the recipient can be quite different. The knowledge output of the sender is often the knowledge input of the recipient, and there may hardly be any other overlap between the parties involved. If so, knowledge transfer and learning would be more problematic.

In the new product development literature, it is recognised that shared interpretation of knowledge is essential for collaboration in new product development activities (Dougherty, 1992). It has been found that, for organisational learning to take place, the knowledge distance or 'gap' between two parties must not be too great (Hamel, 1991).

The reason is that too many learning steps will be required if the knowledge gap (or distance) is significant.

In this sense, it is believed that knowledge redundancy and overlapping areas of expertise facilitate knowledge transfer (Nonaka and Takeuchi, 1995). In addition, the literature on inter-firm learning has emphasized the concept of "absorptive capacity", which means that firms differ in terms of their ability to learn (Cohen and Levinthal, 1990; Szulanski, 1996).

Recently, it was further argued that this capacity might be "relative" in nature (Lane and Lubatkin, 1998). That is, a firm's ability to learn is related to the fit between the knowledge of the source and of the recipient. It can be argued (Dixon, 2000) that firms with significant common knowledge (or low knowledge distance) would have a high "relative absorptive capacity". Additionally, they have also argued that too small a knowledge gap may burden the recipient with unlearning old knowledge prior to learning any new knowledge (Burgelman, 1983).

If the knowledge gap is to narrow, it is not attractive to transfer design relevant knowledge. I would even argue that there is no reason to transfer it, if it exists already in a similar version by the receiver. For that reason, a knowledge gap should exist to make knowledge exchange attractive for parties involved, but it should not be too great.

Here we see that knowledge transfer is a dynamic process, if the knowledge gap is too big it is very demanding to transfer complex design knowledge.

Project two, put on view that for the knowledge transfer process it is very difficult to create a common understanding if the sender and receiver expertise differs greatly in context.

If sender and receiver do not understand the domain specific knowledge of each other at all we can state in a simplified form that the knowledge gap is the maximum. For example if the receiver doesn't understand the knowledge provided at all, a successful application of the provided knowledge would be impossible in a new product development process.
Therefore the underlying assumption is that knowledge transfer success is very limited if knowledge provided is by the receiver hardly understood. In other terms:

Hypothesis 3: *Transfer success decreases as the knowledge gap between sender and receiver increases*

4.1.4 Knowledge integration in the product development process

From a theoretical perspective, the need for a culture of learning in an organisation to facilitate organisational learning in general, and knowledge transfer specifically has been emphasised by many researchers for example, (Aubrey and Cohen, 1995; Teece, 2000; Cohen and Levinthal, 1990).

Additional previous research revealed that knowledge integration in complex new product development projects is enhanced by highly interactive and iterative communications by cross-functional teams (Brown and Eisenhardt, 1995; Takeuchi and Nonaka 1995).

Project two put on view, that an involvement of both parties in the identification and combination of knowledge procedures helps to create an understanding of the knowledge elements that need to be transferred, and the description of knowledge creates an interaction between both parties, and can be seen as a knowledge creation process. Externalisation and internalisation is created through interaction and, therefore, communication, is a vital and basic necessity for product development activities. As a result, the people involved created social networks where a combination of new knowledge was shared and actively used. These networks proved to be essential to externalise and internalise knowledge.

Additional project two showed that knowledge transfer improved strongly with the learning steps teams made together, so unit one gained an understanding of vehicle engineering and unit two gained expertise of several material combinations. The learning steps to understand each other's expertise increased with the lifetime of the project. With increasing number of knowledge transfer activities the business units become familiar with each other's expertise and created more confidence to integrate the provided expertise into the development process.

Aligned to this research finding, I assume that with increasing frequency of knowledge transfer, which is facilitated through interactive and iterative communication between sender and receiver knowledge elements are generated and integrated in social networks.
In a similar mind:

Hypothesis 4: *With increasing frequency of transfer; knowledge is created and integrated in the sending and receiving business units*

4.1.5 Knowledge creation and combination in the product development process

In previous research it is recognised that product development teams create new knowledge by turning tacit knowledge into explicit knowledge and by passing tacit knowledge on to others (Nonaka and Takeuchi, 1995).

Additional studies suggest that ability to implement and appropriate new technology is a key success factor in organisations today (Willmann, 1991). How this might be achieved is described in terms of the knowledge transfer capability of the organisation. This argument is developed by Cohen and Levinthal (1990), who suggest that knowledge transfer is a critical factor in the ability of a firm to innovate.

Project two showed that new knowledge for product development activities is subject to negotiation and argument and as such it is to some extent integrated into the product development process. Transferring and combining design knowledge is a continuous and cross-functional process involving and integrating a growing number of different technological capabilities between parties involved. In other words: it is the process of combining new technologies with existing technologies to generate new applications for tangible products.

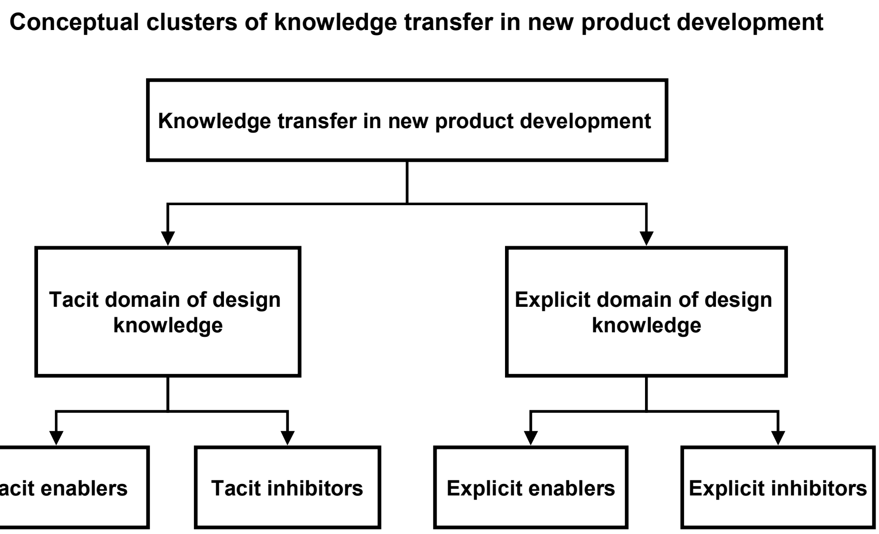
Based on these findings, it is apparent that successful knowledge transfer helps to pass on tacit design knowledge, which makes complex design tasks more robust.

Therefore engineers of different engineering disciplines are able to understand the requirement in a broader context: *they create a common language.* This creates the basis for implementing new technologies into products and additionally this shared knowledge base gives birth to new findings. They understand and accept knowledge from the development partner, because it is understood and therefore it is combined with own product development knowledge to solve complex design tasks for new applications.
In formal terms:

Hypothesis 5: *If knowledge is accepted by the receiver, and combined with their own knowledge, new knowledge is created.*

4.1.6 The tacit and explicit design domain related to knowledge transfer

In project two, I identified two streams of knowledge transfer in new product development projects. Firstly, complex design tasks rely more on a tacit domain of design knowledge and are therefore strongly influenced by tacit enablers and inhibitors. However, basic design tasks (for example described in technical specifications) rely more on an explicit domain of design knowledge and therefore they are more influenced by explicit enabler and inhibitors.
Figure P3.2: Tacit and explicit design domain and their relation to enablers and inhibitors



Based on this finding, it is very interesting to investigate what types of knowledge engineers use to solve complex design tasks. Is their knowledge, used for new product development, embedded more in the tacit design domain or the explicit design domain?

The nature of design knowledge is identified under the use of constructed statements [S20] and [S21], (table P3.1).

4.2 Method and data collection

This research used a survey questionnaire approach to test the hypotheses that were framed out of the research results of project one and project two. Both the project one and project two case studies took place in major automotive engineering companies, which are in a direct cooperation with major automotive manufacturers. The environment where these companies are operating is very sensitive, from a confidentiality perspective.

These companies are engaged in vehicle development contracts with market launch scheduled in three or four years time from now. Because of this it was very important to target a population of engineers that have participated in similar product development projects to those where the case studies took place.

Both companies are product development partners of BMW, a Bavarian Automotive Manufacturer, very well known for its premium brands.

Unlike to a classic mail survey , I used my personal contacts to the managing directors of EDF Engineering and Magna Engineering to provide the engineers personally with the questionnaires (see statements S1-S25 in table P3.1 to test the hypothesis 1-5).

The maximum sample size would be 32 product development engineers from Magna Engineering centre and 34 product development engineers from EDF Engineering.

I collected 44 useable responses, which is a response rate of 66 %. It was interesting to note that the responses were predominantly from engineers (69.5%) with a work experience over ten years. The second group was mostly engineers with a work experience between five and ten years (17.4%), followed by engineers with a work experience between three and five years (8.8%). 4.3% of engineers had less than three years of work experience.

The questionnaire used tick-box type questions, (figure P3.3) and rating questions, whereby respondents could rate a particular issue ranging from negative to positive.

The extent of use of knowledge transfer practices was measured with a five-point Likert scale, where 0 represents completely disagree and 4 represents completely agree.

The unit of analysis for testing the hypothesis is the individual, and all measures reflect the engineer's perceptions of and experiences with knowledge transfer activities in the new product development process in the automotive industry.

Figure P3.3: Tick box type questionnaire

Questionnaire

This questionnaire contains statements, which describe a number of different types of knowledge transfer outcomes, which you may have encountered in knowledge transfer activities. We are referring to such activities, to recognise, knowledge identification, knowledge description, knowledge gaps and integration of know how by the receiving parties. Please identify the extent to which any of the statements you agree or disagree with your experience of knowledge transfer activities.

To what extent do you agree with the statements listed below in relation to your experience of knowledge transfer activities in product development projects?

DISAGREE | **EXTENT SCALE OF AGREEMENT 1- 4**

0	1	2	3	4
Completely disagree	**Agree to very little extent**	**Agree to little extent**	**Agree to large extent**	**Completely agree**

Example to answer the questions

	Knowledge transfer process in product development teams	**0** Completely disagree	**1** Agree to very little extent	**2** Agree to little extent	**3** Agree to large extent	**4** Completely agree
S	People have invested significantly their time, ideas, skills and physical and intellectual energies in the know how transferred					X

Please tick in your perception on the extent scale on following pages → "Statement : S 1 – S 25 "

The survey investigates how engineers in the product development process transfer, combine, share and use knowledge for new product development. Most of the survey measures, [S1-S25], were constructed out of my previous research findings using qualitative methodology. With the aim of analysing what meaning engineers independently attach to the previous research findings, I constructed the survey measures to quantitatively test the developed model of knowledge transfer. The five hypotheses are tested in statements [S1-S25], and are shown in (table P3.1). The research was carried out in Munich so the original questionnaire was in German, but for analysis and discussion statements [S1 – S 25] it has been translated into English.

Table P3.1: Overview tested hypothesis 1-5 and statements S1 – S 25

Hypothesis 1: Knowledge identification	**S1**	It is uncomplicated for the receiver to identify source personnel who could help them reconfigure and implement requested design expertise.
	S2	It is uncomplicated for the receiver to identify the source personnel to spot necessary design requirements and understand the technologies related to this expertise.
	S3	It is uncomplicated for the receiver to identify which tools (CAE; CAD) to use to perform design tasks on provided knowledge.
	S4	It is easy for the receiver to locate and extract the information needed to understand design relevant expertise.

Hypothesis 2: Knowledge articulation	**S5**	New engineers can easily learn this know-how by studying a complete set of technical specifications, documents or plans.
	S6	New engineers can easily learn this know-how by talking to experienced personnel
	S7	Educating and training new engineers regarding this know-how is a quick and easy job
	S8	The engineering tasks require that personnel have long experience in this industry sector to achieve high product development performance
	S9	The engineering tasks require that new engineers have to work with experienced engineers as apprentices for a long time (2-3 years) to learn their jobs within important areas. (BIW engineering or Interior engineering for example.)

Hypothesis 3: Knowledge gaps	**S10**	Given the overlap of the source and receiver knowledge bases, source personnel could easily independently solve the same design tasks as the receiving engineers.
	S11	The receiver had the knowledge base necessary to easily understand and put to use the provided know-how.
	S12	The source had the knowledge base necessary to easily understand how the recipient planned to use the transferred know-how.
	S13	Differences in the knowledge bases made integration of provided know how in the receiving unit very difficult.

Hypothesis 4: Knowledge integration	**S14**	The receiving unit feels a sense of responsibility for how this know how gets used
	S15	Both parties, sender and receiver, really care about the implementation of the provided know-how.
	S16	Both parties have had sufficient interaction with this know-how to develop an intimate understanding of it.
	S17	The receiver developed a high degree of ownership of provided know-how.
	S18	Sender and receiver refer to this know-how in the teams, as important to the development process.
	S19	People have invested significantly their time, ideas, skills and physical and intellectual energies in the know-how transferred between sender and receiver.

Explicit domain	**S20**	The knowledge that I use to solve design tasks is embedded and collected out of technical description, technical specification and specific literature.
Tacit domain	**S21**	The knowledge that I use to solve design task comes mainly from previous projects and my work experience.

Hypothesis 5: Knowledge combination and creation	**S22**	We systematically use knowledge generated in previous projects as a knowledge platform for new projects.
	S23	We use intensive collaboration with our partners to generate new knowledge for new applications in new product development projects.
	S24	We use intensive collaboration with our partners to define objectives and targets to deliver requested design solutions for new products.
	S25	The knowledge generated in previous projects exists and is available for application, if we start new projects.

As illustrated in (table P3.1), knowledge transfer in new product development is measured using a 25-item scale that includes two items to investigate the nature of transferred knowledge.

Respondents are asked if they rely more on experience *"tacit design domain",* or on technical information *"explicit design domain",* if they solve complex design tasks. Knowledge identification was measured on a 4-item scale. The four items asked respondents, how easy it was to identify knowledge source and to request needed knowledge.

Knowledge articulation was measured on 5-item scale exploring the issues around how easy or complicated it is to learn and use design relevant knowledge for new product development projects.

Knowledge gaps are measured on a 4-item scale, asking the respondents how easy or difficult it was to understand and use provided knowledge.

Integration of knowledge was measured on a 7-item scale, asking the respondents if knowledge provided a part of active interaction between sender and receiver and if an engagement of sender and receiver existed to implement provided knowledge.

Knowledge combination and creation was measured on a 4-item scale, asking the respondents to identify the extent to which intensive collaboration is used to create and combine knowledge, and to what extent knowledge created in previous projects is used as a knowledge platform for new projects.

4.2.1 Survey results project three

Table P3.2 presents the results of the survey. The result of EDF Engineering and Magna Engineering is shown in column one and two and column three shows the difference between the two. In general the individual results of these companies do not differ much in detail.

For further analysis and discussion of the survey results, I used the performance gaps of the master score shown in the sixth column of the table below.

Table P3.2: Results Hypothesis one to five and performance gaps

Hypothesis 1-5: Results and performance gaps	**EDF N=23 [%]**	**Magna Engineering centre MEC N=21 [%]**	**Delta EDF vs. MEC [% Δ]**	**Master Score N=44 [%]**	**Maximum Performance [%]**	**Performance gaps N=44 [%]**
Hypothesis 1: Knowledge identification	63	67	4	**65**	100	**35**
Hypothesis 2: Knowledge articulation	56	61	5	**58.5**	100	**41.5**
Hypothesis 3: Knowledge gaps	67	70	3	**68.5**	100	**31.5**
Hypothesis 4: Knowledge integration	70	68	2	**69**	100	**31**
Hypothesis 5: Knowledge combination and creation	76	73,5	2,5	**74.75**	100	**25.25**
Knowledge embedded in the tacit design domain	36	40	4	**82**	See conceptual framework of knowledge transfer: Project two figure P2.16	
Knowledge embedded in the explicit design domain	82	82	0	**38**	See conceptual framework of knowledge transfer: Project two figure P2.16	

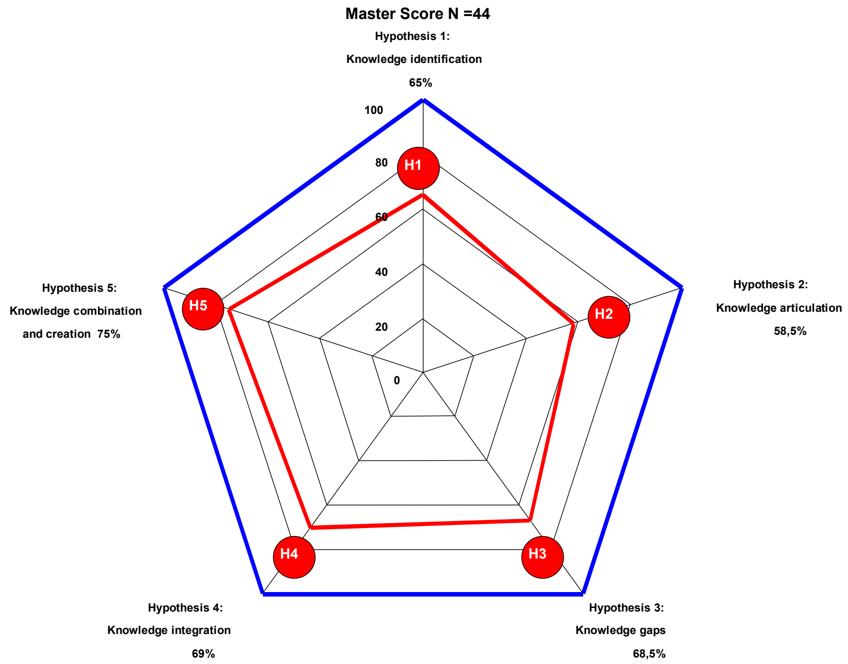
As the table above shows, the primary performance gap in knowledge transfer relates to knowledge articulation and knowledge identification. The secondary performance gaps are in knowledge integration and knowledge combination and creation. Notably knowledge gaps are partly related to knowledge identification and knowledge articulation, but are not perceived as such a strong performance gap as identification and articulation.

It is also important to analyse the nature of knowledge that is transferred. Is it tacit or explicit design knowledge and what interdependence does the nature of knowledge create in relation to identified performance gaps.

The analysis of the interdependence and independence of identified performance gaps in the ensuing sections will detail and identify specific areas, to help product decision makers and product developers to focus their attention on driving improvement of future knowledge transfer processes in new product development.

To visualise the master score, I used a “spidergram” (figure P3.4) which is an effective method of compiling a performance profile based on empirical data.

Figure P3.4: Survey Master Score N = 44 Knowledge transfer in new product development



The red line graphically represents the achieved results of the survey. The blue line in contrast, is indicative of the maximum rate of agreement related to the tested hypothesis. For example hypothesis one, knowledge identification is tested over a 4-item scale and if every respondent ticks in the questionnaire completely agree, knowledge identification would achieve a 100 percent rate of agreement, as the blue line indicates. The underlying assumption for hypothesis one is that if everybody agrees that knowledge transfer is successful supported through a clear identification of available knowledge resources, it is also successful implemented by the engineers in the product development process. Therefore a 100 percent rate of agreement as it is indicated with the blue line related to the tested hypothesis would represent successful knowledge in the tested knowledge transfer model.

The survey results created a performance gap, as it is indicated by the difference between the red and blue line. The delta between the red and blue line represents the rate of disagreement with the tested hypothesis and in a similar mind it represents the disappointing perception of the engineers with knowledge transfer activities related to tested hypothesis. For further discussion is the term performance gap used, which represents, the delta between maximum agreement represented through the blue line and the achieved survey results represented through the red line.

The identified performance gaps helps product decision makers in realising the areas in the product development process where the potential for value creation is not fully exploited. They can then direct future investments to these identified fields, to improve knowledge transfer in new product development. This will facilitate knowledge sharing and knowledge creation and thus enhance the capability to integrate innovation into new products.

To ensure reliability all survey results are tested with one sample statistic test, correlations and partial correlation analysis, using the statistic software package SPSS 9.0 for Windows. The results are shown in detail in appendix 3 and briefly discussed in following chapters.

4.3 Analysis and discussion of survey results

A significant issue for knowledge transfer in new product development is the nature of knowledge. Is the required knowledge tacit, explicit, or a combination of both?

How can we communicate the required knowledge, tacit and explicit, to engineering disciplines in need for that specific knowledge?

To use tacit and explicit design knowledge product developers must invest energy and efforts to transfer and share it between several engineering disciplines. Research project one and two identified significant enablers [8] and inhibitors [9] (see figure P3.1) of knowledge transfer activities in new product development projects. The nature of tacit and explicit knowledge is strongly influenced by the newness of the technologies that come to life in the new product. The degree of newness of technologies used in the product development process increases as a consequence the level of development uncertainty. A team confronted with high uncertainty will have to process additional technical and conceptual information and develop new ways of performing the task at hand (Brown and Utterback, 1985; Dewar and Dutton, 1986). With respect to previous research and my findings, it is worth investigating what role the nature of knowledge plays in relation to the proposed knowledge transfer model (figure P3.1) in new product development in the automotive industry.

4.3.1 The primacy of the tacit design domain in new product development

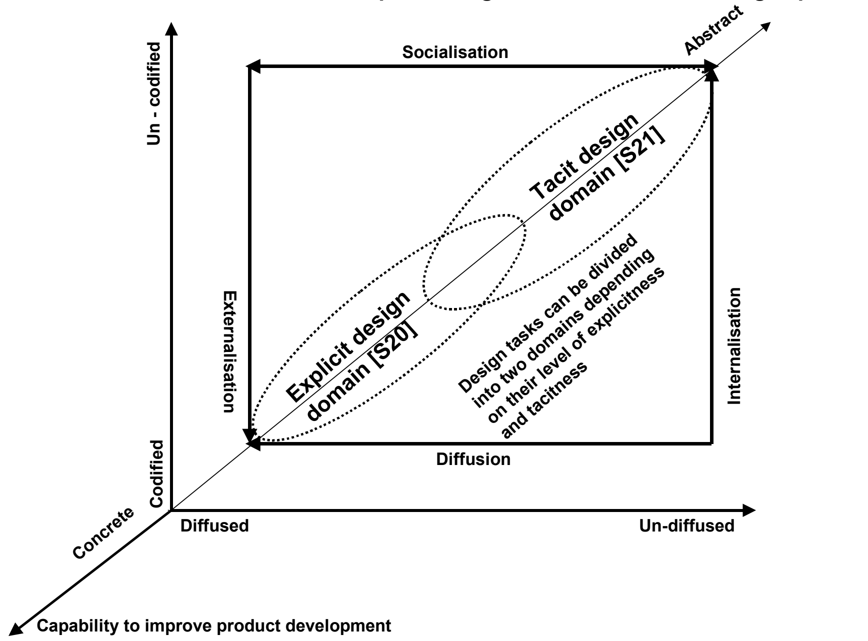
In general product developers collect and combine existing and new knowledge for applications in new products. Knowledge transfer takes place. It is obvious that explicit knowledge, in a technical specification for example, is much easier to identify and articulate for transfer activities than tacit knowledge, embedded in the skills of a few product development specialists. Therefore, whether knowledge relevant for new product development is mainly embedded in the tacit or explicit design domain, is very significant.

To classify the nature of design knowledge used in automotive product development, I applied statements [S20] and [S21] in the survey. Statements and results are exemplified in following table.

Table P3.3: Results Master Score N=44; Explicit design domain and tacit design domain

Results: Explicit design domain and tacit design domain			Master Score N= 44 [%]	Note
Explicit domain	**S20**	The knowledge that I use to solve design tasks is embedded and collected out of technical description, technical specification and specific literature.	38	See framework below: Tacit and explicit design domain in the knowledge space
Tacit domain	**S21**	The knowledge that I use to solve design tasks comes mainly from previous projects and my work experience.	82	See framework below: Tacit and explicit design domain in the knowledge space

Framework: Tacit and explicit design domain in the knowledge space



The survey supports my previous findings that knowledge for new product development activities is mainly embedded in the tacit design domain. The survey generated an agreement rate of eighty-two percent, with the statement that engineers use knowledge to solve design tasks comes mainly from work experience and previous projects.

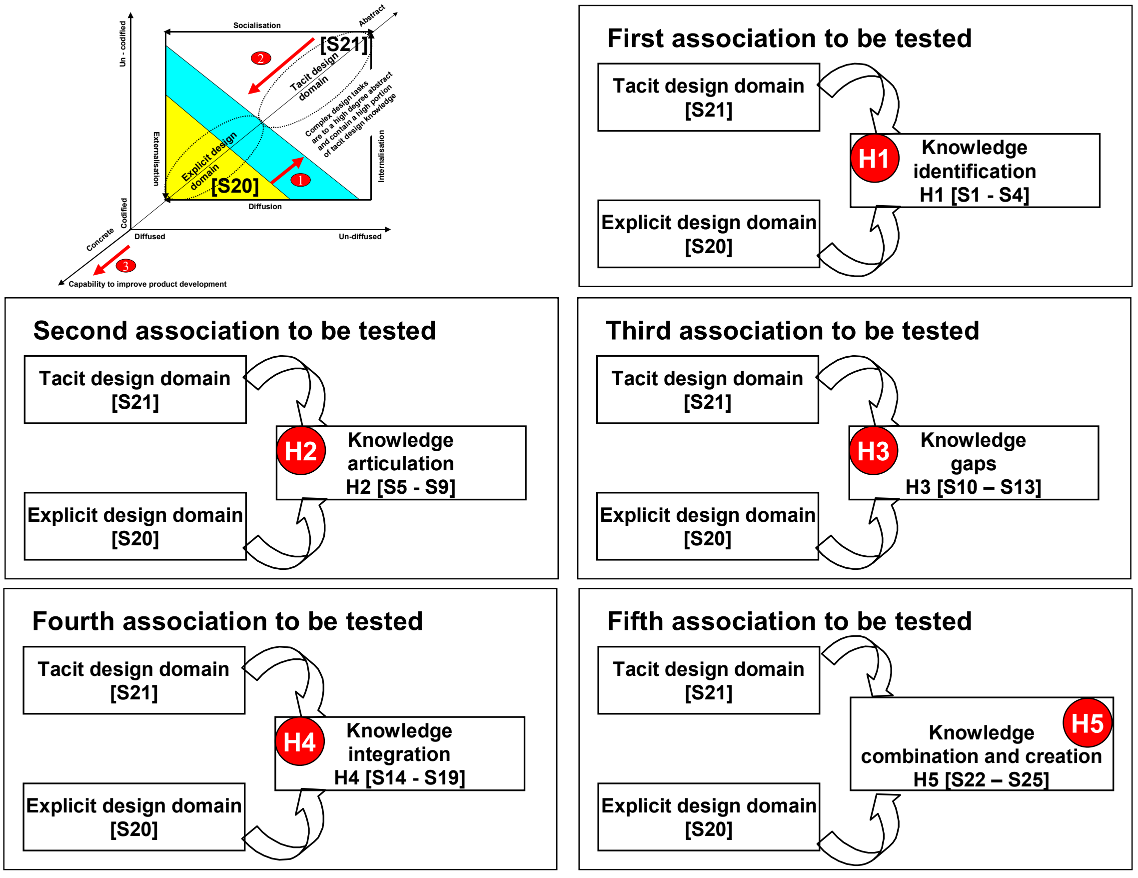
On the other hand, there is no new product development without the use of technical descriptions and existing theories as platform knowledge to solve design tasks. Thirty-eight percent of agreement achieved the statement, that engineers use knowledge from technical descriptions, technical specifications and specific literature to solve design tasks. These activities are embedded in the explicit design domain. As a consequence of these findings, product developers must be aware that engineers confronted with complex design tasks in automotive development use mainly tacit knowledge to develop new solutions for new product development.

From the perspective to knowledge transfer it is interesting to explore the existence of possible direction of association between the tacit and explicit design domain and the identified performance gaps exposed in (table P3.2).

4.3.2 Tacit and explicit design knowledge in association with hypothesis 1 – 5

To explore the direction of association between the nature of design knowledge and the identified performance gaps, I tested the associations illustrated in (figure P3.5).

Figure P3.5: Nature of design knowledge in association with hypothesis 1- 5



To test the associations shown in (figure P3.5) I used, as a first step, a bivariate two Pearson correlation analysis and, as a second step, a partial correlation analysis.

Correlations are measures of linear association. To identify the correlation of the association shown in (figure P3.5), I used a bivariate two-tailed Pearson correlation analysis.

I take into account that although two variables can be perfectly related, this doesn't guarantee that it is a reasonable association with regard to tested model of knowledge transfer (figure P3.1). This is why I used a partial correlations analysis as well, to test the significance level of the correlations.

In (table P3.4), I have summarised significant correlations of association of tacit design domain [S 21] and explicit design domain [S 20] with hypothesis 1-5. The calculated results are presented in appendix three.

Table P3.4: Results of correlations, explicit and tacit design domain in association with hypothesis 1 –5

Results: Explicit design domain tacit design domain with hypothesis 1: Knowledge identification		Significant correlation H1-S2 with S20	Significant correlation H1-S4 with S21	
H1-S2	It is uncomplicated for the receiver to identify the source personnel to spot necessary design requirements and understand the technologies related to this expertise.	**0.453 0.002 44		
H1-S4	It is easy for the receiver to locate and extract the information needed to understand design relevant expertise.		*0.332 0.280 44	
Explicit domain S20	The knowledge that I use to solve design tasks is embedded and collected out of technical description, technical specification and specific literature.	**0.453 0.002 44		
Tacit domain S21	The knowledge that I use to solve design task comes mainly from previous projects and my work experience.		*0.332 0.280 44	
Results: Explicit design domain tacit design domain with hypothesis 2: Knowledge articulation		Significant correlation H2-S5 with S20	Significant correlation H2-S7 with S20	Significant correlation H2-S9 with S20
H2-S5	New engineers can easily learn this know-how by studying a complete set of technical specifications, documents or plans.	**0.490 0.001 44		
H2-S7	Educating and training new engineers regarding this know-how is a quick and easy job		*0.345 0.022 44	
H2-S9	The engineering tasks require that new engineers have to work with experienced engineers as apprentices for a long time (2-3 years) to learn their jobs within important areas. (BIW engineering or Interior engineering for example)			*-0.352 0.190 44
Explicit domain S20	The knowledge that I use to solve design tasks is embedded and collected out of technical description, technical specification and specific literature.	**0.490 0.001 44	*0.345 0.022 44	*-0.352 0,190 44
Results: Explicit design domain tacit design domain with hypothesis 3: Knowledge gaps		Significant correlations H3-S12 with S21		
H3-S12	The source had the knowledge base necessary to easily understand how the recipient planned to use the transferred know-how.	*0.310 0.41 44		
Tacit domain S21	The knowledge that I use to solve design task comes mainly from previous projects and my work experience.	*0.310 0.41 44		
Correlations flagged with** is significant at the 0.01 level and correlations flagged with * is significant at the 0.05 level. (2-tailed)				

Continuous table P3.4: Results of correlations, explicit and tacit design domain in association with hypothesis 1 –5

Results: Explicit design domain tacit design domain with hypothesis 4: Knowledge integration		Significant correlations H4-S16 with S20	Significant correlations H4-S16 with S21	
H4-S16	Both parties have had sufficient interaction with this know-how to develop an intimate understanding of it.	*0.339 0.240 44	**0.413 0.005 44	
Explicit domain S20	The knowledge that I use to solve design tasks is embedded and collected out of technical description, technical specification and specific literature.	*0.339 0.240 44		
Tacit domain S21	The knowledge that I use to solve design task comes mainly from previous projects and my work experience.		**0.413 0.005 44	
Results: Explicit design domain tacit design domain with hypothesis 5: Knowledge combination and creation		Significant correlations H5-S22 with S21	Significant correlations H4-S24 with S20	Significant correlations H5-S16 with S21
H5-S22	We systematically use knowledge generated in previous projects as a knowledge platform for new projects.	*0.326 0.031 44		
H5-S24	We use intensive collaboration with our partners to define objectives and targets to deliver requested design solutions for new products.		*0.315 0.037 44	**0.445 0.002 44
Explicit domain S20	The knowledge that I use to solve design tasks is embedded and collected out of technical description, technical specification and specific literature.		*0.315 0.037 44	
Tacit domain S21	The knowledge that I use to solve design task comes mainly from previous projects and my work experience.	*0.326 0.031 44		**0.445 0.002 44
Correlations flagged with** is significant at the 0.01 level and correlations flagged with * is significant at the 0.05 level. (2-tailed)				

In (table P3.4) we can identify two significant correlations for the explicit design domain and two significant correlations for the tacit design domain. The four correlations are significant at the 0.01 level. The maximum of a correlation between two variables would be the value 1, which would indicate that the variables are identical.

The identified associations between knowledge identification and articulation and the two domains of design knowledge are briefly discussed in following sections.

4.4 The positive effect of knowledge identification and articulation to transfer explicit design knowledge

There is a significant association between the statement that it is uncomplicated for the receiver to identify the source to spot necessary design requirements and to understand the technologies related to this expertise.

This statement is represented in hypothesis one, which stands for knowledge identification; (table P 3.4), [H1-S2 with S 20 / ** 0.4532]. The explicit design domain claims, in statement [S 20], that knowledge is available and collectable from an illustrative source.

The importance of knowledge identification and articulation as activities to expand the explicit design domain is supported by the existence of the second significant association in hypothesis two.

Knowledge articulation in the survey was measured in four independent variables. One of these claims that engineers can easily learn the know-how to solve design tasks by studying a complete set of technical specifications, documents or plans (table P3.1, hypothesis two, statement five [H2-S5]).

The result of the survey produced a significant correlation, between [H2-S5] and statement [S 20]. The result, shown in (table P 3.4), [H2-S5 with S 20 / **0.490], is that knowledge is available and collectable from an illustrative source. These two associations support the findings of project two, that before knowledge can be transferred, it must be identified and available in an articulated form.

For example, project two showed that where the product development team was geographically dispersed it was essential to identify the knowledge source. Who and where to ask was an important issue with regard to creating knowledge transfer in the product development team. If knowledge was identified, the second step was to structure and express the knowledge in a way that was appropriate to the product developers in need of it.

Projects two and three showed that successful knowledge transfer requires both parties to develop an understanding of where desired knowledge resides within a given source, and that sender and receiver participate in the processes by which knowledge is articulated. Further, knowledge identification and articulation is a core activity in transforming tacit knowledge into explicit knowledge.

4.4.1 The positive effect of knowledge integration and combination to transfer tacit design knowledge

Complex design tasks require some form of estimates or judgements, which cannot easily be expressed in plain language. It is a combination of experience and theory and classified in project two as the tacit design domain.

In this project I identified that knowledge used to solve complex design tasks is largely embedded in the tacit design domain (table P3.3). To transfer tacit design knowledge, product developers perceive collaboration and communication as efficient ways to share and transfer tacit design knowledge.

This project produced significant correlations between knowledge integration and the tacit design domain. Statement [H4-S16] (table P 3.4) in hypothesis four claims that both parties involved have had sufficient interaction with the transferred know-how to develop an intimate understanding of it. This statement correlates [H4-S16 with S21 /** 0.413] (table P 3.4) with the tacit design domain [S21].

The importance of intensive collaboration in transferring tacit design knowledge is also identified in the second significant correlation, which states that product developers use intensive collaboration with their partners to define objectives and targets to deliver requested design solutions for new products. This is illustrated in (table P 3.4), [H5-S24 with S 21 / **0.445] with the tacit design domain [S21].

The research envisages that intensive interaction, communication and collaboration are efficient ways to pass tacit knowledge on to other product developers.

Similarly, project two shows that most of the knowledge needed to solve complex design tasks must be individually developed to cope with specific design tasks. For that reason the identification, combination and presentation of knowledge is an active process that depends on the willingness of the engineers involved. Therefore to support the transfer of tacit design knowledge, product decision makers must create an environment that facilitates interaction and collaboration to share knowledge embedded in individuals as their experience and expertise.

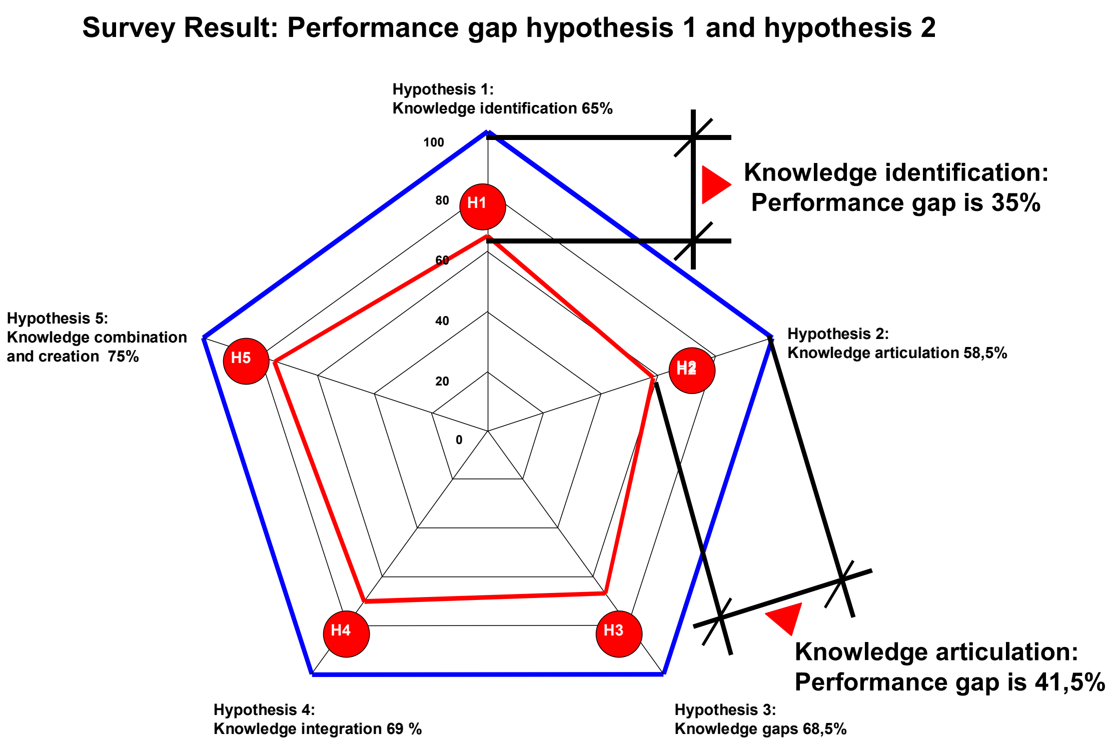
This view is aligned with the findings of previous research, where product development is described as a knowledge intensive process (Balasubramanian and Tiwana, 1999; Davenport and Prusak, 1998; Drucker, 1993; Nonaka and Takeuchi, 1995). It can be described as an information transformation process where information is gathered, processed and transferred in a creative way. Therefore communication and collaboration are vital and basic necessities to integrate, combine and create tacit design knowledge.

4.4.2 Knowledge identification and articulation in relation to the knowledge transfer process

Effective knowledge exchange is positively influenced if both parties have a clear identification of knowledge elements; in other words, if it is known where the required knowledge is located and whom and where to ask.

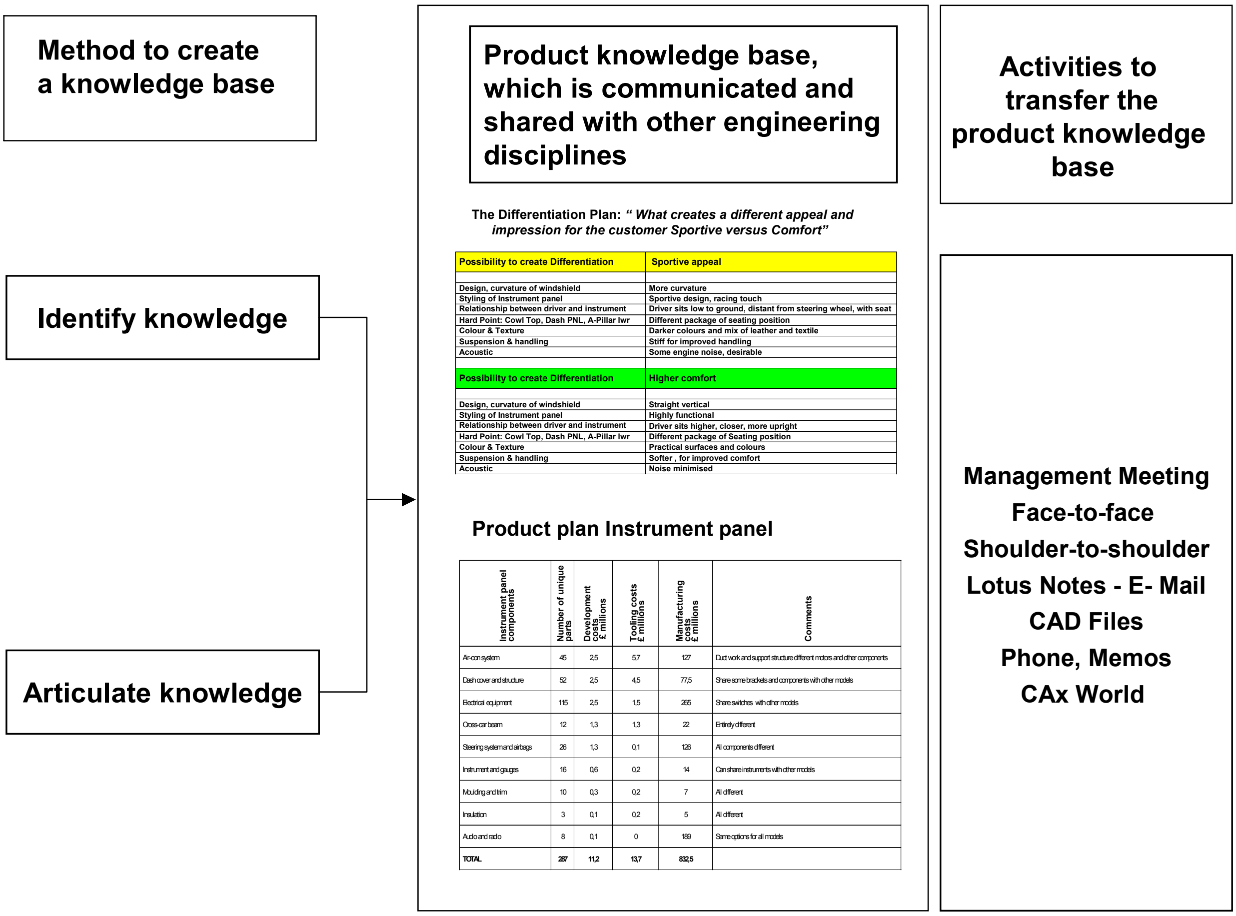
In order of the size of the percentage gap, knowledge identification [35%] and articulation [41.5%] are the most significant areas for value creation through improved knowledge transfer processes in the future.

Figure P3.6: Results Master Score N = 44, Performance gap knowledge identification and knowledge articulation



To demonstrate the value creation potential of knowledge identification and articulation, I will give an example from project one. To create a common knowledge base about a new product, an identification of knowledge takes place. The questions to ask are what is the right expertise; who possesses the expertise; and how should we combine this expertise? The complexity of vehicle development activities makes it obvious that a single person cannot perform this activity: not even a single department is able to develop a car. Therefore engineers of several engineering disciplines must create a common understanding of the new vehicle. In a similar frame of mind, Nonaka and Johansson (1985, p. 183) describe this as involving “...an organisational process where individual knowledge is shared, evaluated and integrated with others in the organisation”. From this perspective engineers must create, identify and articulate knowledge, to facilitate knowledge transfer between different functional areas.

Figure P3.7: Example knowledge identification and articulation in automotive product development



The Differentiation Plan: ***“ What creates a different appeal and impression for the customer Sportive versus Comfort”***

Possibility to create Differentiation	Sportive appeal
Design, curvature of windshield	More curvature
Styling of Instrument panel	Sportive design, racing touch
Relationship between driver and instrument	Driver sits low to ground, distant from steering wheel, with seat
Hard Point: Cowl Top, Dash PNL, A-Pillar lwr	Different package of seating position
Colour & Texture	Darker colours and mix of leather and textile
Suspension & handling	Stiff for improved handling
Acoustic	Some engine noise, desirable
Possibility to create Differentiation	**Higher comfort**
Design, curvature of windshield	Straight vertical
Styling of Instrument panel	Highly functional
Relationship between driver and instrument	Driver sits higher, closer, more upright
Hard Point: Cowl Top, Dash PNL, A-Pillar lwr	Different package of Seating position
Colour & Texture	Practical surfaces and colours
Suspension & handling	Softer , for improved comfort
Acoustic	Noise minimised

Product plan Instrument panel

Instrument panel components	Number of unique parts	Development costs £ millions	Tooling costs £ millions	Manufacturing costs £ millions	Comments
Air-con system	45	2,5	5,7	127	Duct work and support structure different motors and other components
Dash cover and structure	52	2,5	4,5	77,5	Share some brackets and components with other models
Electrical equipment	115	2,5	1,5	265	Share switches with other models
Cross-car beam	12	1,3	1,3	22	Entirely different
Steering system and airbags	26	1,3	0,1	126	All components different
Instrument and gauges	16	0,6	0,2	14	Can share instruments with other models
Moulding and trim	10	0,3	0,2	7	All different
Insulation	3	0,1	0,2	5	All different
Audio and radio	8	0,1	0	189	Same options for all models
TOTAL	**287**	**11,2**	**13,7**	**832,5**	

Figure P3.7 demonstrates the importance of identifying the linking expertise to create a common understanding between different engineering disciplines. For example an instrument panel is built out of 300 unique parts. To create a knowledge base of this product, it must be translated into a form that is available for product development teams. Knowledge must be identified and articulated. Identifying and articulating knowledge means deciding what describes the product in a manner that other functional departments can use, and handle, the information provided by domain specific engineering disciplines. As a next step it must be prepared for the transfer. This activity can be seen as a pre-knowledge creation activity; it needs some energy and time, but as soon as the product knowledge is available in a visual context, embedded in a presentation or CAD model, it is able to be transferred and shared between different parties.

A real challenge for all engineers involved in this activity is to create group expertise from individual expertise and to articulate this group expertise so as to transfer it in an efficient way.

Project three demonstrated that a remarkable underperformance still exists in knowledge identification [35%] and knowledge articulation [41.5%] in new product development in the automotive industry (table P3.2).

Building on four years engagement with knowledge transfer research, I consider that organisations in the automotive sector still rely on methods and processes that were successful in the past and strictly directed to exploit tangible assets.

For example, to create a modular product knowledge base of a vehicle and keep it current means that financial resources and time must be invested upfront. This may require a cultural shift by vehicle manufacturers with regard to how they steer and allocate resources to future vehicle development programmes.

The concept of front loading and problem solving on product development performance has been discussed in previous studies (Thomke and Fujimoto 2000, Clark and Fujimoto, 1989). The concept is also broadly accepted in the product development processes of all automotive manufacturers on the opposite the term *"pre-knowledge creation"* is widely ignored in the vehicle development process.

In vehicle development, non-routine tasks are high on complexity. To solve such complex design tasks, a high degree of task interdependence between technical disciplines is necessary to evaluate and investigate proper design solutions. This means that team members have an understanding of the complete product system architecture. To create such an understanding, engineers need to identify and articulate knowledge; these activities can be seen as a pre-knowledge creation.

The result is a shared product knowledge base, which makes it possible that people engaged in the vehicle development process use different kinds of knowledge to capture and link new technologies into innovative products.

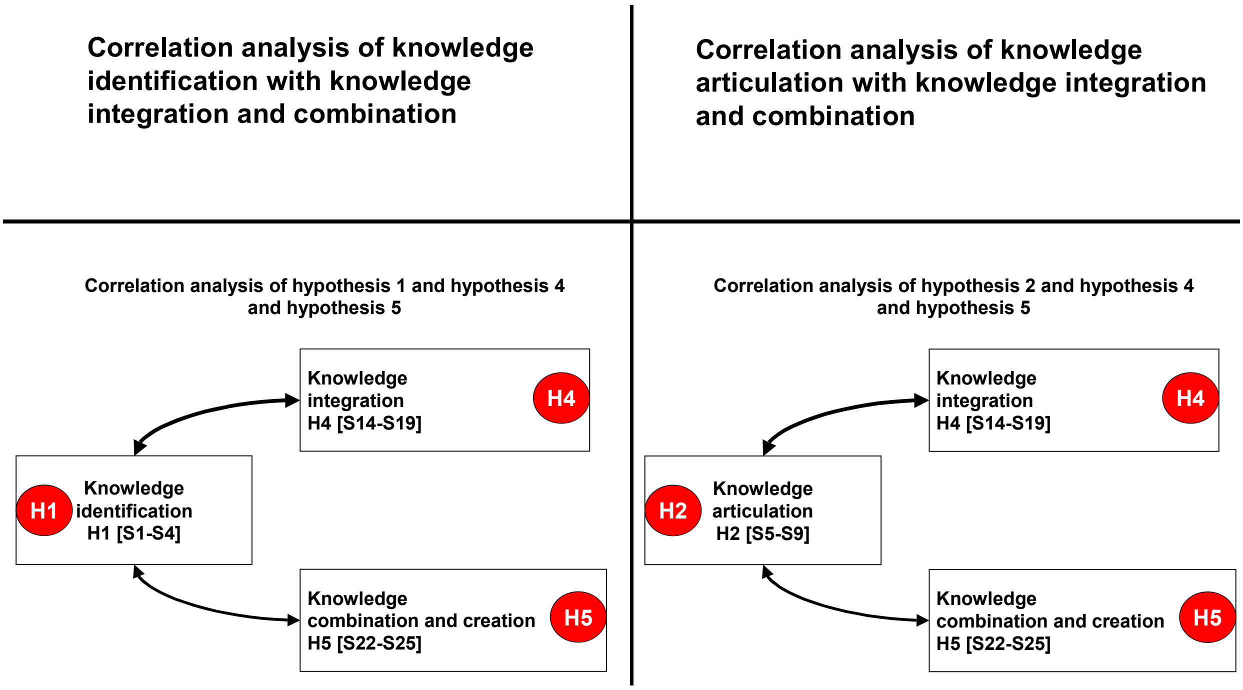
For automotive organisations, an improvement in knowledge identification and articulation create an enormous potential to integrate and combine knowledge in an efficient way for future product development projects.

As a researcher it is interesting to explore the existence of evidence that successful knowledge identification and articulation enhance knowledge integration and knowledge combination in the product development process. Therefore I tested and analysed the associations of hypothesis one and hypothesis two with hypotheses four and five, illustrated in (figure P3.8), and briefly discussed in following section.

4.4.3 The positive effect of knowledge identification and articulation to integrate and combine knowledge in the product development process

This project illustrated that the identification and articulation of knowledge creates an interaction between both parties, which supports knowledge integration and combination. To prove this logical assumption, I tested following associations, which are illustrated in following figure.

Figure P3.8: Knowledge identification and articulation in relation to knowledge integration and combination



In the following table (table P3.5), I have summarised significant correlations of associations between knowledge identification, knowledge integration and knowledge combination and creation.

Table P3.5: Results significant correlations between hypothesis 1 – hypothesis 4 – hypothesis 5

Results: Correlations between hypothesis 1 – hypothesis 4 – hypothesis 5		**Significant correlations H1-S1 with H4-S14**	**Significant correlations H1-S1 with H4-S16**	**Significant correlations H1-S1 with H4-S17**	
H1-S1	It is uncomplicated for the receiver to identify source personnel who could help them reconfigure and implement requested design expertise.	**0.385 0.010 44	**0.548 0.000 44	**0.449 0.002 44	
H4-S14	The receiving unit feels a sense of responsibility for how this know-how gets used	**0.385 0.010 44			
H4-S16	Both parties have had sufficient interaction with this know-how to develop an intimate understanding of it.		**0.548 0.000 44		
H4-S17	The receiver developed a high degree of ownership of provided know-how.			**0.449 0.002 44	
Results: Correlations between hypothesis 1 – hypothesis 4 – hypothesis 5		**Significant correlations H1-S2 with H4-S16**	**Significant correlations H4-S16 with H1-S4**	**Significant correlations H1-S4 with H5-S25**	
H1-S2	It is uncomplicated for the receiver to identify the source personnel to spot necessary design requirements and understand the technologies related to this expertise.	**0.468 0.001 44			
H4-S16	Both parties have had sufficient interaction with this know-how to develop an intimate understanding of it.	**0.468 0.001 44	**0.572 0.000 44		
H1-S4	It is easy for the receiver to locate and extract the information needed to understand design relevant expertise.		**0.572 0.000 44	**0.518 0.000 44	
H5-S25	-The knowledge generated in previous projects exists and is available for application, if we start new projects.			**0.518 0.000 44	
		Significant correlations H1-S3 with H4-S18	**Significant correlations H5-S24 with H5-S4**		
H1-S3	It is uncomplicated for the receiver to identify which tools (CAE; CAD) to use to perform design tasks on provided knowledge.	**0.497 0.001 44			
H4-S18	-Sender and receiver refer to this know-how in the teams, as important to the development process.	**0.497 0.001 44			
H5-S24	We use intensive collaboration with our partners to define objectives and targets to deliver requested design solutions for new products.		**0.421 0.004 44		
H1-S4	It is easy for the receiver to locate and extract the information needed to understand design relevant expertise.		**0.421 0.004 44		
Correlation flagged with** is significant at the 0.01 level and correlation flagged with * is significant at the 0.,05 level. (2-tailed)					

The results of significant correlations (table P3.5) between knowledge identification hypothesis1, knowledge integration hypothesis 4, and knowledge combination and creation hypothesis 5, give support to the assumption that successful knowledge identification supports the integration, combination and creation of knowledge in the product development processes.

The correlations in (table 3.5) demonstrate a strong relationship between how uncomplicated it is to identify the source of knowledge [H1-S1 with H4-S14 / **0.385],
[H1-S1 with H4S16 / **0.548] and [H1-S1 with H4-S17 / **0.449] and the integration of knowledge, which is tested in the survey through seeing if sender and receiver have sufficient interaction to create an understanding of the transferred knowledge.

A second indicator of the positive effect of knowledge identification is presented in correlation [H1-S1 with H4-S17 / **0,449] (table P3.5). If the receiver develops a high degree of ownership of the provided know-how, we can assume that the partner in need of the knowledge integrates knowledge transferred in an efficient way.

If product developers in need of knowledge have the possibility of locating and extracting the needed knowledge to use this design relevant expertise for new product development activities, the knowledge exists and is available for application. For statistical evidence, see correlation [H1-S4 with H5-S25 / **0.518] (table P3.5).

The simplicity of locating and extracting knowledge for proper design solutions positively supports the aim of product developers to deliver requested design solutions for new products. This relation is identified in (table P3.5), correlation [H4-S25 with H1-S4 / **0.421].
All identified associations give evidence that successful knowledge identification supports knowledge integration and combination.

To identify the positive effect of knowledge articulation in relation to knowledge integration, and combination, I have summarised significant correlations of associations between knowledge articulation, knowledge integration and knowledge combination and creation, illustrated in (table P3.6).

Table P3.6: Results of significant correlations between hypothesis 2 –hypothesis 4 – hypothesis 5

Results: Correlations between hypothesis 2 – hypothesis 4 – hypothesis 5		**Significant correlations H2-S8 with H4-S15**				
H2-S8	The engineering tasks require that personnel have long experience in this industry sector to achieve high product development performance	*0.313 0.039 44				
H4-S15	Both parties, sender and receiver, really care about the implementation of the provided know-how.	*0.313 0.039 44				
Correlation flagged with** is significant at the 0.01 level and correlation flagged with * is significant at the 0.05 level. (2-tailed)						

Continuous table P3.6: Results of significant correlations between hypothesis 2 – hypothesis 4 – hypothesis 5

Results: Correlations between hypothesis 2 – hypothesis 4 – hypothesis 5		**Significant correlations H2-S8 with H4-S15**	**Significant correlations H4-S18 with H2-S5**	**Significant correlations H2-S7 with H5-S22**		
H4-S18	Sender and receiver refer to this know-how in the teams, as important to the development process.		*0.321 0.034 44			
H2-S5	New engineers can easily learn this know-how by studying a complete set of technical specifications, documents or plans.		*0.321 0.034 44			
H2-S8	The engineering tasks require that personnel have long experience in this industry sector to achieve high product development performance	*0.324 0.032 44				
H5-S23	We use intensive collaboration with our partners to generate new knowledge for new application in new product development projects.	*0.324 0.032 44				
H2-S7	Educating and training new engineers regarding this know how is a quick and easy job			*-0.321 0.034 44		
H5-S22	We systematically use knowledge generated in previous projects as a knowledge platform for new projects.			*-0.321 0.034 44		
Results: Correlations between hypothesis 2 – hypothesis 4 – hypothesis 5		**Significant correlations H2-S5 with H4-S24**				
H2-S5	New engineers can easily learn this know how by studying a complete set of technical specifications, documents or plans.	*0.322 0.033 44				
H5-S24	We use intensive collaboration with our partners to define objectives and targets to deliver requested design solutions for new products.	*0.322 0.033 44				
Correlation flagged with** is significant at the 0.01 level and correlation flagged with * is significant at the 0.05 level. (2-tailed)						

The results of significant correlations (table P3.6) between knowledge articulation hypothesis 2, knowledge integration hypothesis 4 and knowledge combination and creation hypothesis 5 support the assumption that successful knowledge articulation supports integration, combination and creation of knowledge in the product development processes.

The correlation [H2-S8 with H4-S15 / *0.313] in (table P3.6), demonstrates that knowledge articulation is an intensive process of interactions between product developers. It is necessary that both parties involved in the knowledge transfer process care about the implementation of the provided know how.

The knowledge for successful product development builds on a high degree of experience and therefore, to transfer this sort of knowledge intensive interaction, is necessary to articulate and transfer the knowledge mainly embedded in the tacit design domain.

Knowledge articulation is a way of transforming tacit knowledge into explicit knowledge.

In correlation [H4-S18 with H2-S5 / *0.321] (table P3.6), we see that individual engagement, know-how is actively discussed in groups, articulation takes place and as a result we integrate knowledge in product development teams. If knowledge is articulated and therefore available in an explicit form, it is easier for less experienced engineers to study the relevant know-how available in technical specifications, documents, drawings and plans, for example.

In line with this finding also, is the correlation [H2-S7 with H5-S22 / *-0.321] (table P3.6), which shows that knowledge articulation is a very intensive process, but if knowledge is available in an explicit form it facilitates the learning of inexperienced engineers in the product development process.

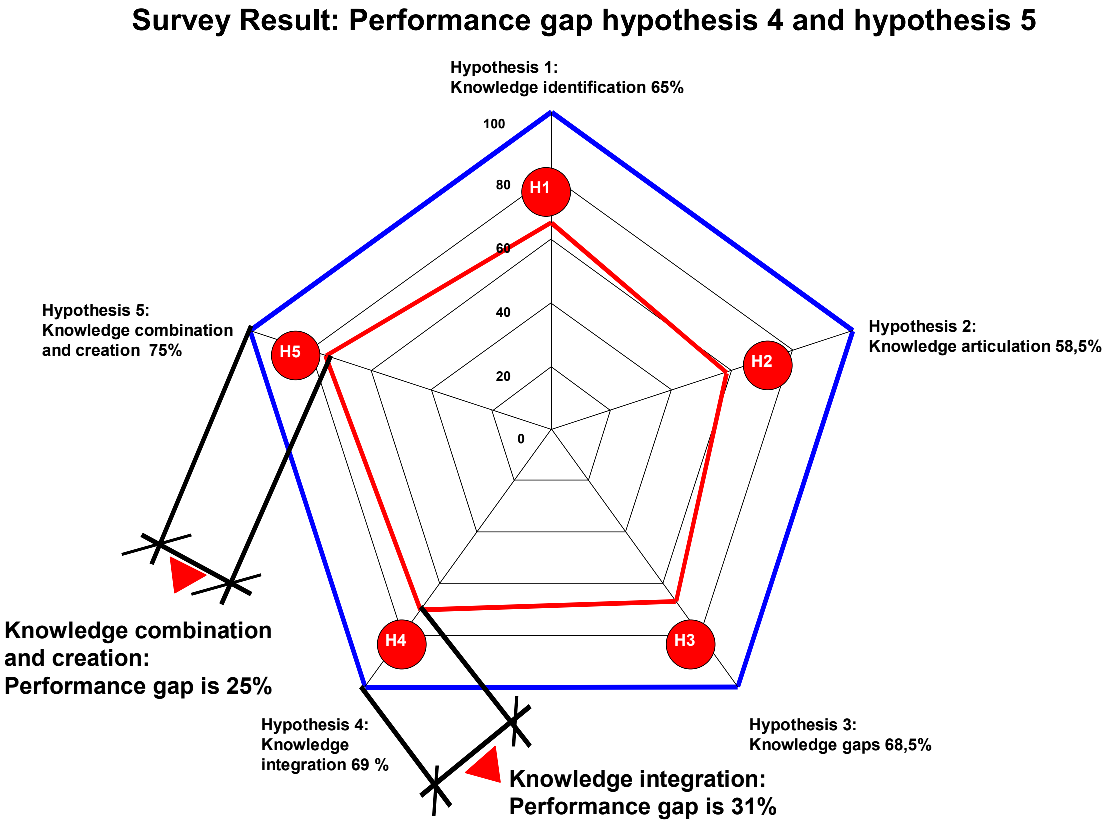
This finding is also supported by the fact that educating and training of new engineers regarding this know-how to solve complex design tasks is not seen to be a quick and easy job.

The identified relationships show that knowledge articulation needs interaction and communication in the product development process, which can be very demanding if most of the knowledge is embedded in the tacit design domain. But if product decision makers recognise the strategic importance of knowledge articulation, it can be a great opportunity to enhance knowledge integration and combination for new product development projects.

4.4.4 Knowledge integration, combination and creation in relation to the knowledge transfer process

To produce efficient knowledge transfer in new product development, product developers must be able to integrate and combine knowledge that is embedded in people, tools and routines. The issue is how many knowledge elements and related networks must be created in order to pass on to others tacit and explicit design knowledge. In order of the size of the identified percentage gap, knowledge integration [31%] and knowledge combination and creation [25%] still leave a significant performance gap to close.

Figure P3.9: Results Master Score N = 44, Performance gap knowledge integration and knowledge combination and creation



As shown on the knowledge transfer model (figure P3.1), knowledge integration hypothesis four and knowledge combination and creation hypothesis five are in closely related.

The results of this project showed that there is still a significant value creation potential left for knowledge integration and knowledge combination in new product development projects.

Both fields rely on active interaction between people engaged in product development projects, to assist knowledge transfer with the aim to integrate and combine new technologies to generate innovative products.

As a basis for further discussions, it is worth investigating the existence of significant correlations between hypothesis 4, which represents knowledge integration, and hypothesis 5, which represents knowledge combination and creation. In (table P3.7) the significant correlations of hypothesis four and five are illustrated.

Table P3.7: Results significant correlations between hypothesis 4 and hypothesis 5

Results: Correlations between hypothesis 4 and hypothesis 5		**Significant correlations H4-S14 with H5-S23**	**Significant correlations H4-S14 with H5-S25**	**Significant correlations H4-S15 with H5-S24**	**Significant correlations H5-S24 with H4-S16**	
H4-S14	The receiving unit feels a sense of responsibility for how this know how gets used	**0.564 0.000 44	**0.448 0.002 44			
H5-S23	We use intensive collaboration with our partners to generate new knowledge for new application in new product development projects.	**0.564 0.000 44				
H5-S25	The knowledge generated in previous projects exists and is available for application, if we start new projects.		**0.448 0.002 44			
H4-S15	Both parties, sender and receiver, really care about the implementation of the provided know-how.			**0.547 0.000 44		
H5-S24	We use intensive collaboration with our partners to define objectives and targets to deliver requested design solutions for new products.			**0.547 0.000 44		
H5-S24	We use intensive collaboration with our partners to define objectives and targets to deliver requested design solutions for new products.				**0.513 0.000 44	
H4-S16	Both parties have had sufficient interaction with this know how to develop an intimate understanding of it.				**0.513 0.000 44	
Results: Correlations between hypothesis 4 and hypothesis 5		**Significant correlations H4-S16 with H5-S25**	**Significant correlations H5-S25 with H4-S18**			
H4-S16	Both parties have had sufficient interaction with this know-how to develop an intimate understanding of it.	**0.467 0.001 44				
H5-S25	The knowledge generated in previous projects exists and is available for application, if we start new projects.	**0.467 0.001 44				
H5-S25	The knowledge generated in previous projects exists and is available for application, if we start new projects.		**0.388 0.009 44			
H4-S18	Sender and receiver refer to this know-how in the teams, as important to the development process.		**0.388 0.009 44			
Correlation flagged with** is significant at the 0.01 level and correlation flagged with * is significant at the 0.05 level. (2-tailed)						

The correlations in (table P3.7) are a powerful demonstration, that knowledge integration, combination and creation in product development need intensive interaction and collaboration.

Additionally the correlation [H4-S14 with H5-S23 / **0.448] and [H4-S15 with H5-S24 / **0,513] (table P3.7) show that the receiving development partner integrates new knowledge if they feel a sense of responsibility for the provided expertise. Knowledge ownership between both parties is created if sender and receiver talk up this know-how. A result of this interaction is that new knowledge elements are generated and integrated in social networks. The enormous importance of interaction and collaboration to integrate and combine knowledge has its origin in the nature of design knowledge.

The primacy of tacit design knowledge, for example *engineers produced in the survey a 82 % rate of agreement with the statement that they use mainly knowledge that comes from their past work experience as product developers, in order to solve complex design tasks.* As a consequence of these findings engineers are forced to transfer tacit design knowledge most of the time. The effectiveness of the knowledge transfer process is related to the fit between available tools for knowledge transfer and the communication patterns used by engineers involved in complex design tasks.

For example, in project two engineers faced the complex task of exploring and defining new design methodologies to substitute a traditional vehicle metal floor pan with a multifunctional composite floor pan. The new system needed to focus on design for lightweight, design for assembly and design for cost effectiveness, to get feasibility for a hardware generation. To meet these objectives design teams had to select the right piece of information and expertise out of functional departments and business units and use it in the right way, at a right time and place.

To combine and transfer this knowledge base engineers must identify, articulate, collect and combine knowledge to create innovative solutions for complex design tasks. This can be face-to-face, verbal, or a process driven data exchange, for example CAD files or e-mail conversation.

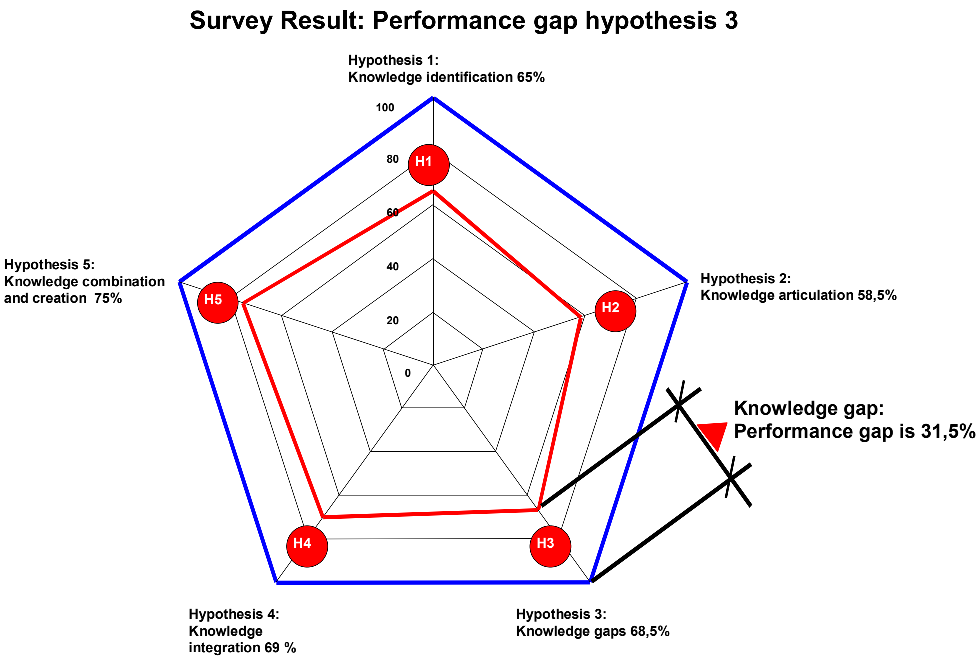
Engineers engaged in these processes need a systematic approach to transfer knowledge, which I called, in project two, the "core process of knowledge transfer". This process built on, {I} identify, {A} assess, {C} collect and {C} combine knowledge, which is a course of actions to structure knowledge and express it in a way that it is appropriate to receiver needs. An involvement of both parties in the identification and combination of knowledge helps to create an understanding of the knowledge elements needing to be transferred, and the articulation of knowledge creates an interaction between both parties, and can be seen as a knowledge creation process.

Externalisation and internalisation is created through interaction and therefore communication is a vital and basic necessity for product development activities to integrate and combine knowledge in the product development process.

4.4.5 Knowledge gaps in relation to the knowledge transfer process

In new product development projects, engineers are confronted with a high degree of uncertainty, which has it origin in the combination and application of new technologies. The degree of uncertainty created out of new technologies could be seen as a critical factor. In this phase, team members can become frustrated by a lack of a common understanding, which is generated through a knowledge gap between development partners. Project two showed that a lack of common understanding has a negative impact on the overall performance of the project. A clear definition of the targets and the right organisational process to allow teams to work together effectively are key issues from a management perspective. A clear identification of expertise is key, therefore product development partners must identify what relevant knowledge each development partner possesses and what activities are necessary to combine the knowledge of different development partners to generate new products.

Figure P3.10: Survey Master Score N=44, Hypothesis three: knowledge gaps



Product development managers must classify what knowledge they need to close technological gaps and how realistic it is to transfer this sort of knowledge. A clear definition of existing and required knowledge assists in identifying knowledge gaps. As soon as they are identified, teams can act to close the gap. With the information in hand, the knowledge transfer process can be organised to share and transfer knowledge between development partners.

Considering the size of the percentage gap [31.5%] identified in this project, product development managers are confronted with a significant performance gap, which leaves some space for future improvement of knowledge transfer in new product development.

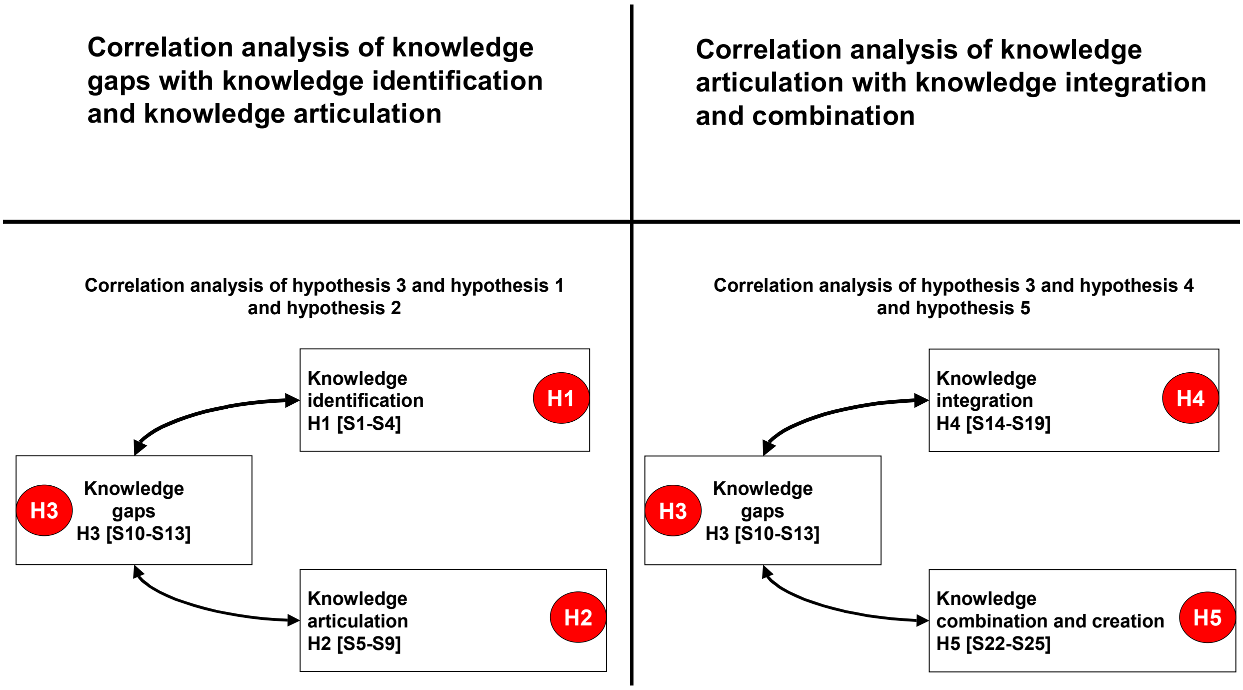
To improve knowledge transfer it is interesting to investigate the origin of knowledge gaps and what role they play in relation to the knowledge transfer process.

As identified in this project, identification and articulation of knowledge creates an interaction between development partners, which supports knowledge integration and combination.

Based on this finding, it is worthwhile to explore the relationship of knowledge gaps to the four key factors of knowledge transfer. Here we see that knowledge transfer is a dynamic process; if the knowledge gap is too big it is very demanding to transfer complex design knowledge, but if the knowledge gap is to narrow, it is not attractive to transfer design relevant knowledge. To understand the influence of knowledge gaps in relation to the knowledge transfer process, it helps to investigate what knowledge we need in order to close technological gaps, and how realistic is to transfer this sort of knowledge.

To explore the influence of knowledge gaps to the knowledge transfer model in product development projects, I tested following association illustrated in (figure P.3.11) on following page.

Figure P3.11: Knowledge gaps in relation to knowledge identification, articulation, integration and combination and creation



In (table P3.8), I have summarised significant correlations between knowledge gaps, knowledge identification and knowledge articulation.

Table P3.8: Results significant correlations between hypothesis 3 – hypothesis 1 and hypothesis 2

Results: Correlations between hypothesis 3 and hypothesis 1 and hypothesis 2		**Significant correlations H1-S2 with H3-S10**	**Significant correlations H1-S4 with H3-S10**	**Significant correlations H1-S1 with H3-S11**	**Significant correlations H5-S2 with H3-S11**	
H1-S1	It is uncomplicated for the receiver to identify source personnel who could help them reconfigure and implement requested design expertise.			**0.562 0.000 44		
H1-S2	It is uncomplicated for the receiver to identify the source personnel to spot necessary design requirements and understand the technologies related to this expertise.	**0.537 0.000 44			**0.423 0.004 44	
H1-S4	It is easy for the receiver to locate and extract the information needed to understand design relevant expertise.		**0.484 0.001 44			
H3-S10	Given the overlap of the source and receiver knowledge bases, source personnel could easily independently solve the same design tasks as the receiving engineers.	**0.537 0.000 44	**0.484 0.001 44			
H3-S11	The receiver had the knowledge base necessary to easily understand and put to use the provided know-how.			**0.562 0.000 44	**0.423 0.004 44	
Correlation flagged with** is significant at the 0.01 level and correlation flagged with * is significant at the 0.05 level. (2-tailed)						

Continuous table P3.8: Results significant correlations between hypothesis 3 – hypothesis 1 and hypothesis 2

Results: Correlations between hypothesis 3 and hypothesis 1 and hypothesis 2		**Significant correlations H1-S4 with H3-S11**	**Significant correlations H2-S7 with H3-S10**	**Significant correlations H2-S7 with H3-S13**	**Significant correlations H2-S7 with H3-S11**	
H1-S4	It is easy for the receiver to locate and extract the information needed to understand design relevant expertise.	**0,603 0,000 44				
H3-S11	The receiver had the knowledge base necessary to easily understand and put to use the provided know-how.	**0,603 0,000 44			**0,462 0,002 44	
H2-S7	Educating and training new engineers regarding this know how is a quick and easy job		**0,560 0,00 44	**-0,403 0,007 44	**0,462 0,002 44	
H3-S10	Given the overlap of the source and receiver knowledge bases, source personnel could easily independently solve the same design tasks as the receiving engineers.		**0,560 0,00 44			
H3-S13	Differences in the knowledge bases made integration of provided know how in the receiving unit very difficult.			**-0,403 0,007 44		

Correlation flagged with** is significant at the 0.01 level and correlation flagged with * is significant at the 0.05 level. (2-tailed)

The correlations [H1-S1 with H3-S10 / **0.537] (table P3.8) and [H1-S4 with H3-S10 / **0.484] (table P3.8) are in line with the theory that when the product team is informed of who knows what, performance of knowledge transfer activities increases. If the knowledge source is identified and the knowledge differs little between sender and receiver, engineers are able to solve design tasks independently from the knowledge source. Knowledge is understood by the development partner and implemented in the design process.

The correlation [H1-S1 with H3-S11 / **0.562], [H1-S2 with H3-S11 / **0.423] and [H1-S4 with H3-S11 / **0.603] (table P3.8), shows an association that if knowledge is articulated and identified, it is perceived by product developers as uncomplicated to transfer and easily understood and applied in new product development activities.

The correlation [H2-S7 with H3-S11 / **0.462] (table P3.8) showed that if development partners have a knowledge base about the provided know-how and it is available in an explicit form, the education and training of new engineers regarding this know-how is positive effected.

With respect to the positive effects of articulation and identification to close technological knowledge gaps we face, in new product development projects, many constraints in creating a seamless knowledge transfer process.

A fundamental limitation is that tacit design knowledge is hard to communicate, because it is deeply rooted in action, involvement and commitment of the engineers involved in the product development process. "It is a continuous activity of knowing" (Nonaka, 1994). If knowledge is articulated, it is converted from the tacit design domain into the explicit design domain and this conversion integrates also externalisation.

If we talk about externalisation of knowledge embedded in the tacit design domain, we face following limitations:

- Not all tacit design knowledge is capable of being codified
- How much effort should be invested to codify tacit knowledge?

Therefore product development managers must decide to put more weight on the creation of social networks and face-to-face contacts to foster diffusion and socialisation, to transfer tacit design knowledge.

On the other hand, if management can invest time and resources in externalisation, codification takes place, because the aim is to provide this sort of knowledge to a large number of geographical dispersed employees.

Both strategic directions build on knowledge identification and articulation with the aim of integrating new knowledge in the product development process.

With respect to the knowledge transfer model, I used project three to explore the existence of relations between knowledge gaps hypothesis 3, knowledge integration hypothesis 4 and knowledge creation and combination hypothesis 5, illustrated in (figure P3.11).

The outcome of this analysis is summarised in (table P3.9), which shows the significant correlations between knowledge gaps, knowledge integration, and knowledge combination and creation.

Table P3.9: Results significant correlations between hypothesis 3, hypothesis 4 and hypothesis 5

Results: Correlations between hypothesis 3, hypothesis 4 and hypothesis 5		**Significant correlations H3-S11 with H4-S16**	**Significant correlations H3-S12 with H5-S24**	**Significant correlations H3-S11 with H5-S25**		
H3-S11	The receiver had the knowledge base necessary to easily understand and put to use the provided know how.	**0.512 0.000 44		**0.457 0.002 44		
H4-S16	Both parties have had sufficient interaction with this know how to develop an intimate understanding of it.	**0.512 0.000 44				
H3-S12	The source had the knowledge base necessary to easily understand how the recipient planned to use the transferred know – how.		**0.393 0.008 44			
H5-S24	We use intensive collaboration with our partners to define objectives and targets to deliver requested design solutions for new products.		**0.393 0.008 44			
H5-S25	The knowledge generated in previous projects is existing and available for application, if we start with new projects.			**0.457 0.002 44		
Correlation flagged with** is significant at the 0.01 level and correlation flagged with * is significant at the 0.05 level. (2-tailed)						

The correlations [H3-S11 with H4-S16 / **0.512] and [H3-S12 with H5-S24 / **0.393] (table P3.9) identified that active interaction and collaboration facilitates the combination of transferred knowledge and further new knowledge comes to live in design solutions for new products.

The correlation [H3-S11 with H5-S25 / **0.457] (table P3.9) shows that if knowledge is received and it is understood and used, it exists and is available for applications in new product development projects.

The integration of new knowledge into the product development process by closing technical gaps, is facilitated through interaction and collaboration between engineers who posses the knowledge and engineers in need of this sort of knowledge. Identification of these technological gaps helps to spot what sort of knowledge is required to solve complex design tasks.

This portion of knowledge is embedded in the explicit domain of design knowledge and is transferred very efficiently in the vehicle development process, as seen in project one. In a perfect form it would create the opportunity to replicate design knowledge but in reality we know that knowledge for new product development is embedded in individuals, tools and routines and therefore too complex to be replicated.

To close the “ knowledge gaps “, existing in the tacit and explicit design domain, knowledge must be transferred between individuals. Engineers combine their individual knowledge, which exists in explicit and tacit form, and create a common understanding and a shared knowledge base in the product development team.

Knowledge transfer is a dynamic process and is influenced by the nature of the knowledge that is transferred, how easy or difficult it is to identify the needed knowledge and to articulate the identified knowledge.

In general the newness of technologies creates uncertainty for product developers and a clear articulation and definition of existing and needed expertise helps to identify knowledge gaps. As soon as they are identified, product development teams can act to close them.

The identified design knowledge, tacit and explicit, is communicated using knowledge transfer activities from technical disciplines possessing the knowledge, to product development teams in need of the identified target knowledge. A clear identification of knowledge gaps helps to close the technological gaps between different engineering disciplines and facilitates the integration and combination of new knowledge in the product development process.

4.5 Discussion and conclusion

The vehicle development process is an interaction of many functional areas from styling through to manufacturing, which involves the co-operation and collaboration of multi-disciplinary people who need to communicate and exchange information.

To understand how product developers create and share knowledge in the automotive product development process, and what supports and inhibits this activity, creates the opportunity to enhance future product development processes.

From that perspective, engineers are forced to combine high functional expertise of different engineering disciplines, which requires a high degree of coordination between different companies departments.

This combination and integration of expertise into the product development process is generated through knowledge transfer activities.

The active co-ordination of knowledge transfer among product development teams takes place between individuals and teams. With this in mind, I identified and grouped nine key factors in project three to optimise knowledge transfer, and as a result the integration and combination of new technology in product development projects is improved. Consequently the capability of a company to develop innovative products increases.

Based on projects one and two, it is evident that successful knowledge transfer needs to classify to what degree it is relevant design knowledge embedded in the tacit [6] or explicit [7] design domain see (figure 3.1). The results of project three are a powerful demonstration that knowledge integration, combination and creation in product development need intensive interaction and collaboration.

Additionally, the project confirms my previous finding, that new knowledge is successfully integrated [4] by the receiving development partner, if they feel a sense of responsibility for the provided expertise.

Knowledge ownership between both parties is created if sender and receiver discuss this know-how. A result of this interaction is that new knowledge elements are identified [1] and integrated in social networks. Knowledge comes to live, it is subject to negotiations and arguments and as such it is articulated [2] and integrated into the product development process.

The enormous importance of interaction and collaboration in integrating and combining knowledge has its origin in the nature of design knowledge. The primacy of tacit design knowledge means that engineers are forced to transfer tacit design knowledge most of the time. For example engineers produced in the survey a 82 % rate of agreement with the statement that they use mainly knowledge that comes from their past work experience as product developers, in order to solve complex design tasks. The effectiveness of the knowledge transfer process is related to the fit between available tools for knowledge transfer and the communication patterns used by engineers involved in complex design tasks.

This procedure must be able to transfer intangible ideas and findings, and here we see the difficulty of a successful knowledge transfer process, because the knowledge used in the product development process is not a static knowledge base, is developing under dynamic conditions, due to the fact that a product development is a continuous process of improvement, design trade-offs and new learning loops.

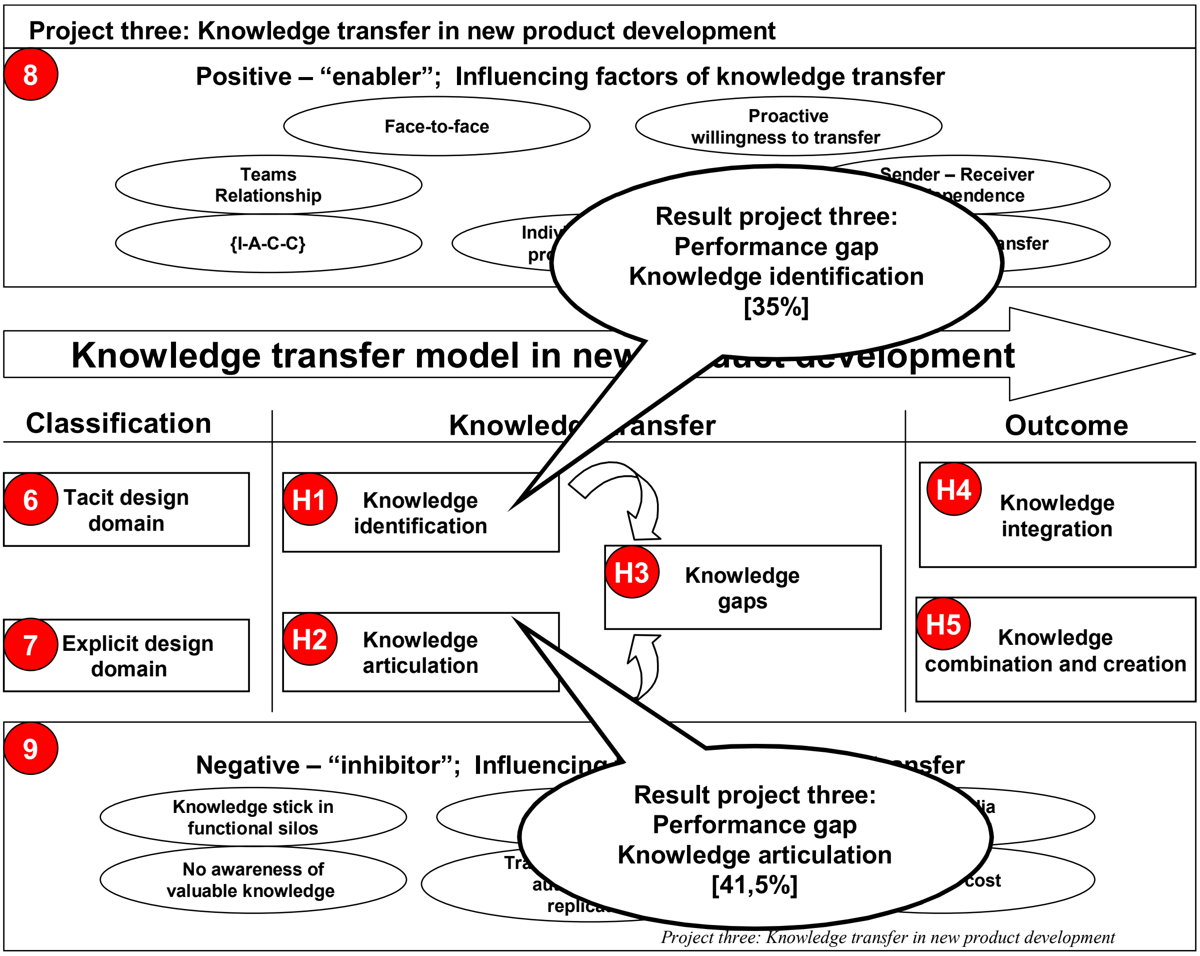
Knowledge is surrounded in people and to release this expertise and share it among individuals involved in product development activities, engineers use communication tools and social networks to identify, articulate and transfer product development expertise.

Identifying and articulating knowledge means deciding what describes the product in a manner that other functional departments can use. This activity can be seen as a pre-knowledge creation activity, it needs some energy and time, but as soon as the product knowledge is available in a visual context, embedded in a presentation or CAD model, it is able to be transferred and shared between different parties.

A real challenge for all engineers involved in this activity is to create group expertise out of individual expertise and to articulate this group expertise and transfer it in an efficient way.

Project three showed that a remarkable underperformance still exists in knowledge identification [35%] and knowledge articulation [41.5%] in new product development in the automotive industry (figure P3.12).

Figure P3.12: Results performance gap knowledge identification and knowledge articulation



Building on four years engagement with knowledge transfer research, my point of view is that organisations in the automotive sector still rely on methods and processes that used to be successful in the past and strictly directed to exploit tangible assets.

4.6 Findings and contribution

In vehicle development we move more and more towards virtual product development supported by computer aided design and computer aided engineering tools. The design tools are the main means to reduce development time and cost, but product development managers must be aware that essential design knowledge to develop new innovative products is still largely embedded in individual experts.

Therefore successful new product development builds on the effective transfer of tacit design knowledge. Such a process would entail the use of multiple presentations, discussions, and dialogues about the knowledge across multiple teams within both the engineers owning the knowledge and engineers in need of knowledge.

Identification and articulation of knowledge benefits from the interaction between teams, and provides the opportunity for the teams to put the knowledge into action.
A result of this interaction is that new knowledge elements are generated and integrated in social networks. Knowledge comes to life if it is subject to negotiations and arguments, and is therefore integrated into the product development process.

The research visualises that intensive interaction, communication and collaboration are efficient ways to pass tacit knowledge on to other product developers.
The enormous importance of interaction and collaboration to integrate and combine knowledge has its origin in the nature of design knowledge.

The primacy of tacit design knowledge means that engineers are mostly forced to transfer this type of knowledge. To combine and transfer this knowledge, engineers must identify, articulate, collect and combine knowledge to create innovative solutions for complex design tasks.

It is worth for product development managers to recognise, that knowledge *identification and articulation* is a core activity to transform tacit knowledge into explicit knowledge. Based on these findings, we can define that effective knowledge exchange is positively influenced if both parties have a clear identification of knowledge elements.

This means that engineers must know where the required knowledge resides and whom and where to ask to collect and combine the requested expertise. In order of the size of the identified performance gap in project three, knowledge identification [35%] and articulation [41.5%] are the most significant areas for value creation through improved knowledge transfer processes in the future illustrated in (figure P3.12)

From a managerial perspective the knowledge transfer model (figure P3.1) illustrates the dynamics and limits of knowledge transfer and as such it serves as a tool to estimate resource requirements to organise successful product development projects.

- The model assist in classifying what knowledge is needed to close technological gaps and how realistic it is to transfer this sort of knowledge. As has been shown, relevant design knowledge is, to a high degree, embedded in the tacit design domain, and therefore, if it can be codified at all one must decide how much effort should be invested in codifying it.

The findings indicate that management should decide to put more weight on the creation of social networks and face-to-face contacts to foster diffusion and socialisation to transfer tacit design knowledge. If management can invest time and resources in externalisation, codification takes place, because the companies aim is to provide this sort of knowledge to a large number of geographically dispersed employees.

By classifying the design tasks in explicit and tacit domains, product developers will gain insight into how, whom, where and when should they co-locate to implement tacit design knowledge into product development process.

Another important issue is that product decision makers can use the model to define how and to what extent product development knowledge should be shared with external partners, to facilitate product innovation. There are, of course, some kinds of knowledge a company does not want to share with external partners, because these are skills to create competitive advantage.

The research challenges the classical project management techniques, which are heavily aligned to the *"targets to perform mentality"*. Implementing innovation should not adopt such a rigid approach. For example the concept of *"front loading"* on product development performance, is broadly accepted in the product development processes of all automotive manufacturers but the term *"pre-knowledge creation"* is widely ignored in the vehicle development process**.**

In vehicle development, non-routine tasks are high on complexity. To solve such complex design tasks, a high degree of task interdependence between technical disciplines is necessary to evaluate and investigate proper design solutions. These require that team members have an understanding of the complete product system architecture. To create such an understanding engineers need to identify, access and combine design relevant knowledge. These activities can be seen as a *pre-knowledge creation*. The result is a shared product knowledge base which makes it possible that people engaged in the vehicle development process use different kinds of knowledge to capture and link new technologies into innovative products.

Thus, this research contributes to the literature by providing empirical support for several theories and previously defined and /or tested constructs.

With respect to the research finding that knowledge identification and articulation plays a significant role for successful knowledge transfer, the work of Cooper (1998) and Wheelwright and Clark (1992) is relevant. They found that companies with the desire to enhance the product development process are in need of people who are able to generate new products with existing systems, technologies, and market experiences. This is facilitated if the product development team is able to articulate product concepts to all parties involved, so sustained innovation also relies heavily on articulated knowledge.

Research results with respect to knowledge integration and combination, supplement the findings that knowledge creation in complex new product development projects is enhanced by highly interactive and iterative communications by cross-functional teams (Brown and Eisenhardt, 1995; Takeuchi and Nonaka 1995).

Project three also demonstrates, in several correlations (table P3.7), that engineers use intensive collaboration with their development partners to define objectives and targets to deliver requested design solutions for new products. This is in line with Nonaka and Takeuchi (1995) and their process model of knowledge creation. This builds on the crucial presupposition that human knowledge is created and enlarged by means of a social interaction between tacit and explicit knowledge. This interaction is called a knowledge conversion. It is further important to note that this conversion does not take place within individuals but between individuals within an organisation.

Additionally, project three showed that engineers felt that it was very important that both parties involved in the product development process need sufficient interaction with the transferred know-how to develop an intimate understanding of it, which creates the ability to combine knowledge for new applications in product development. This finding is aligned with previous research. For example Leonard-Barton (1995) stated that individuals develop knowledge commitment to the extent that they see the value of the knowledge, and therefore they develop competence in using the knowledge.

4.7 Limitations and further research

The results of this study are of course subject to a number of limitations. First, the research model in this study integrates a lot of specific project characteristics of vehicle development projects. For example new product development of personal computers, for which technology and markets are still rapidly and unpredictable evolving need a different product development process. This fast product development processes are sometimes improvisational, they combine real time learning through design iterations and extensive testing with the focus to achieve product functionality. For example new applications substitute design solutions, which fail to create functionality, and engineers maybe use completely different approaches for the next design iteration.

Therefore the knowledge transfer model (figure P3.1), which builds on the basic assumption that knowledge created is collected and combined and reused in future application maybe has for such a dynamic product development environment a limited value creation potential.

Therefore generalisation of my findings to other industry sectors should be made with caution.

To break it down further, the research builds on the control mode of existing literature. Taking the broad spectrum of knowledge management literature into account, which spans from strategy and leadership, culture and climate, nature of knowledge down to innovation and technological learning, I used mainly the part of literature which integrates knowledge transfer activities into the field of study as a control mode and link to previous findings. As Bernard (1998, p. 317) puts it, such analysis "makes complicated things understandable by reducing them to their component parts". While every attempt was made to avoid such a generalisation by including only constructs in evidence in each of the building literature the range of the knowledge transfer model (figure P3.1) necessarily including enablers and inhibitors simplifies reality.

In addition, the study's small sample size, although consistent with many studies of knowledge transfer (Zander and Kogut, 1995; Lane and Lubatkin, 1998; Szulanski, 1996), limits the finding's statistical power. On the other hand, as we see in (table P3.2) the results of the two researched companies are nearly identical, which lends weight to the findings, if we strictly relate them to knowledge transfer activities in automotive product development.

Future research on the factors affecting knowledge transfer in new product development could benefit from the following approach in which the knowledge transfer model tested in project three and discussed and analysed in depth, is used for research in other industry sectors as well.

5. Reference list

Ahituv, N., Igbaria, M., & Sella, A. 1998. The effects of time pressure and completeness of information on decision-making. *Journal of Management Information Systems, 15 (2), 153±172.*

Allen, T.J 1977. Managing the Flow of Technology: Technology Transfer and Dissemination of Technological Information Within the R&D Organization, *Press, Cambridge, MA, 1977.*

Almeida, P., Kogut, B. 1999. Localization of knowledge and the mobility of engineers in regional networks. *Management Science 45, 905–917.*

Andrews, F. and Farris, G. 1972. Time pressure and performance of scientists and engineers: A five year panel study. *Organisational Behaviour Human Performance, 24: 202-227.*

Appleyard, M. M. 1996. How does knowledge flow: interfirms patterns in the semiconductor industry. *Strategic Management Journal 17 (Winter Special Issue), 137±154.*

Argyris, C. 1994. Good communication that blocks learning. *Harvard Business Review, July, August 77-104.*

Aubrey, R., Cohen, P.1995. Working Wisdom: Timeless Skills and Vanguard Strategies for Learning Organizations. *Jossey-Bass, San Francisco, CA.*

Balasubramanian, R., Tiwana, A., 1999. Supporting collaborative process knowledge in new product development teams. *Decision Support Systems 27 (1–2), 113–135.*

Berg, B. L. 1989. Qualitative Research Methods for the Social Sciences. *Allyn & Bacon: Needham Heights, MA.*

Bernard, H.R.1988. Research methods in cultural anthropology. *Newbury Park, CA: Sage.*

Blackler, F. 1995. Knowledge, knowledge work and organizations: an overview and interpretation. *Organization Studies, 16 1021-1046.*

Blumentritt, R., Johnston R. 1999. Towards a strategy for knowledge management. *Technology Analysis & Strategic Management 11, 287-300.*

Bohn, R.E. 1994. Measuring and managing technological knowledge. *Sloan Management Review, 26 (1), 61±73.* 67-73.

Boisot, M.H. 1998. Knowledge Assets, *Oxford University Press*

Borghoff, U., Pareschi, R., 1999. Information Technology for Knowledge Management. *Springer-Verlag, Heidelberg.*

Brannen, M. Y., Wilson III, M. 1996. Wilson recontextualization and internalization: lessons in transcultural materialism from the Walt Disney company. *CMES Business* Review, 1 (1/2), 97±100.

Bresman, H., Birkinshaw, J.M., Nobel, R., 1999. Knowledge transfer in international acquisitions. *Journal of International Business Studies 30 (3), 439–462.*

Brown, J.S., Duguid, P. 1991. Organizational learning and communities-of-practice: towards an unified view of working learning and innovation. *Organizational Science 2, 40-57.*

Brown, J.S., Duguid, P. 1998. Organizing knowledge. *California Management Review, 40, 90-111.*

Brown, S.L., Eisenhardt, K.M., 1995. Product development: past research, present findings, and future directions. *Academy of Management Review 20, 343–378.*

Brown, S. L., Eisenhardt, K. M. 1997. The art of continuous change: Linking complexity theory and time-paced evolution in relentlessly shifting organizations. *Administrative Science Quarterly, 42,1, 34.*

Brown, J., Utterback, J., 1985. Uncertainty and technical communication patterns. *Management Science, 31: 301-311.*

Buckley, P.J, M.J. Carter, M.J, 1998. Managing Cross Border Complementary Knowledge: The Business Process Approach Knowledge Management in Multinational Firms, C*arnegie Bosch Institute [working paper].*

Burgelman, R., 1983. A process model of internal corporate venturing in the diversified major firm. *Administrative Science Quarterly 28, 223–244.*

Burgelman, R.; Maidique M.A; Wheelwright S.C., 2001 *(Eds.), Strategic Management of Technology and Innovation, third ed., McGraw-Hill, New York*

Burns, T., Stalker, G. M. 1961. The management of innovation. *London: Tavistock.*

Carayannis, E., Forbes, J. 2001. A pragmatic representation of systems engineering based on technological learning. *Technovation, Volume 21, 197-207.*

Churchman, C.W. 1971 The design of inquiring systems: basic concepts of systems and organizations. *Bencis Books*

Clark, K., Fujimoto, T., 1991. Product Development Performance. Harvard Business School Press, Boston.

Clark, K., Fujimoto, T., 1989. Lead times in automobile product development, Explaining the Japanese Advantage, *Journal of Engineering and Technology Management, 6.*

Cohen, W.M., Levinthal, D. 1990. Absorptive capacity: a new perspective on learning and innovation. *Science Quarterly 128-152.*

Collins, H.M. (1993) The structure of Knowledge, *Social Research 95-116.*

Cook, S.D.N., Brown, J.S. 1999 Bridging epistemologies: the generative dance between organizational knowledge and organizational knowing. *Organization Science 10, 381-400.*

Cooper, R., 1998. Product Leadership: Creating and Launching Superior New Products. Perseus Books, Reading, A.

Crawford, C. 1983. New Products Management, *Homewood Illinois : Richard D. Irwin*

Daal, B.V., Hass, M. & Weggemann, M. 1998. Define the knowledge matrix: a participatory method for individual knowledge gap determination. *Knowledge and Process Management, 5, 255-263.*

Dark, G. Shanks, M. Broadbent, 1998 Successfully completing case study research: combining rigor, relevance and pragmatism, *Information Systems Journal 8 (4).*

Davenport, T. H., Klahr, P. 1998. Managing customer support knowledge. *California Management Review, 40 (3), 195±209.*

Davenport, T. H., Long, D. W., & Beers, M. C. 1998a. Successful knowledge management projects. *Sloan Management Review, 39 (2), 43±57.*

Davenport, T.H., Prusak, L., 1998. Working Knowledge: How Organisations Manage What They Know. *Harvard Business Press, Boston.*

Davidson, W.H., 1980. The location of foreign direct investment activity: country characteristics and the theory of the firm. *Journal of International Business Studies 11, 9–22.*

Day, G., 1990. Market Driven Strategy: Processes for Creating Value. *The Free Press, New York*

Delphi Group, 1999. Knowledge Management Onsite Seminar, *http: www. delphigroup.com*

Demarest, M. 1997. Understanding knowledge management. *Journal of Long Range Planning 30, 374-384.*

Devadas, R., Argote, L., 1995. Collective learning and forgetting: the effects of turnover and group structure. *In: Paper Presented at Midwestern Psychological Association Meeting, Chicago.*

Dewar, R., Dutton, J., 1986. The adoption of radical and incremental innovations: An empirical analysis. *Management Science, 32: 1422-1433.*

Dewey, D. 1979. Information entry and welfare: the case for collusion. *The American Economic Review 69, 587-603.*

Dinur, A., Inkpen, A.C. & Hamilton, R.D., 1998. Knowledge transfer in the multinational corporation. In: *Paper Presented at the Academy of International Business, Vienna, Austria.*

Dixon, N.M., 1994. The Organizational Learning Cycle: How We Can Learn Collectively. *McGraw-Hill, NewYork.*

Dixon, N.M., 2000. Common Knowledge: How Companies Thrive by Sharing What They Know. *Harvard Business School Press, Boston, MA.*

Dosi, G. 1988. Sources, procedures and microeconomic effects of innovation, *Journal for Economic Literature 26 1120–1171.*

Dougherty, D. 1992. Interpretative barriers to successful product innovation in large firms. *Organization Science 3, 179-202.*

Doz, Y., Santos J.F.P. 1997. On the management of knowledge: from the transparency of co-location and cosseting to the quandary of dispersion and differentiation. *Working Paper, INSEAD.*

Dretske, F.I. 1999. Knowledge and the flow of Information. *Stanford, CA: CLSI Stanford, CA: CLSI Publications*

Drucker, P. 1993. Post-capitalist society, *Harper Business, New York*

Duncan, R., Weiss, A., 1979. Organizational learning: Implications for organizational design. In: L.L. Cummings and B. Staw (Eds.), *Research in Organizational Behaviour, Vol*. 1. JAI Press, Greenwich, CT.

Eisenhardt, K. M. 1989. Building theories from case study research. *Academy of Management Review 14(4): 532–550.*

Eisenhardt, K. M., Martin J. 2000. Dynamic Capabilities: What Are They? *Strategic Management Journal 21: 1105 -1121*

Ernst & Young 1997 Executive perspectives on knowledge in the organization. *Ernst & Young Centre for Business Innovation and Business Intelligence, Report.*

Fleck, J. 1997. Contingent knowledge and technology development. *Technology Analysis & Strategic Management 9, 383-397.*

Frappaolo, C., Capshaw, S. 1999. Knowledge management software: capturing the essence of know-how and innovation. *Information Management Journal* 33.

Galbraith, C.S., 1990. Transferring core manufacturing technologies in high technology firms. *California Management Review 32 (4), 56–70.*

George, J., Easton, G. Nunamaker, J. & Northcraft, G. 1990. A study of collaborative group work with and without computer-based support. *Information Systems Research 394-415.*

Gergen, K.J. 1994. Realities and relationships: soundings in social construction. *Cambridge, Mass: Harvard University Press.*

Ghoshal, S., Bartlet, C.A. 1994. Linking organizational context and managerial action: the dimensions of quality of management. *Strategic Management Journal 15, 91-112.*

Grant, R.M. 1996. Prospering in dynamically-competitive environments: organisational capability as knowledge integration. *Organization Science 7, 375-387.*

Griffin, A., Hauser, J., 1993. The voice of the customer. *Management Science 12, 1–27.*

Grossman, S.J., Hart, O.D. 1986.The costs and benefits of ownership: a theory of vertical and lateral integration. *Journal of Political Economics 94, 691-719.*

Gupta, A.K., Govindaraja, V. 1991. Knowledge flows and the structure of control within multinational corporations. *Academy of Management Journal 16, 768-792.*

Hakanson, L., Nobel, R., 1998. Technology characteristics and reverse technology transfer. *In: Paper Presented at the Annual Meeting of the Academy of International Business, Vienna, Austria.*

Hall, P. 1986. Technology Innovation and Economic Policy, *St. Martin's Press, New York.*

Hall, P. 1994. Innovation, Economics and Evolution, *Prentice Hall, New York, 1994, p. 18.*

Hamel, G. 1991. Competition for competence and interpartner learning within international strategic alliances. *Strategic Management Journal 12, 83-103.*

Hammer, M., Champny J. 1995. Reengineering the corporation. *London: Nicholas Brealey*

Hansen, M.T. 1999. The search-transfer problem: the role of weak ties in sharing knowledge across organization subunits. *Administrative Science Quarterly March 44: 82–111.*

Hargadon, A., Sutton RI. 1997. Technology brokering and innovation in a product development firm. *Administrative Science Quarterly 42 (4): 716–749.*

Harris, D.B. 1999. Creating a knowledge centric information technology environment. *Technology In Education Institute, URL: http://www.htcs.com/ckc.htm*

Harrison, A. 2002. Case study research. In: *Essential Skills for Management Research , edited by David Partington, Sage Publications*

Hart, O., Moore J. 1990. Property rights and the nature of the firm. *Journal of Political Economy 98, 1119-1158.*

Henderson, R. 1994. The evolution of integrative capability: innovation in cardiovascular drug discovery. *Industrial and Corporate Change, 3, 607- 630.*

Henderson, R., Cockburn, I. 1994. Measuring competence? exploring firms effects in pharmaceutical research. *Strategic Management Journal, 15, 63 - 84.*

Hippel, E. 1994 Von sticky information and the locus of problem solving: implication for innovation. *Management Science* 40, 429-439.

Hirschman, EC. 1986. Humanistic inquiry in marketing research: philosophy, method, and criteria. *Journal of Marketing Research 23(August): 237–249.*

Holsapple, C.W., Joshi, K.D. 1998. In Search of a Descriptive Framework for Knowledge Management: *Preliminary Delphi Results, Kentucky Initiative for Knowledge Management, Paper No. 118.*

Holsapple, C.W, Joshi, K. D. 2000. An investigation of factors that influence the management of knowledge in organizations. *The Journal of Strategic Information Systems 9, 235-261.*

Holsapple, C.W, Singh, M. 2001. The knowledge chain model: activities for competitiveness. *Expert Systems with Applications Volume 20, Pages 77-98.*

Holzner, B., Marx, J. 1979. The knowledge application: the knowledge system in society. *Boston: Allyn and Bacon*

Huber, G. 1991. Organizational learning: the contributing processes and the literatures. *Organization Science, 88-115.*

Husyman, M., Cremers, M. & Derkson, F.1998. Learning from the environment: exploring the relationship between organizational learning, knowledge management and information/communication technology. *Fourth Americas Conference on Information Systems Baltimore.*

Hutchins, E. 1991. Organizing work by adaptation. Organization Science 14-39.

Jones, P., Jordan, J., 1998. Knowledge orientations and team effectiveness. *International Journal of Technology Management 16, 152–161.*

Jones, T. 1997. New Product Development: An introduction to a Multifunctional Process. *Butterworth Heinemann.*

Jick, T.D. 1979. Mixing Qualitative and Quantitative Methods: Triangulation in Action Administrative Science Quarterly , 24 , 602 – 611.

Joshi, K. 1998. An investigation of knowledge management characteristics: synthesis, delphi study, analysis. *Dissertation, Carol M. Gatton, College of Business and Economics, University of Kentucky, Lexington, KY.*

Junnarkar, B., Crawford, B. & Alchian, A. A. 1997. Re-assessing the enabling role of information technology in KM. *Journal of Knowledge Management 1, 142-148.*

Kahn, K.B, McDonough III, F. 1997. Co-location, Integration, Performance and Satisfaction, Journal *Product Innovation Management; 14, 161 – 178.*

Kantrow, A. M.1980. The strategy–technology connection, *Harvard Bus. Rev. 58 (4) 13–21.*

Katz, R., Allen, T.J. 1982. Investigating the not invented here (NIH) syndrome: a look at the performance tenure and communication patterns of 50 r&d project groups. *R&D Management 12, 7-19.*

Katz, R. 1997. The Human Side of Managing Technological Innovation, *Oxford University Press, Oxford, 1997.*

Kelly, J., McGrath, J., 1985. Effects of time limits and task types on task performance and interaction of four person groups. *J. Personality Sot. Psychol., 49: 395-407.*

Kim, L., Nelson, R.R., 2000. Technology, Learning, and Innovation: Experiences of Newly Industrializing Economies. *Cambridge University Press, Cambridge, UK.*

Klein, B., Crawford, R. & Alchian, A. A. 1978. Vertical integration appropriable rents and the competitive contracting process. Journal of Law and Economics 21, 297-326.

Kock, N., McQueen, R. 1998. Knowledge and information communication in organizations: an analysis of core, support and improvement process. *Knowledge and Process Management 5, 29-40.*

Koenig, M.E.D. 1983. A bibliometric analysis of pharmaceutical research. *Research Policy 12*

Koenig, M.E.D. 1990. Information services and downstream productivity. *NewYork: Elsevier. Vol. 25, 55-86.*

Kogut, B., Zander U. 1993. Knowledge of the firm and the evolutionary theory of the multinational corporation. *Journal of International Business Studies 24, 625-645.*

Kogut, B., Zander U. 1992. Knowledge of the firm, combinative capabilities, and the replication of technology. *Organization Science 3: 383–397.*

Kogut, B., Zander U. 1996. What firms do? coordination identify and learning. *Organization Science 7, 502-518.*

Kostova, T., 1999. Transnational transfer of strategic organizational practices: a contextual perspective. *Academy of Management Review 24 (2), 308–324.*

Kovel, J., Quirk, K. & Gabin, J.1996. The Lotus Notes Idea Book. *MA: Addison-Wesley.*

Krogh, G.V. 1998. Care in knowledge creation. California Management Review 133-153.

Krogh, G., Roos J. & Slocum, K. 1994. An essay on corporate epistemology. Strategic Management Journal 53-71.

Krone, K. J., Jablin, F. M., & Putnam, L. L. 1987. Communication theory and organized communication: an interdisciplinary perspectives. In F.M. Jablin, L.L. Putnam, K.M. Robert, & L.W. Porter (Eds.), *Handbook of organizational communication (pp. 18±40). Newbury Park, CA: Sage.*

Lane, P.J., Lubatkin, M., 1998. Relative absorptive capacity and interorganizational learning. *Strategic Management Journal 19, 461–477.*

Larson, E. W. , Gobeli, D.H, 1985. Project Management Structures : Is there a common language? *Project Management Journal 16 (2): 40 – 44 (June 1985)*

Larson, E. W. , Gobeli, D.H, 1988. Organizing for Product Development Projects *Journal for Product Innovation Management: 1988; 5 180 -190*

Leonard-Barton, D., 1988. Implementation as mutual adaptation of technology and organization. *Research Policy 17, 251–267.*

Leonard-Barton, D.1992. Core capabilities and core rigidities: A paradox in managing new product development, *Strategic Management Journal J. 13 (1992) 111–125.*

Leonard-Barton, D. 1995. Wellsprings of knowledge: building and sustaining the source of innovation. *Boston: Harvard Business School Press.*

Levinthal, D.A., March, J.G. 1993. The myopia of learning. *Strategic Management Journal 14, (Special Issue), 95-113.*

Levitt, B., March. J.G. 1988. Organizational learning. *Annual Review of Sociology 14 319-340.*

Liebeskind, J.P. 1996. Knowledge strategy and the theory of the firm. *Strategic Management Journal 17 (Winter Special Issue), 93-107.*

Liebowitz, J. 1999. Key ingredients to the success of an organizations knowledge management strategy. *Key ingredients to the success of an organizations knowledge management strategy. 6, 37-40.*

Lincoln, Y.S., Guba, E.G. 1985. Naturalistic Inquiry. *Sage: Beverly Hills, CA.*

Lyles, M.A. 1998.Learning among joint venture sophisticated firms. *Management International Review 88 (Special Issue), 85-97.*

Madhavan, R., Prescott, J. E. 1995. Market value impact of joint venture: the effect of industry information- processing overload. *Academy of Management Journal 38, 900-915.*

Maes, P. 1994. Agents that reduce work and information overload. *Communications of the ACM* 30, 30-40.

Mansfield, E., Romeo, A., 1980. Technology transfer to overseas subsidiaries by US-based firms. *Quarterly Journal of Economics 95, 737–750.*

Mansfield, E., Romeo, A., Wagner, S., 1979. Foreign trade and US research and development. *Review of Economics and Statistics 61, 49–57.*

Markland, R. E., Vickery, S. K., & Davis, R. A. 1995. Operations management: concepts in manufacturing and services, *New York: West.*

Marquardt, M., 1996.Building the Learning Organization: A Systems Approach to Quantum Improvement and Global Success, *McGraw-Hill, New York, 1996.*

Marshall, L. 1997. Facilitating knowledge management and knowledge sharing. *Online 21, 92-98.*

McDermot, R. 1999. Why information technology inspired but cannot deliver knowledge management. *California Management Review 41, 103-117.*

McQueen, R.J. 1998. Four views of knowledge and knowledge management. *Fourth Americas Conference on Information Systems, 14±16 August 1998, Baltimore*

Meyer, J., Rowan, B., 1977. Institutionalized organizations: formal structure as myth and ceremony. *American Journal of Sociology 83, 340–363.*

Meyer, M.H., Lehnerd A.P, 1997. The Power of Product Platforms. Building Value and Cost Leadership, *Free Press, New York, 1997.*

Miles, M.B., Huberman A. M. 1994. *Qualitative Data Analysis*. Sage: Beverly Hills, CA.

Millar, J., Demaid, A. & Quintas, P. 1997. Trans-organizational innovation: a framework for research. *Technology Analysis & Strategic Management* 9, 399-418.

Moenaert, R.K., Souder W.E. 1990. An information transfer model for integrating marketing and R&D personnel in new product development projects. *Journal of Product Innovation Management 7, 91-107.*

Moorman, C., Miner A.S. 1998. Organizational improvisation and organizational memory. *The Academy of Management Review 23, 698-723.*

Moreland, R.L., Argote, L. & Krishnan, R., 1996. Socially shared cognition at work: transactive memory and group performance. In: Nye, J.L., Brower, A.M. (Eds.), What's So Social About Social Cognition? Social Cognition Research in Small Groups. *Sage, Thousand Oaks, CA, pp. 57–84.*

Mowday, R., Steers & R., Porter, L., 1979. The measurement of organizational commitment. Journal of Vocational Behavior 14, 224–247.

Nelson, R. 1993. National Innovation Systems: A Comparative Analysis. *Oxford University Press, NewYork.*

Nelson, R., Winter, S., 1982. An Evolutionary Theory of Economic Change. *Belknap Press, Cambridge.*

Nevis, E. C., DiBella, A. J. & Gould, J.M. 1995. Understanding organizations as learning systems. *Sloan Management Review, 36 (2), 73 – 87.*

Nicolini, D., March M.B. 1995. The social construction of organizational learning: conceptual and practical issues in the field. *Human Relations 727-746.*

Nixon, C., Padgett, L. 1989. From hands-on science to hands-on information retrieval. *Medford, NJ: Learned Information 26, edn. 96- 100 pages.*

Nonaka, I. 1994. A dynamic theory of organizational knowledge creation. *Organization Science 5, 14-37.*

Nonaka, I.1998. Management focus: the `ART' of knowledge systems to capitalize on market knowledge. *European Management Journal 16, 673-684.*

Nonaka, I., Johansson, J., 1985. Japanese management: What about the 'hard' skills? *The Academy of Management Review lO (2): 181-191.*

Nonaka, I., Takeuchi, H. 1995. The knowledge creating company. *New York: Oxford University Press.*

Nonaka I., Teece D. 2001. Managing Industrial Knowledge, *Sage, London, 2001.*

O'Reilly III, C.A. 1982. Variations in decision maker's use of information sources: the impact of quality and accessibility of information. *Academy of Management Journal, 25, 756-771.*

Offeys, S. 1997. Knowledge management: linking people to knowledge for bottom line results. *Journal of Knowledge Management 1, 113-122.*

Pascarella, P. 1997. Harnessing knowledge. *Management Review, 86, 37-40.*

Pavitt, K.1990. What we know about the strategic management of technology, *California Management Review 32 (1990) 17–26 (Spring).*

Peitrangelo, J. 1993. Mustang engineers slash cycle time. *Ward's Auto World 29; 71*

Pentland, B.T. 1995. Information systems and organizational learning: the social epistemology of organizational knowledge systems. *Accounting Management and Information Technologies 5.*

Pinto, J.K., Mantel, S.J.J., 1990. The causes of project failure. *IEEE Transactions on Engineering Management, 37.*

Pisano, G.P. 1994. Knowledge, integration, and the locus of learning: an empirical analysis of process development. *Strategic Management Journal 15 (Special Issue), 85-100.*

Polany, M. 1958. Personal knowledge. *The University of Chicago Press*

Polanyi, M. 1962. Personal knowledge: towards a post-critical philosophy. *London: Routledge & Kegan Paul.*

Polany, M. 1966. The tacit dimension. *Routledge & Kegan Paul, London*

Porter, M. E. 1980. Competitive Strategy. *Free Press: New York.*

Porter, M. E 1983. The technological dimension of competitive strategy, in: R.A. Burgelman, M.A. Maidique (Eds.), *Strategic Management of Technology and Innovation, Richard D. Irwin, Homewood, IL, 1983, pp. 211–233.*

Quinn, J.B.1985. Managing innovation: Controlled chaos, *Harvard Business Review 63 (3), 73–84.*

Ragatz, G., Handfield, B. & Scannell, T. 1997. Success Factors for Integrating Suppliers into New Product Development, *Journal Product Innovation Management; 14, 190 –202.*

Rogers, E. 1983. The diffusion of innovation. *New York: Free Press.*

Rubenstein - Montano, B., Liebowitz J. 2001. A system thinking framework for knowledge management. *Decision Support Systems 31, 5 - 16*

Ruggles, R. 1998. The state of the notion: knowledge management in practice. *California Management Review 40 (3), 80-89.*

Sarvary, M.1999. Knowledge management and competition in the consulting industry. *California Management Review 41 (2), 95–107.*

Schumpeter, J. A.1942. Capitalism, Socialism and Democracy, *Harper & Row, New York*

Shin, M., Holden, T. & Schmidt R. A. 2001. From knowledge theory to management practice: towards an integrated approach. *Information Processing & Management Volume 37, Pages 335-355.*

Simpson, C.W., Prusak L. 1995. Troubles with information overload-moving from quantity to quality in information provision. *International Journal of Information Management 15, 413-42.*

Singer, L.P. 1981. Supply decisions of professional artists. *The American Economic Review, 71 (2), 341±347. 71, 341-347.*

Slater, S.F., Narver, J.C. 1995. Market orientation and the learning organization. *Journal of Marketing, 59, 63 – 67.*

Spender, J.C. 1994. Organizational knowledge collective practice and Penrosian rents. *International Business Review 3, 353-367.*

Spender, J.C. 1996. Organizational knowledge learning and memory: three concepts in search of a theory. *Journal of Organizational Change Management 9, 63-78.*

Spender, J.C., Grant, R.M., 1996. Knowledge of the firm: overview. *Strategic Management Journal 17, 45 - 62.*

Stasser, G., Stewart, D.D. & Wittenbaum, G.M., 1995. Expert roles and information exchange during discussion: the importance of knowing who knows what. *Journal of Experimental Social Psychology 31, 244–265.*

Stopford, J.M. 1995. Competing globally for resources. Transnational Corporation 4, 34-57.

Strauss, AL. 1987. Qualitative Analysis for Social Scientists. *Cambridge University Press: New York.*

Sveiby, K.E. 1999. Intellectual capital and knowledge management. *Sveiby Knowledge Management, URL:http:// www.sveiby.com.au*

Szulanski, G., 1996. Exploring internal stickiness: impediments to the transfer of best practice within the firm. *Strategic Management Journal 17 (Summer special issue), 27–43.*

Takeuchi, H. 1998. Beyond knowledge management: lessons from Japan. *Sveiby Knowledge Management, URL:http:// www.sveiby.com.au/LessonsJapan.htm*

Taylor, R.N. 1994. Behavioral decision making. *Glenview, IL: Scott and Foresman.*

Teece, D. 1976. The Multinational Corporation and the Resource Cost of International Technology Transfer. *Ballinger, Cambridge, MA.*

Teece, D. 1977. Technology transfer by multinational firms: the resource cost of transferring technological know-how. *The Economic Journal 87, 242–261.*

Teece, D. 1990. Dynamic Capabilities and Strategic Management, *UC Berkley*

Teece, D. 1992. Competition, cooperation, and innovation: organizational arrangement for regimes of rapid technological progress. *Journal of Economic Behavior and organization 18, 1–25.*

Teece, D., Pisano, G. & Shuen, A. 1997. Dynamic capabilities and strategic management. *Strategic Management Journal* 18 (7): 509–533.

Teece, D., 2000. Strategies for managing knowledge assets: the role of firm structure and industrial context. *Long Rang Planning 33, 35–54.*

Teece, D. 2000. Managing Intellectual Capital, *Oxford University Press, Oxford*

Tenkasi, R.V., Boland R.J. 1996. Exploring knowledge diversity in knowledge intensive firms, a new role for information systems. *Journal of Organizational Change Management 9, 79-91.*

Tidd, J., Bessant, J. & Pavitt, K. 2001. Managing Innovation. Integrating Technological, Market and Organizational Change, *second ed., Wiley, Chichester.*

Todd, P., Benbast, I. 1991. An experimental investigation of the impact of computer-based decision aids on decision making strategies. *Information Systems Research 2, 87-115.*

Thomke, S., Fujimoto, T. 2000. The Effect of "Front-Loading" Problem-Solving on Product Development Performance. *Journal Product Innovation Management 2000,17: 122-142.*

Tsoukas, H. 1996. The firm as a distributed knowledge system: a constructionist approach. *Strategic Management Journal 17 Winter Special Issue, 11-25.*

Tushman, M.L., Anderson P. 1997. Managing Strategic Innovation and Change: A Collection of Readings, *Oxford Univ. Press, Oxford, 1997.*

Tushman, M.L., O'Reilly III C.A. 1997. Winning Through Innovation, *Harvard Business School Press, Boston. MA, 1997.*

Twiss, B. 1986. Managing Technological Innovation, third ed*., Pitman Publishing, London.*

Ulrich, D. 1998. Intellectual Capital = Competence. Commitment. *Sloan Management Review (Winter), 15–26.*

Vernon, R., 1966. International investment and international trade in the product life cycle. *Quarterly Journal of Economics 80, 190–207.*

Vincenti, W. 1993. What Engineers Know and How They Know It, *The John Hopkins University Press.*

Walsh, J.P., Ungson G.R. 1991.Organizational memory. *Academy of Management Review 16, 57-91.*

Ward, A., Liker J., Cristiano J., & Sobek D. 1995. "The Second Toyota Paradox," *Sloan Management Review, volume 36, pp. 43-61.*

Ward, A., Liker J., Cristiano J., & Sobek D. 1998. "Another Look at How Toyota Integrates Product Development", *Harvard Business Review, July – August pp. 36-49.*

Ward, A., Liker J., Cristiano J. & Sobek D.1999."Toyota's principles of set-based concurrent engineering " *Sloan Management Review, volume 40, pp. 60 - 100.*

Wegner, D.M. 1987. Transactive memory: a contemporary analysis of the group mind. *New York: Springer Verlag, pp 185 - 208*

Weick, K.E.1979. The Social Psychology of Organizing. *Random House, New York.*

Weick, K.E., Roberts K.H.1993. Collective mind in organizations-heedful interrelating on flight decks. *Administrative Science Quarterly 38, 357-381.*

Whiting, R. 1999. Myths & realities. *Informationweek 762, 42-54.*

Williamson, O.E. 1971. The vertical integration of production: market failure considerations. *The American Economic Review: Papers and Proceeding 61, 12-123.*

Willmann, P. 1991. Bureaucracy, innovation and appropability. ESCR Industrial Economics Study Group Conference, *London Business School, November.*

Wheelwright, S., Clark, K., 1992. Revolutionizing Product Development, *The Free Press, New York.*

Winter, S.G. 1987. Knowledge and competence as strategic assets. J. Teece (Ed.), The competitive challenge: strategies for industrial innovation and renewal pp. 159±184). *Cambridge, MA: Ballinger.*

Yin, R. 1994. Case Study Research: Design and Methods, *Sage Publications, Thousand Oaks, CA 1994*

Zack, M.H. 1999. Managing codified knowledge. Sloan Management Review, 40, 45-58.

Zander, U., Kogut B. 1995. Knowledge and the speed of transfer and imitation of organizational capabilities: an empirical test. *Organization Science 6, 76-92.*

Zeleny, M. 1987. Management support systems. *Human Systems Management 7, 59-70.*

Zorn, P. 1997. Surfing corporate intranets: search tools that control the undertow. *Online 21, 30-51.*

6. Appendix one:

Project one - data analysis of interviews, main codes, sub-codes and categories

Research question for project one:

What supports knowledge transfer in product development teams?

Level of Analysis: Teams

Unit of Analysis: Knowledge transfer process

Appendix one – project one

Interview questions to analyse the knowledge transfer process between product development teams:

1. In what ways was knowledge transferred between engineering team and product simulation team during the vehicle development process?
2. What influenced the transfer of knowledge during the project?
3. Were there different types of knowledge that were transferred?
4. Were there any types of knowledge that could not be transferred?
5. How did the knowledge groupings differ from those that that could not be transferred?
6. Was this knowledge transferred within the product development group, between the product simulation groups, or between both groups?
7. What type of knowledge was transferred between your engineering group and the other engineering group?
8. Does the transfer of knowledge within your group differ from that transferred between the different functional engineering groups?
9. Was there anything about the project structure that hindered the transfer of knowledge?

With these interview questions, I tried to identify a pattern of relationship, to explain and describe, how engineers engaged in the project track the knowledge transfer process of a new product development activity. The main issue, is to identify the enablers and inhibitors of knowledge transfer, so therefore the main categories are divided in positive influencing factors of knowledge transfer (enablers) and negative influencing factors of knowledge transfer (inhibitors) of knowledge transfer. To identify patterns of relationships, I identified main codes, which are assembled out of several sub-codes based on their relatives to the main codes. On following page, we see an overview of significant codes and sub-codes and categories of the knowledge transfer activities in project one.

6. Appendix one: project one data analysis of interviews, main codes, sub-codes and categories

Table: Main - Codes and categories

Main - Codes to build categories	**Sub - Codes**	**Categories**	**Frequency of occurrence [%]**
C1 Transfer methods	C 1.1 IT infrastructure, C 1.2 Network CAD – CAE → CAx world C 1.3 Storage and retrieve of project data's in CAx world C 1.4 CAD data, CATIA files C 1.5 Lotus notes, for meetings schedule and short memos C 1.6 Intranet C 1.7 DMU – Component matrix C 1.8 Phone C 1.9 Reports provided C 1. 10 Design reviews C 1. 11 Technical specification for quality standards	E	16.4
C2 Personal communication channel	C 2.1 Face-to-face C 2.2 Shoulder-to-shoulder working processes C 2.3 Creation of knowledge patterns	E	12.4
C 3 Personal knowledge sharing	C 3.1 Individual expertise provided to group C 3.2 Proactive – willingness to transfer and share individual knowledge	E	11.6
C4 Group knowledge sharing	C 4.1 Teams C 4.2 Relationship C 4.3 Creation of Knowledge groups	E	14.4

Continuous table: Main - Codes and categories

Main - Codes to build categories	**Sub - Codes**	**Categories**	**Frequency of occurrence [%]**
C5 Barriers of knowledge transfer	C 5.1 Functional knowledge stick in silos C 5.2 Unawareness of valuable knowledge C 5.3 Difficult to articulate C 5.4 Uncertainty	I	24.8
C 6 Explicit knowledge transfer	C 6.1 Project structure C 6.2 Communication channels C 6.3 Categories and Standardisation of knowledge groups C 6.4 Routines	E	15.2
C7 Economical constraints	C 7.1 Time C 7.2 Financial resources	I	5.2

Example, how to build codes and categories:

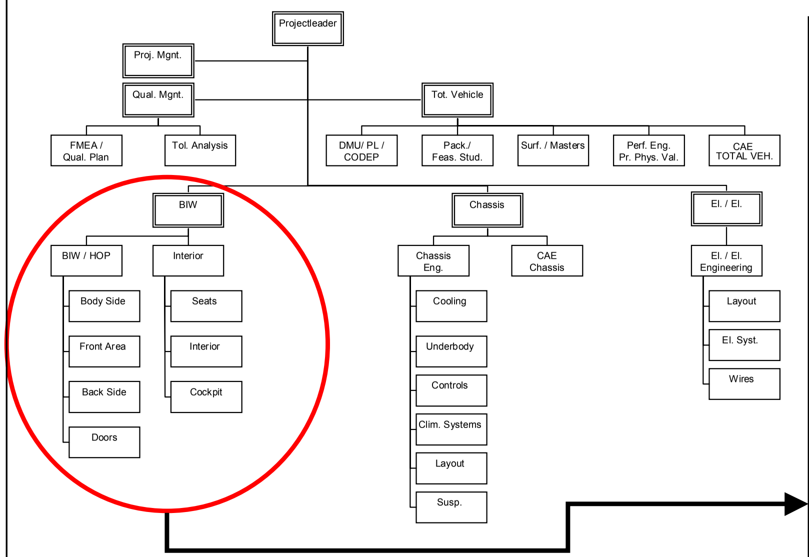
Question 1:
In what ways was knowledge transferred between engineering team and product simulation team during the vehicle development process?

Interviewees Statements	Codes	Categories
Regular design reviews weekly **(C 1.10),** with PM & TL and OEM, to discuss and track the project outcome. In small teams problem solving was very much achieved in shoulder-to-shoulder working processes. **(C 2.2)**	C 2.1 Face-to-face **C 2.2 Shoulder-to-shoulder working processes** C 2.3 Creation of knowledge patterns	Enabler
	C 1.1 IT infrastructure, C 1.2 Network CAD – CAE → CAx world C 1.3 Storage and retrieve of project data's in CAx world C 1.4 CAD data, CATIA files C 1.5 Lotus notes, for meetings schedule and short memos C 1.6 Intranet C 1.7 DMU – Component matrix C 1.8 Phone C 1.9 Reports provided **C 1. 10 Design reviews** C 1. 11 Technical specification for quality standards	

Main Code → C 2 Personally communication channel; Sub Code C 2.2 Shoulder to shoulder working processes

Out of the interviewee's statements, I collected the sub-codes and took them into relation to the main codes.
To calculate the frequency of occurrence, the main code is the basis, because the sub-codes belong to the main code and defined category/ It was helpful to group different interviewee statements into a main code, which interprets the opinion of the interviewee and his perception about the ongoing process.

Organisational chart : Complete vehicle engineering – project one

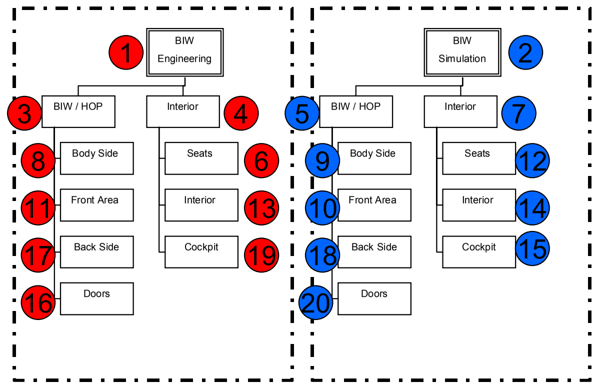


Identification of informants to create a balanced picture of the research phenomenon

The participants were engineers engaged in a prior vehicle development project, and were members of the product engineering and product simulation team.
All 20 engineers are very experienced and in leadership positions.
During this vehicle development process, the work experience of the engineers was, on average, more than ten years.

Unit of analysis: Knowledge transfer process

Knowledge transfer between product development teams



Product Engineering Team **Product Simulation Team**

6. Appendix one: project one data analysis of interviews, main codes, sub-codes and categories

Example : building of codes and categories

Question 1:
In what ways was knowledge transferred between engineering team and product simulation team during the vehicle development process?

	Interviewee Statements	Main code	Sub Codes	Categories
Interview 17 TL Back side Engineering	CAx world – digitised knowledge transfer Lotus notes, Word, Excel, Power point PDM Tools DMU – Component matrix Part lists Technical Specifications **C1**	**C1 Transfer methods** C 1.1 IT infrastructure, C 1.2 Network CAD – CAE → CAx world C 1.3 Storage and retrieve of project data's in CAx world C 1.4 CAD data, CATIA files, C 1.5 Lotus notes, for meetings schedule and short memos C 1.6 Intranet C 1.7 DMU – Component matrix C 1.8 Phone C 1.9 Reports provided C 1. 10 Design reviews C 1. 11 Technical specification for quality standards		Enablers

6. Appendix one: project one data analysis of interviews, main codes, sub-codes and categories

Example : building of codes and categories

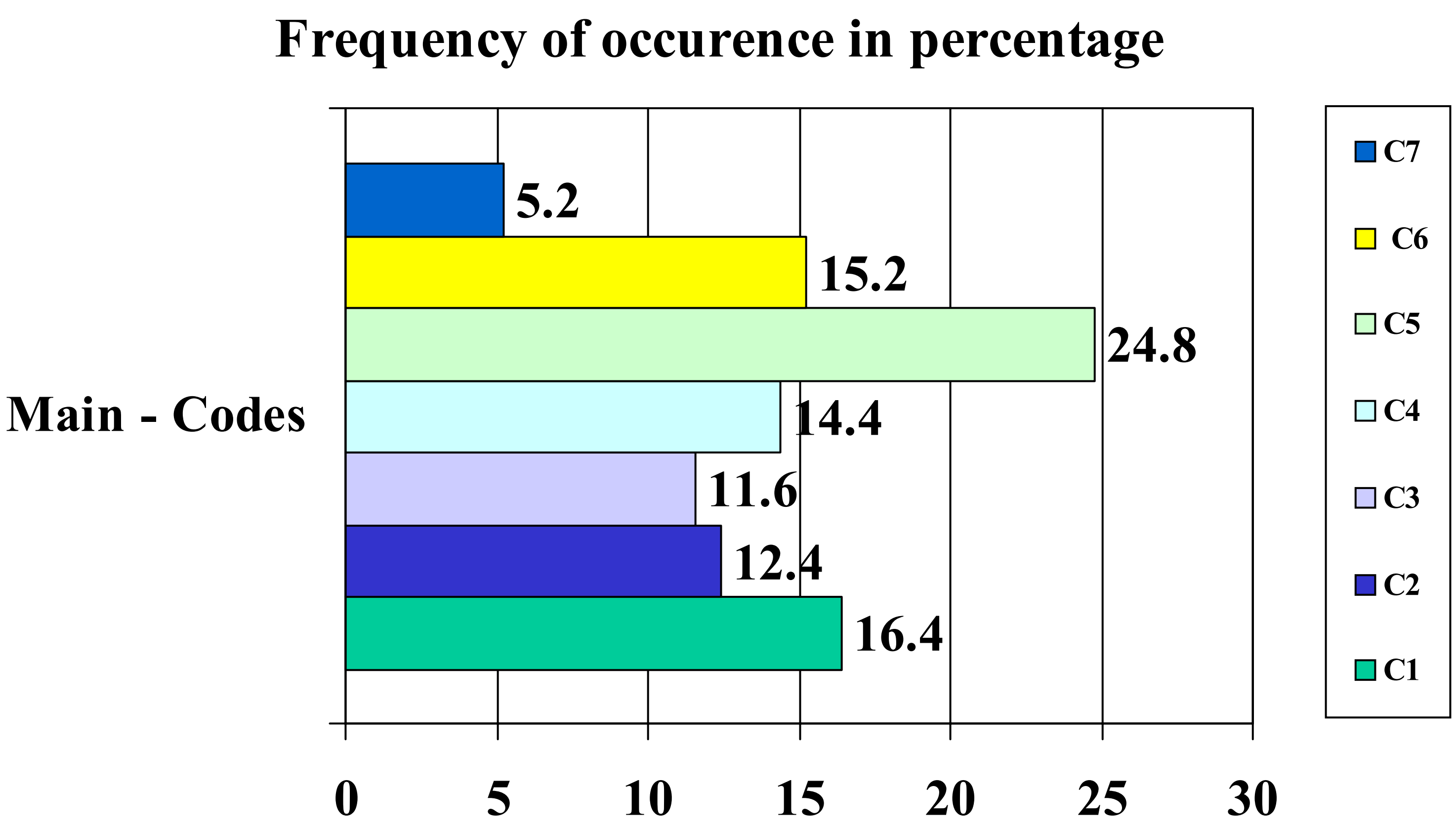
Question 2:
What influenced the transfer of knowledge during the project?

	Interviewee Statements	Main code / Sub Codes	Categories
Interview 3 PM BIW HOP Engineering	The project organisation is internal good aligned between the engineering service teams (C4), the processes with the OEM are to rigid, the activities are to much divided into functional departments (C5.1), people have problems to define, where the right source of knowledge is available (C5.2).	**C4 Group knowledge sharing** C 4.1 Teams C 4.2 Relationship C 4.3 Creation of Knowledge groups	Enablers
		C5 Barriers of knowledge transfer C 5.1 Functional knowledge stick in silos C 5.2 Unawareness of valuable knowledge C 5.3 Difficult to articulate C 5.4 Uncertainty	Inhibitors
Interview 4 PM Interior Engineering	Failure avoiding culture, targets from OEM, we perform as requested and under strong financial control. (C7)	**C7 Economical constraints** C 7.1 Time C 7.2 Financial resources	Inhibitors
Interview 5 PM BIW HOP Simulation	Team communication Understanding and creation of a common understanding creates the ability to work effective on a cross functional basis, for example from Styling Concept down to manufacturing	**C4 Group knowledge sharing** C 4.1 Teams C 4.2 Relationship C 4.3 Creation of Knowledge groups	Enablers

Overall Results: Frequency of occurrence

Main - Codes	Categories	Frequency of occurrence	Frequency of occurrence [%]
C1	E	41	16.4
C2	E	31	12.4
C3	E	29	11.6
C4	E	36	14.4
C5	I	62	24.8
C6	E	38	15.2
C7	I	13	5.2
		250	100 %

Overall Results as Chart on following page


Frequency of occurence in percentage
Main - Codes
5.2
15.2
24.8
14.4
11.6
12.4
16.4
0
5
10
15
20
25
30
C7
C6
C5
C4
C3
C2
C1

7. Appendix two

Appendix two: project two data analysis of interviews, main codes, sub-codes and categories

Research question for project two:

What enables and supports knowledge transfer between business units?

Level of Analysis: Product development teams

Unit of Analysis: Knowledge transfer process

7. Appendix two: project two data analysis of interviews, main codes, sub-codes and categories

Appendix two – project two

Interview questions to analyse the knowledge transfer process between business units:

1. In what ways was knowledge transferred between business unit one and business unit two?
2. How is relevant knowledge, produced in the business units, made available to those units that need it?
3. What is the way of communication between those units which need the knowledge and those units who posses the knowledge?
4. Were there different types of knowledge that were transferred between the business units?
5. Were there any types of knowledge that could not be transferred between the business units?
6. Was there anything about the organisational structure that hindered the transfer of knowledge between the business units?

To identify patterns of relationships, I identified main codes, which are assembled out of several sub-codes based on their relationship to the main codes. On following page, there is an overview of significant codes and sub-codes and categories of the knowledge transfer activities in project two.

7. Appendix two: project two data analysis of interviews, main codes, sub-codes and categories

Table: Main - Codes and categories

Main - Codes to build categories	**Sub - Codes**	**Categories**	**Frequency of occurrence [%]**
C1 Core process of knowledge transfer	C 1.1 Identifying knowledge C 1.2 Assessing knowledge C 1.3 Collecting knowledge C 1.4 Combining knowledge	E	14.8
C2 Transfer methods	C 2.1 Management Meeting C 2.2 Video Conferences C 2.3 Intranet C 2.4 Lotus Notes - E- Mail C 2.5 Cad Files C 2.6 Phone, Memos C 2.7 CAx World	E	7.4
C3 Personal communication channel	C 3.1 Face-to-face C 3.2 Personal engagement	E	11.1
C4 Wrong media	C 4 Wrong media to transfer knowledge	I	3.7
C5 Personal knowledge sharing	C 5.1 Individual expertise provided to group C 5.2 Proactive – willingness to transfer	E	8.3
C6 Receiver reproduction	C 6.1 Transfer does not automatically create replication	I	6.5

Continuous table: Main - Codes and categories

Main - Codes to build categories	**Sub - Codes**	**Categories**	**Frequency of occurrence [%]**
C7 Sender receiver exchange	C 7.1 Sender / Receiver Interdependence C 7.2 Frequency of transfer	E	12
C8 Group knowledge sharing	C 8.1 Teams C 8.2 Relationship	E	9.3
C9 Barriers of knowledge transfer	C 9.1 Functional knowledge stick in silos C 9.2 Unawareness of valuable knowledge C 9.3 Difficult to articulate C 9.4 Uncertainty	I	11.1
C10 Explicit knowledge transfer	C 10.1 Project structure C 10.2 Communication channels C 10.3 Categories and Standardisation C 10.4 Routines	E	10.2
C11 Economical constraints	C 11.1 Time C 11.2 Financial resources	I	5.6

As we see in the table above, I used the transcription of interviews, to identify the main codes and sub-codes, and classify them into categories. This allowed me to identify the importance of enablers and inhibitors by the role they played during the project and why they were perceived by engineers as more or less important in the knowledge transfer process.

7. Appendix two: project two data analysis of interviews, main codes, sub-codes and categories

Example, how to build codes and categories

Question 1:
In what ways was knowledge transferred between business unit one and business unit two?

Interviewees Statements	Codes	Categories
Several management meetings (C2.1) are essential in order to determine the expertise possessed in the business units and to align resources to project objectives. In this phase, we found out, how difficult it is to reapply team and individuals knowledge at distance. Time consuming (C11.1) co-ordination of management meetings, taking into account that many key players are engaged in several projects of their parenting unit as well. Also financial resources put an upper limit, (C11.2) on what you can expect from the knowledge transfer processes. Management Meetings, face-to-face meetings, are perceived as one of the strongest activities to transfer expertise, but to create a knowledge flow based only on face-to-face contact, would increase the project costs to a level, no one likes to pay. (C11.2)	**C 11 Economical constraints** C 11.1 Time C 11.2 Financial resources	Inhibitor
Articulated knowledge, for example techn. spec. , is very effective provided to all team members by e-mail (C2.4), phone (C2.6), CAD files (C2.5), Intranet (C2.3), Memos (C2.6) and CAx world (C2.7)	**C2: Communication Channels** C 2.1 Management Meeting C 2.2 Video Conferences C 2.3 Intranet C 2.4 Lotus Notes - E- Mail C 2.5 Cad Files C 2.6 Phone, Memos C 2.7 CAx World	Enabler

Main Code → C11 Economical constraints:

Main Code is economical constraints, we know that knowledge transfer is not cost free, especially if we talk about, face-to-face meetings, and management meetings, travel expenses. We can see that transaction costs are a clear constraint for knowledge transfer.
A profound study, is D. Teece, The Multinational Corporation and the Resource Cost of International Technology Transfer, Ballinger, Cambridge, MA (1976).
Out of the interviewee's statements, I collected the sub-codes and took them into relation to the main codes.

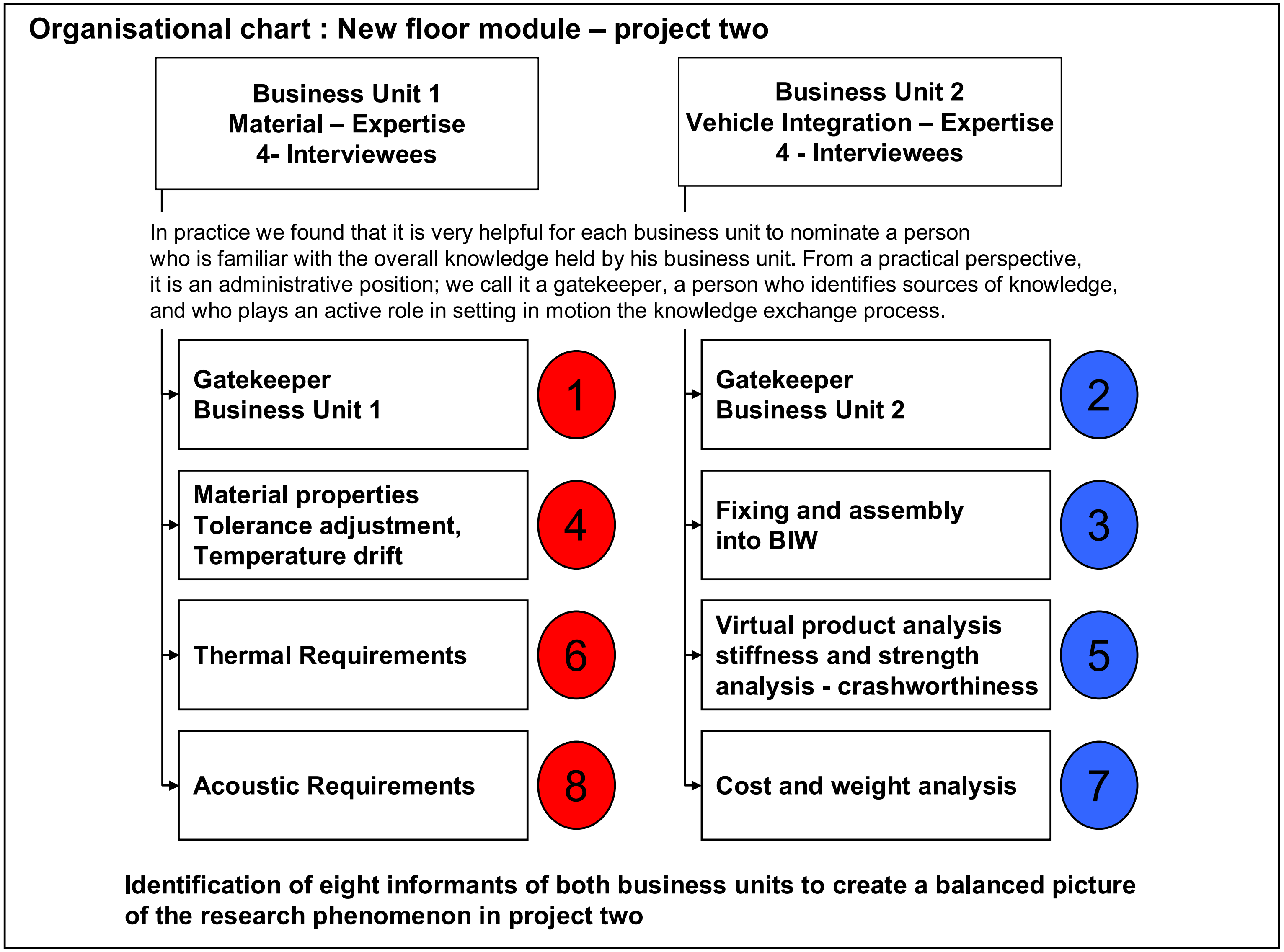
7. Appendix two: project two data analysis of interviews, main codes, sub-codes and categories

Continuous example, how to build codes and categories

Interviewees Statements
Several management meetings (C2.1) are essential in order to determine the expertise possessed in the business units and to align resources to project objectives. In this phase, we found out, how difficult it is to reapply team and individuals knowledge at distance. Time consuming (C11.1) co-ordination of management meetings, taking into account that many key players are engaged in several projects of their parenting unit as well. Also financial resources put an upper limit, (C11.2) on what you can expect from the knowledge transfer processes. Management Meetings, face-to-face meetings, are perceived as one of the strongest activities to transfer expertise, but to create a knowledge flow based only on face-to-face contact, would increase the project costs to a level, no one likes to pay. (C11.2)

Main - Code	**Sub-codes**	**Categories**
	C 11.1 Time	
C 11 Economical constraints		**Inhibitor**
	C 11.2 Financial resources	

To calculate the frequency of occurrence, the main code is the basis, because the sub-codes belong to the main code and defined category. It helped to put different interviewee statements, into a main code, which interprets the opinion of the interviewee regarding the ongoing process.


Organisational chart : New floor module – project two
Business Unit 1
Material – Expertise
4- Interviewees
Business Unit 2
Vehicle Integration – Expertise
4 - Interviewees
In practice we found that it is very helpful for each business unit to nominate a person who is familiar with the overall knowledge held by his business unit. From a practical perspective, it is an administrative position; we call it a gatekeeper, a person who identifies sources of knowledge, and who plays an active role in setting in motion the knowledge exchange process.
Gatekeeper
Business Unit 1
1
Material properties
Tolerance adjustment,
Temperature drift
4
Thermal Requirements
6
Acoustic Requirements
8
Gatekeeper
Business Unit 2
2
Fixing and assembly
into BIW
3
Virtual product analysis
stiffness and strength
analysis - crashworthiness
5
Cost and weight analysis
7
Identification of eight informants of both business units to create a balanced picture of the research phenomenon in project two

7. Appendix two: project two data analysis of interviews, main codes, sub-codes and categories

Example, how to build codes and categories

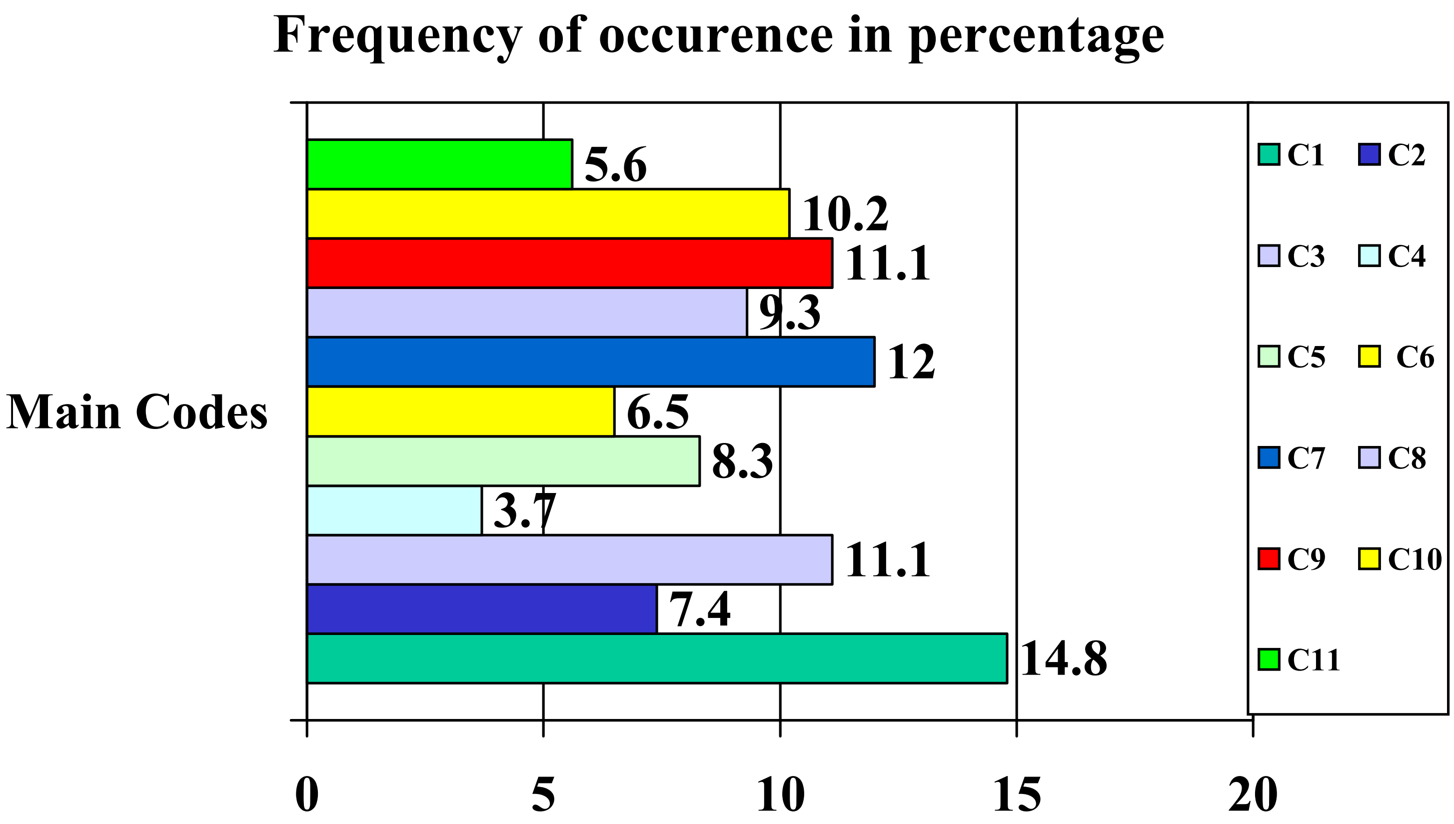
Question 1:
In what ways was knowledge transferred between business unit one and business unit two?

	Interviewee Statements	Main code / Sub Codes	Categories
Interview 5 – unit 2	Scheduled Business Meetings – Face to Face (C 3.1) meetings, Relationship between teams (C 8.2) played a great role, networks between business units, was emerging during the project.	**C3 Personally communication channel** C 3.1 Face to face C 3.2 Personally engagement	Enablers
Interview 5 – unit 2	Knowledge transfer relies on rules, forms, procedures and databases. (C 10.4 = C 10.1).	**C10 Explicit knowledge transfer** C 10.1 Project structure C 10.2 Communication channels C 10.3 Categories and Standardisation C 10.4 Routines	Enablers
Interview 6 – unit 1	Real design knowledge, which integrates a high portion of tacit and informal knowledge, and is transferred mainly by face-to-face (C 3.1) interactions.	**C3 Personally communication channel** C 3.1 Face to face C 3.2 Personally engagement	Enabler
Interview 7 – unit 2	Sharing of design specific knowledge, is very difficult, if the context of knowledge differs very much between the business (C9.2) units and for the reason hardly understood by the receiving participates (C 9.3)	**C9 Barriers of knowledge transfer** C 9.1 Functional knowledge stick in silos C 9.2 Unawareness of valuable knowledge C 9.3 Difficult to articulate C 9.4 Uncertainty	Inhibitor

Overall Results

Main - Codes	Categories	Frequency of occurrence	Frequency of occurrence [%]
C1	E	16	14.8
C2	E	8	7.4
C3	E	12	11.1
C4	I	4	3.7
C5	E	9	8.3
C6	I	7	6.5
C7	E	13	12
C8	E	10	9.3
C9	I	12	11.1
C10	E	11	10.2
C11	I	6	5.6
		108	100 %

Overall Results as Chart on following page

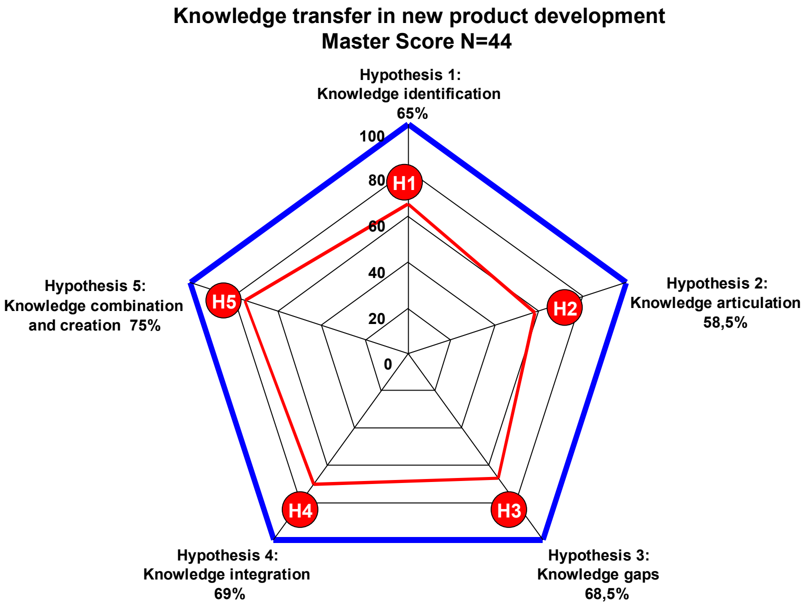

Frequency of occurence in percentage
Main Codes
5.6
10.2
11.1
9.3
12
6.5
8.3
3.7
11.1
7.4
14.8
0
5
10
15
20
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C11

8. Appendix three - project three

Survey results; Master Score N=44

To represent the master score, I used a *"spidergram",* which is an effective method of compiling a performance profile based on empirical data. The red line in the figure below graphically represents the achieved results of the survey. The blue line in contrast, is indicative of the maximum performance, which organisations can achieve with respect to the five hypotheses, which were tested in the survey.

Result Master Score N = 44 Knowledge transfer in new product development



Knowledge transfer in new product development	Achieved [%]	Maximum [%]	Gap [%]
Hypothesis 1: Knowledge identification	65	100	35
Hypothesis 2: Knowledge articulation	58,5	100	41,5
Hypothesis 3: Knowledge gaps	68,5	100	31,5
Hypothesis 4: Knowledge integration	69	100	31
Hypothesis 5: Knowledge combination and creation	74,75	100	25,25

The size of the performance gap is indicated by the difference between the red and blue line. A more detailed view of achieved vs. potential of knowledge transfer is represented in following table: Results hypothesis one to five and performance gaps.

Table: Results hypothesis one to five and performance gaps

Survey Results: Hypothesis 1 – 5 knowledge transfer in new product development	**EDF N=23 [%]**	**Magna Engineering centre MEC N=21 [%]**	**Delta EDF vs. MEC [% Δ]**	**Master Score N=44 [%]**	**Maximum Result [%]**	**Master Gap N=44 [%]**
Hypothesis 1: Knowledge identification	63	67	4	65	100	35
Hypothesis 2: Knowledge articulation	56	61	5	58.5	100	41.5
Hypothesis 3: Knowledge gaps	67	70	3	68.5	100	31.5
Hypothesis 4: Knowledge integration	70	68	2	69	100	31
Hypothesis 5: Knowledge combination and creation	76	73.5	2,5	74.75	100	25.25
Knowledge embedded in the tacit design domain	36	40	4	82		
Knowledge embedded in the explicit design domain	82	82	0	38		

As the table above illustrates, the primary performance gap in knowledge transfer relates to knowledge articulation and knowledge identification. The secondary performance gaps are in knowledge integration and knowledge combination and creation. Notably, there are knowledge gaps related to knowledge identification and knowledge articulation, but these are not perceived as such a strong performance gap as identification and articulation.

It is also important to analyse the nature of knowledge that is transferred. Is it tacit or explicit design knowledge and what interdependence does the nature of knowledge create in relation to identified performance gaps? The survey results and analysis of the interdependence and independence of identified performance gaps are provided on following pages. All survey results are tested to secure reliability with one sample statistic test, correlations and partial correlation analysis, using the statistic software package SPSS 9.0 for windows.

Results: Master score N=44; Knowledge identification, Descriptive statistics
Statements S1-S25, N=44, Minimum, Maximum, Mean and Standard deviation

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
S1	44	.00	4.00	2.5227	.8488
S2	44	1.00	4.00	2.4091	.7256
S3	44	1.00	4.00	2.9773	1.0227
S4	44	1.00	4.00	2.5455	.7911
S5	44	.00	4.00	1.7500	.9675
S6	44	1.00	4.00	2.3864	.7538
S7	44	.00	3.00	1.2273	.8856
S8	44	2.00	4.00	3.3182	.6388
S9	44	1.00	4.00	3.0455	.8880
S10	44	.00	4.00	2.7045	.7947
S11	44	2.00	4.00	3.0000	.6820
S12	44	1.00	4.00	2.5455	.8478
S13	44	1.00	4.00	2.5227	.9273
S14	44	2.00	4.00	3.0909	.5631
S15	44	1.00	4.00	2.8409	.6078
s16	44	1.00	4.00	2.5227	.9997
S17	44	.00	4.00	3.0682	.7594
S18	44	1.00	4.00	2.9773	.7310
S19	44	1.00	4.00	2.3182	1.0949
S20	44	.00	4.00	1.5227	.8209
S21	44	2.00	4.00	3.2727	.6599
S22	44	2.00	4.00	3.2273	.6773
S23	44	1.00	4.00	2.9545	.7457
S24	44	1.00	4.00	2.7727	1.0084
S25	44	1.00	4.00	3.0227	.8209
Valid N (listwise)	44				

The table above controls the summary statistic displayed for the selected data column variable Statements S1-S25. Available summary statistics are sum, mean, minimum, maximum and number of cases.

With the One-Sample T-Test procedure, I test how much of each variable S1-S25 differs from the average of all variables 2, 66182 of the survey at the 95% confidence level.

For each test variable is in following table: mean, standard deviation, and standard error of the mean calculated. The average difference between each data value and the hypothesized test value 2, 66182, is by the One-Sample T-Test, that tests this difference is 0.

One-Sample Test

	Test Value = 2.66182					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
VAR00001	-1.087	43	.283	-.1391	-.3971	.1190
VAR00002	-2.311	43	.026	-.2527	-.4733	-3.21E-02
VAR00003	2.046	43	.047	.3155	4.513E-03	.6264
VAR00004	-.976	43	.335	-.1164	-.3569	.1241
VAR00005	-6.252	43	.000	-.9118	-1.2060	-.6177
VAR00006	-2.424	43	.020	-.2755	-.5046	-4.63E-02
VAR00007	-10.744	43	.000	-1.4345	-1.7038	-1.1653
VAR00008	6.816	43	.000	.6564	.4622	.8506
VAR00009	2.866	43	.006	.3836	.1137	.6536
VAR00010	.357	43	.723	4.273E-02	-.1989	.2843
VAR00011	3.289	43	.002	.3382	.1308	.5455
VAR00012	-.910	43	.368	-.1164	-.3741	.1414
VAR00013	-.995	43	.325	-.1391	-.4210	.1428
VAR00014	5.054	43	.000	.4291	.2579	.6003
VAR00015	1.954	43	.057	.1791	-5.71E-03	.3639
VAR00016	-.923	43	.361	-.1391	-.4430	.1649
VAR00017	3.550	43	.001	.4064	.1755	.6372
VAR00018	2.863	43	.006	.3155	9.321E-02	.5377
VAR00019	-2.082	43	.043	-.3436	-.6765	-1.08E-02
VAR00020	-9.204	43	.000	-1.1391	-1.3887	-.8895
VAR00021	6.140	43	.000	.6109	.4103	.8115
VAR00022	5.538	43	.000	.5655	.3595	.7714
VAR00023	2.604	43	.013	.2927	6.602E-02	.5194
VAR00024	.730	43	.470	.1109	-.1957	.4175
VAR00025	2.916	43	.006	.3609	.1113	.6105

As an outcome of one sample T- test, we see that statement S5, S7 and S 20 produce a great delta to the average mean 2, 66182 of the survey result.

	Statements	Score N= 44 [%]	Score Mean N=44	Survey Mean N=44
S5	New engineers can easily learn this know-how by studying a complete set of technical specifications, documents or plans.	44	1.7500	2.66182
S7	Educating and training new engineers regarding this know how is a quick and easy job	30	1.2273	2.66182
S20	The knowledge, which I use to solve design tasks is embedded and collected out of technical description, technical specification and specific literature.	38	1.5227	2.66182

All three statements differ from statistical perspective to the average score with a high delta, but from the survey result there is nothing wrong with the low degree of agreement with this two statements. Based on my previous research finding, I did expect a high agreement with this statement.

To test the significance and the direction of association, I used a two-tailed Pearson correlation analysis. Correlation coefficients range in value from -1 (a perfect negative relationship) and +1 (a perfect positive relationship). A value of 0 indicates no linear relationship. Correlation coefficients significant at the 0.05 level are identified with a single asterisk, and those significant at the 0.01 level are identified with two asterisks.

Results hypothesis 1: Master score N=44; Knowledge identification

Results: Knowledge identification			Master Score N= 44 [%]	Hypothesis Mean [%]	Note
Hypothesis 1: Knowledge identification	**S1**	It is uncomplicated for the receiver to identify source personnel who could help them reconfigure and implement requested design expertise.	63	65	
	S2	It is uncomplicated for the receiver to identify the source personnel to spot necessary design requirements and understand the technologies related to this expertise.	60		
	S3	It is uncomplicated for the receiver to identify which tools (CAE; CAD) to use to perform design tasks on provided knowledge.	74		
	S4	It is easy for the receiver to locate and extract the information needed to understand design relevant expertise.	64		

Correlations

		VAR00001	VAR00002	VAR00003	VAR00004
VAR00001	Pearson Correlation	1.000	.513**	.202	.431**
	Sig. (2-tailed)	.	.000	.190	.003
	N	44	44	44	44
VAR00002	Pearson Correlation	.513**	1.000	.170	.413**
	Sig. (2-tailed)	.000	.	.271	.005
	N	44	44	44	44
VAR00003	Pearson Correlation	.202	.170	1.000	.389**
	Sig. (2-tailed)	.190	.271	.	.009
	N	44	44	44	44
VAR00004	Pearson Correlation	.431**	.413**	.389**	1.000
	Sig. (2-tailed)	.003	.005	.009	.
	N	44	44	44	44

**. Correlation is significant at the 0.01 level (2-tailed).

Results: Correlation analysis hypothesis 1			**C1**	**C2**	**C3**	**C4**
Hypothesis 1: Knowledge identification	**S1**	It is uncomplicated for the receiver to identify source personnel who could help them reconfigure and implement requested design expertise.	**0.513 0,000 44	**0.413 0.003 44		
	S2	It is uncomplicated for the receiver to identify the source personnel to spot necessary design requirements and understand the technologies related to this expertise.	**0.513 0.000 44		**0.413 0.005 44	
	S3	It is uncomplicated for the receiver to identify which tools (CAE; CAD) to use to perform design tasks on provided knowledge.				**0.389 0.009 44
	S4	It is easy for the receiver to locate and extract the information needed to understand design relevant expertise.		**0.413 0.003 44	**0.413 0.005 44	**0.389 0.009 44

Results hypothesis 2: Master score N=44; Knowledge articulation

Results: Knowledge articulation			Master Score N= 44 [%]	Hypothesis Mean [%]	Note
Hypothesis 2: Knowledge articulation	**S5**	New engineers can easily learn this know how by studying a complete set of technical specifications, documents or plans.	44	58.5	
	S6	New engineers can easily learn this know-how by talking to experienced personnel	60		
	S7	Educating and training new engineers regarding this know-how is a quick and easy job	30		
	S8	The engineering tasks require that personnel have long experience in this industry sector to achieve high product development performance	83		
	S9	The engineering tasks require that new engineers have to work with experienced engineers as apprentices for a long time (2-3 years) to learn their jobs within important areas. (BIW engineering, Interior engineering for example)	76		

Correlations

		VAR00005	VAR00006	VAR00007	VAR00008	VAR00009
VAR00005	Pearson Correlation	1.000	.167	.366*	-.056	-.365*
	Sig. (2-tailed)	.	.277	.014	.716	.015
	N	44	44	44	44	44
VAR00006	Pearson Correlation	.167	1.000	.214	-.020	.043
	Sig. (2-tailed)	.277	.	.164	.899	.783
	N	44	44	44	44	44
VAR00007	Pearson Correlation	.366*	.214	1.000	-.213	-.102
	Sig. (2-tailed)	.014	.164	.	.165	.509
	N	44	44	44	44	44
VAR00008	Pearson Correlation	-.056	-.020	-.213	1.000	.630**
	Sig. (2-tailed)	.716	.899	.165	.	.000
	N	44	44	44	44	44
VAR00009	Pearson Correlation	-.365*	.043	-.102	.630**	1.000
	Sig. (2-tailed)	.015	.783	.509	.000	.
	N	44	44	44	44	44

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Results: Correlation analysis hypothesis 2			**C1**	**C2**	**C3**
Hypothesis 2: Knowledge articulation	**S5**	New engineers can easily learn this know-how by studying a complete set of technical specifications, documents or plans.	*0.366 0.014 44	*-0.365 0.015 44	
	S6	New engineers can easily learn this know-how by talking to experienced personnel			
	S7	Educating and training new engineers regarding this know how is a quick and easy job	*0.366 0.014 44		
	S8	The engineering tasks require that personnel have long experience in this industry sector to achieve high product development performance			**0.630 0.000 44
	S9	The engineering tasks require that new engineers have to work with experienced engineers as apprentices for a long time (2-3 years) to learn their jobs within important areas. (BIW engineering, Interior engineering for example)		*-0.365 0.015 44	**0.630 0.000 44

Results hypothesis 3: Master Score N=44; Knowledge gaps

Results: Knowledge gaps			Master Score N= 44 [%]	Hypothesis Mean [%]	Note
Hypothesis 3: Knowledge gaps	**S10**	Given the overlap of the source and receiver knowledge bases, source personnel could easily independently solve the same design tasks as the receiving engineers.	68	68.5	
	S11	The receiver had the knowledge base necessary to easily understand and put to use the provided know-how.	76.5		
	S12	The source had the knowledge base necessary to easily understand how the recipient planned to use the transferred know-how.	65.5		
	S13	Differences in the knowledge bases made integration of provided know how in the receiving unit very difficult.	64.5		

Correlations

		VAR00010	VAR00011	VAR00012	VAR00013
VAR00010	Pearson Correlation	1.000	.472**	.279	-.038
	Sig. (2-tailed)	.	.001	.066	.806
	N	44	44	44	44
VAR00011	Pearson Correlation	.472**	1.000	.161	-.147
	Sig. (2-tailed)	.001	.	.297	.341
	N	44	44	44	44
VAR00012	Pearson Correlation	.279	.161	1.000	.073
	Sig. (2-tailed)	.066	.297	.	.640
	N	44	44	44	44
VAR00013	Pearson Correlation	-.038	-.147	.073	1.000
	Sig. (2-tailed)	.806	.341	.640	.
	N	44	44	44	44

**. Correlation is significant at the 0.01 level (2-tailed).

Results: Correlation analysis hypothesis 3			**C1**
Hypothesis 3: Knowledge gaps	**S10**	Given the overlap of the source and receiver knowledge bases, source personnel could easily independently solve the same design tasks as the receiving engineers.	**0.472 0.001 44
	S11	The receiver had the knowledge base necessary to easily understand and put to use the provided know how.	**0.472 0.001 44
	S12	The source had the knowledge base necessary to easily understand how the recipient planned to use the transferred know-how.	
	S13	Differences in the knowledge bases made integration of provided know-how in the receiving unit very difficult.	

Results hypothesis 4: Master score N=44; Knowledge integration

Results: Knowledge integration			Master Score N= 44 [%]	Hypothesis Mean [%]	Note
Hypothesis 4: Knowledge integration	**S14**	The receiving unit feels a sense of responsibility for how this know-how gets used	76.5	69.25	
	S15	Both parties, sender and receiver, really care about the implementation of the provided know-how.	70		
	S16	Both parties have had sufficient interaction with this know-how to develop an intimate understanding of it.	61.5		
	S17	Receiver develops a high degree of ownership of provided know-how.	76		
	S18	Sender and receiver refer to this know-how in the teams, as important to the development process.	74		
	S19	People have invested significantly their time, ideas, skills and physical and intellectual energies in the know-how transferred between sender and receiver.	57.5		

Correlations

		VAR00014	VAR00015	VAR00016	VAR00017	VAR00018	VAR00019
VAR00014	Pearson Correlation	1.000	.111	.327*	-.124	.231	.367*
	Sig. (2-tailed)	.	.472	.030	.424	.131	.014
	N	44	44	44	44	44	44
VAR00015	Pearson Correlation	.111	1.000	.370*	-.127	.096	.148
	Sig. (2-tailed)	.472	.	.014	.411	.534	.339
	N	44	44	44	44	44	44
VAR00016	Pearson Correlation	.327*	.370*	1.000	.105	.112	.142
	Sig. (2-tailed)	.030	.014	.	.497	.469	.358
	N	44	44	44	44	44	44
VAR00017	Pearson Correlation	-.124	-.127	.105	1.000	.338*	.085
	Sig. (2-tailed)	.424	.411	.497	.	.025	.582
	N	44	44	44	44	44	44
VAR00018	Pearson Correlation	.231	.096	.112	.338*	1.000	.387**
	Sig. (2-tailed)	.131	.534	.469	.025	.	.009
	N	44	44	44	44	44	44
VAR00019	Pearson Correlation	.367*	.148	.142	.085	.387**	1.000
	Sig. (2-tailed)	.014	.339	.358	.582	.009	.
	N	44	44	44	44	44	44

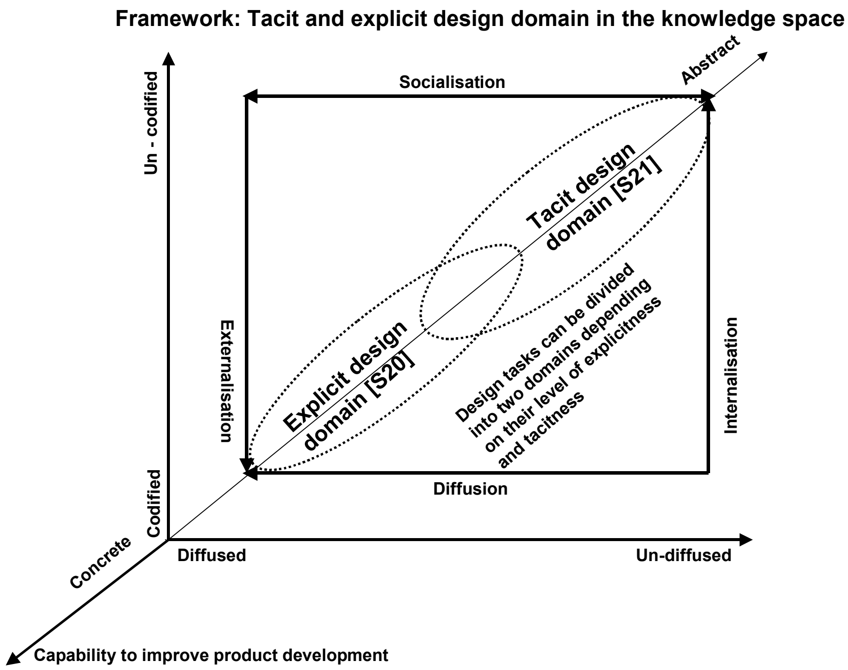
*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Results: Correlation analysis hypothesis 4			**C1**	**C2**	**C3**	**C4**	**C5**
Hypothesis 4: Integration of knowledge	**S14**	The receiving unit feels a sense of responsibility for how this know-how gets used	*0.327 0.030 44		*0.367 0.014 44		
	S15	Both parties, sender and receiver, really care about the implementation of the provided know-how.		*0.370 0.014 44			
	S16	Both parties have had sufficient interaction with this know-how to develop an intimate understanding of it.	*0.327 0.030 44	*0.370 0.014 44			
	S17	Receiver develops a high degree of ownership of provided know-how.				*0.338 0.025 44	
	S18	Sender and receiver refer to this know-how in the teams, as important to the development process.				*0.338 0.025 44	**0.387 0.009 44
	S19	People have invested significantly their time, ideas, skills and physical and intellectual energies in the know-how transferred between sender and receiver.			*0.367 0.014 44		**0.387 0.009 44

Results: Master score N=44; Explicit design domain and tacit design domain

Result: Explicit design domain and tacit design domain			Master Score N= 44	Hypothesis Mean	Note
Explicit domain	**S20**	The knowledge, which I use to solve design tasks is embedded and collected out of technical description, technical specification and specific literature.	38		See framework below
Tacit domain	**S21**	The knowledge, which I use to solve design tasks, comes mainly from previous projects and my work experience.	82		See framework below



The survey supports my previous findings, that knowledge for new product development activities is mainly embedded in the tacit design domain; 82 % said that knowledge used to solve design tasks comes mainly from work experience and previous projects.

There is no new product development without the use of technical descriptions and existing theories as platform knowledge to solve design tasks; 32 % of the engineers said that they use knowledge out of technical descriptions, technical specifications and specific literature to solve design tasks. These activities are embedded in the explicit design domain. As a consequence of these findings product developers must be aware that engineers confronted with complex design tasks in automotive development use mainly tacit knowledge to develop new solutions for new product development. Therefore product developers must be able identify and facilitate the articulation of valuable tacit design knowledge that is potentially useful when it becomes explicit, not to elucidate tacitness itself.

Correlations and partial correlation analysis of master score to identify the direction of possible association between tested hypotheses

First I analyse the nature of knowledge that is transferred. Does the tacit design domain or explicit design domain create a direction of association with the tested hypothesis?

Hypothesis 1: [S1, S2, S3, S4]

Hypothesis 2: [S5, S6, S7, S8]

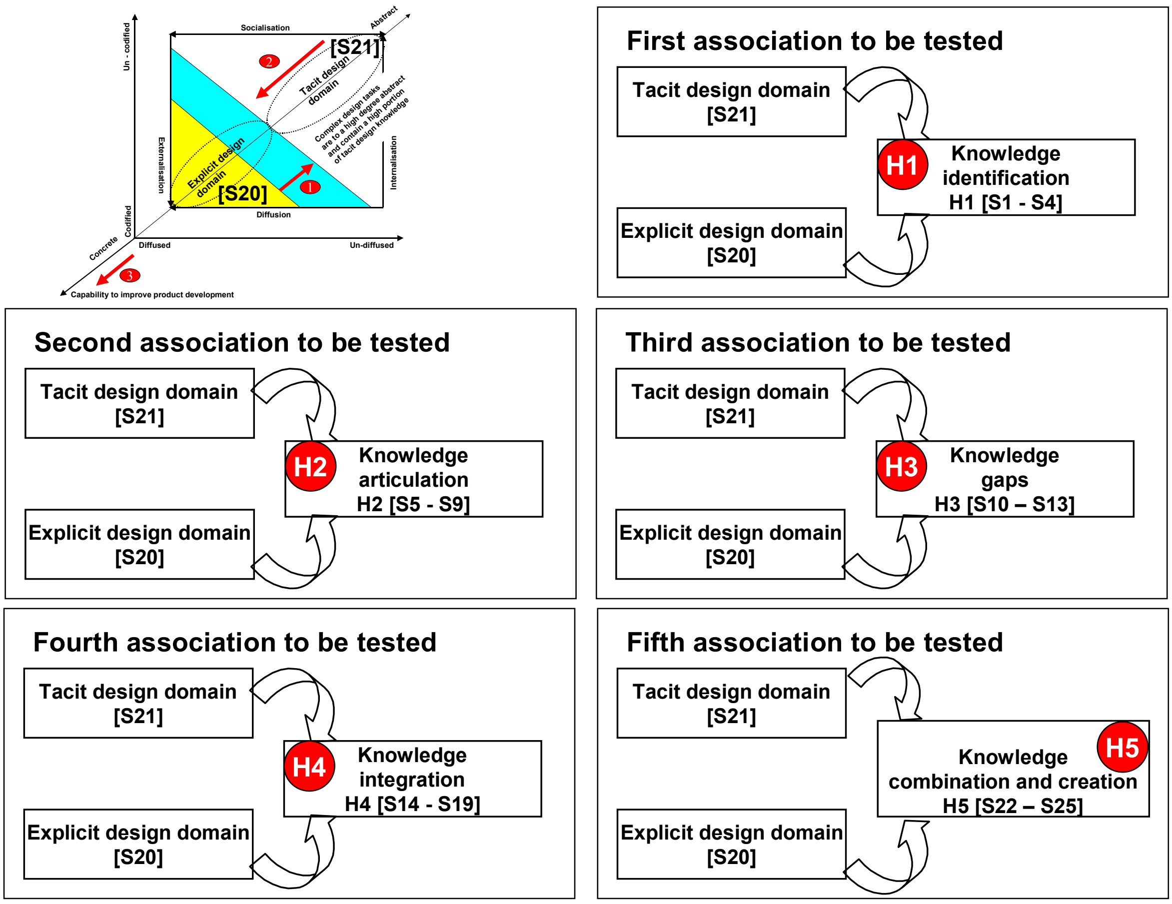
Hypothesis 3: [S10, S11, S12, S13]

Hypothesis 4: [S14, S15, S16, S17, S18, S19]

Hypothesis 5: [S22, S23, S24, S25]

Therefore I test five associations shown in figure below.

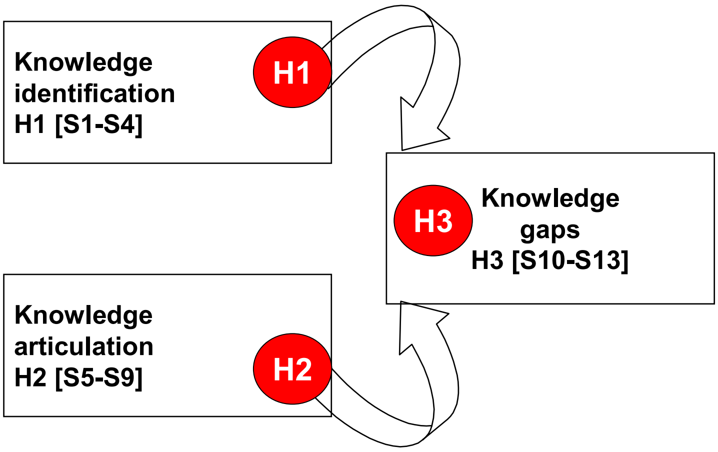
Figure A3: 1: Associations to be tested



Correlations are measures of linear association. Based on a few sample tests with partial correlations, I decided to test the correlation of the association shown in the figure above, with a bivariate two tailed Pearson correlation. I take into account that two variables can be perfectly related, but this not a guarantee that it is a reasonable association related to the tested model of knowledge transfer. Therefore I used additional a partial correlations analysis.

Analysis of correlation between hypothesis 1 – hypothesis 2 – hypothesis 3

Correlation analysis of hypothesis 1 and hypothesis 2 and hypothesis 3



Results: Correlation between hypothesis 1 – hypothesis 2 – hypothesis 3

Correlations

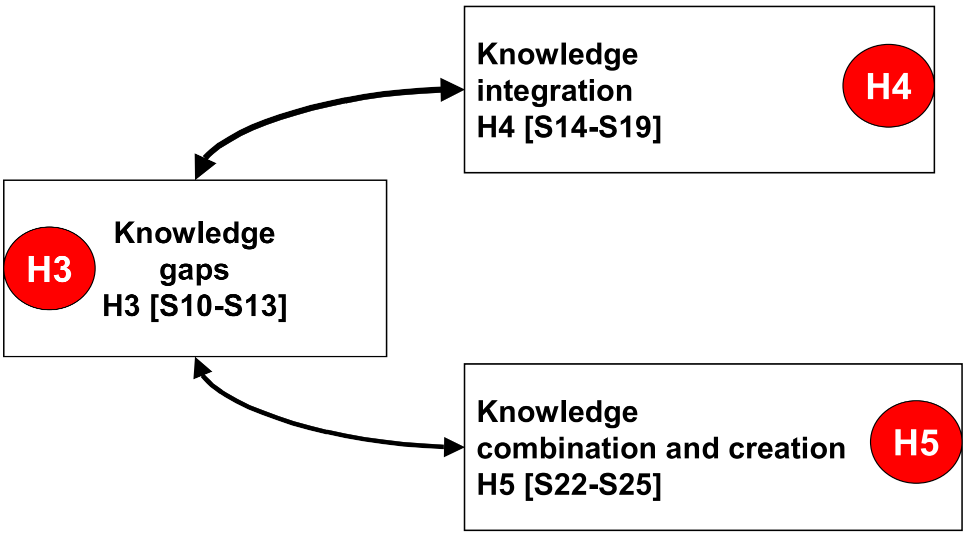
		VAR00001	VAR00002	VAR00003	VAR00004	VAR00005	VAR00006	VAR00007	VAR00008	VAR00009	VAR00010	VAR00011	VAR00012	VAR00013
VAR00001	Pearson Correlation	1.000	.513**	.202	.431**	.389**	.259	.333*	-.099	-.094	.303*	.562**	.112	-.207
	Sig. (2-tailed)	.	.000	.190	.003	.009	.090	.027	.521	.544	.045	.000	.471	.177
	N	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00002	Pearson Correlation	.513**	1.000	.170	.413**	.414**	.087	.540**	-.036	-.174	.537**	.423**	.347*	-.187
	Sig. (2-tailed)	.000	.	.271	.005	.005	.575	.000	.814	.259	.000	.004	.021	.224
	N	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00003	Pearson Correlation	.202	.170	1.000	.389**	.276	.223	.468**	-.345*	-.101	.249	.367*	.256	-.061
	Sig. (2-tailed)	.190	.271	.	.009	.070	.146	.001	.022	.513	.103	.014	.093	.695
	N	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00004	Pearson Correlation	.431**	.413**	.389**	1.000	.122	.223	.516**	-.167	-.003	.484**	.603**	.344*	-.239
	Sig. (2-tailed)	.003	.005	.009	.	.432	.145	.000	.278	.985	.001	.000	.022	.118
	N	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00005	Pearson Correlation	.389**	.414**	.276	.122	1.000	.167	.366*	-.056	-.365*	.234	.106	.284	.019
	Sig. (2-tailed)	.009	.005	.070	.432	.	.277	.014	.716	.015	.126	.495	.062	.900
	N	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00006	Pearson Correlation	.259	.087	.223	.223	.167	1.000	.214	-.020	.043	.234	.136	-.046	.070
	Sig. (2-tailed)	.090	.575	.146	.145	.277	.	.164	.899	.783	.127	.380	.765	.650
	N	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00007	Pearson Correlation	.333*	.540**	.468**	.516**	.366*	.214	1.000	-.213	-.102	.560**	.462**	.265	-.403**
	Sig. (2-tailed)	.027	.000	.001	.000	.014	.164	.	.165	.509	.000	.002	.083	.007
	N	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00008	Pearson Correlation	-.099	-.036	-.345*	-.167	-.056	-.020	-.213	1.000	.630**	.006	-.053	.144	.184
	Sig. (2-tailed)	.521	.814	.022	.278	.716	.899	.165	.	.000	.968	.731	.350	.232
	N	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00009	Pearson Correlation	-.094	-.174	-.101	-.003	-.365*	.043	-.102	.630**	1.000	.217	.230	-.219	.112
	Sig. (2-tailed)	.544	.259	.513	.985	.015	.783	.509	.000	.	.157	.132	.153	.470
	N	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00010	Pearson Correlation	.303*	.537**	.249	.484**	.234	.234	.560**	.006	.217	1.000	.472**	.279	-.038
	Sig. (2-tailed)	.045	.000	.103	.001	.126	.127	.000	.968	.157	.	.001	.066	.806
	N	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00011	Pearson Correlation	.562**	.423**	.367*	.603**	.106	.136	.462**	-.053	.230	.472**	1.000	.161	-.147
	Sig. (2-tailed)	.000	.004	.014	.000	.495	.380	.002	.731	.132	.001	.	.297	.341
	N	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00012	Pearson Correlation	.112	.347*	.256	.344*	.284	-.046	.265	.144	-.219	.279	.161	1.000	.073
	Sig. (2-tailed)	.471	.021	.093	.022	.062	.765	.083	.350	.153	.066	.297	.	.640
	N	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00013	Pearson Correlation	-.207	-.187	-.061	-.239	.019	.070	-.403**	.184	.112	-.038	-.147	.073	1.000
	Sig. (2-tailed)	.177	.224	.695	.118	.900	.650	.007	.232	.470	.806	.341	.640	.
	N	44	44	44	44	44	44	44	44	44	44	44	44	44

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Analysis of correlation between hypothesis 3 – hypothesis 4 – hypothesis 5

Correlation analysis of hypothesis 3 and hypothesis 4 and hypothesis 5



Results: Correlation between hypothesis 3 – hypothesis 4 – hypothesis 5

Correlations

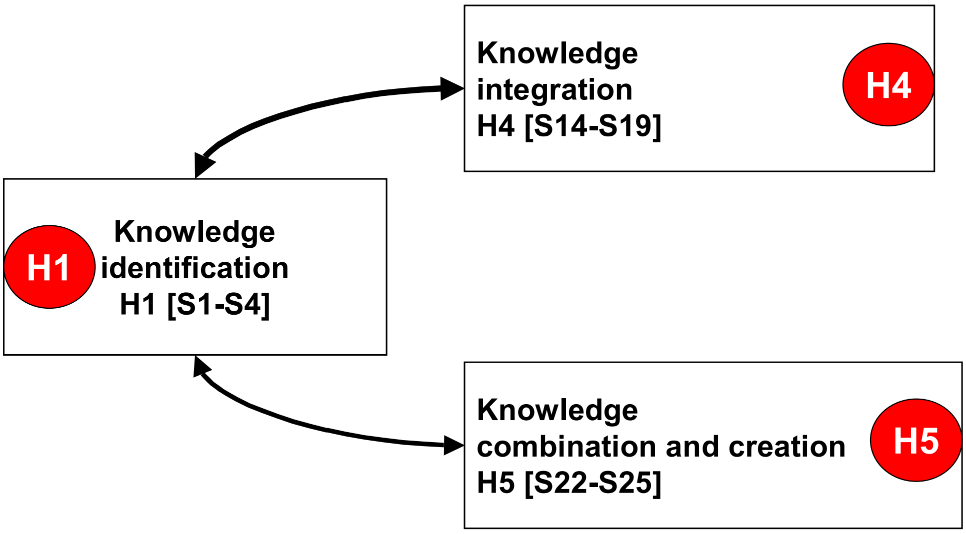
		VAR00010	VAR00011	VAR00012	VAR00013	VAR00014	VAR00015	VAR00016	VAR00017	VAR00018	VAR00019	VAR00022	VAR00023	VAR00024	VAR00025
VAR00010	Pearson Correlatio	1.000	.472**	.279	-.038	.061	.093	.257	.227	.028	-.077	-.218	.016	.321*	.367*
	Sig. (2-tailed)	.	.001	.066	.806	.692	.548	.092	.139	.856	.621	.155	.918	.034	.014
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00011	Pearson Correlatio	.472**	1.000	.161	-.147	.303*	.168	.512**	.269	.327*	-.156	.151	.229	.304*	.457**
	Sig. (2-tailed)	.001	.	.297	.341	.046	.275	.000	.077	.031	.313	.328	.135	.045	.002
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00012	Pearson Correlatio	.279	.161	1.000	.073	.040	.308*	.369*	-.167	.171	.009	.063	.077	.393**	.282
	Sig. (2-tailed)	.066	.297	.	.640	.797	.042	.014	.277	.268	.953	.687	.620	.008	.063
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00013	Pearson Correlatio	-.038	-.147	.073	1.000	.040	.192	-.251	-.118	.189	.336*	.288	-.066	-.119	-.138
	Sig. (2-tailed)	.806	.341	.640	.	.794	.211	.100	.446	.218	.026	.058	.672	.443	.371
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00014	Pearson Correlatio	.061	.303*	.040	.040	1.000	.111	.327*	-.124	.231	.367*	.188	.564**	.365*	.448**
	Sig. (2-tailed)	.692	.046	.797	.794	.	.472	.030	.424	.131	.014	.221	.000	.015	.002
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00015	Pearson Correlatio	.093	.168	.308*	.192	.111	1.000	.370*	-.127	.096	.148	.259	.240	.547**	.101
	Sig. (2-tailed)	.548	.275	.042	.211	.472	.	.014	.411	.534	.339	.089	.116	.000	.516
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00016	Pearson Correlatio	.257	.512**	.369*	-.251	.327*	.370*	1.000	.105	.112	.142	.301*	.313*	.513**	.467**
	Sig. (2-tailed)	.092	.000	.014	.100	.030	.014	.	.497	.469	.358	.047	.038	.000	.001
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00017	Pearson Correlatio	.227	.269	-.167	-.118	-.124	-.127	.105	1.000	.338*	.085	.014	.088	-.192	.221
	Sig. (2-tailed)	.139	.077	.277	.446	.424	.411	.497	.	.025	.582	.926	.571	.212	.149
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00018	Pearson Correlatio	.028	.327*	.171	.189	.231	.096	.112	.338*	1.000	.387**	.199	.382*	-.007	.388**
	Sig. (2-tailed)	.856	.031	.268	.218	.131	.534	.469	.025	.	.009	.196	.010	.963	.009
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00019	Pearson Correlatio	-.077	-.156	.009	.336*	.367*	.148	.142	.085	.387**	1.000	.214	.360*	.278	.173
	Sig. (2-tailed)	.621	.313	.953	.026	.014	.339	.358	.582	.009	.	.163	.016	.068	.262
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00022	Pearson Correlatio	-.218	.151	.063	.288	.188	.259	.301*	.014	.199	.214	1.000	.113	.248	.283
	Sig. (2-tailed)	.155	.328	.687	.058	.221	.089	.047	.926	.196	.163	.	.465	.105	.062
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00023	Pearson Correlatio	.016	.229	.077	-.066	.564**	.240	.313*	.088	.382*	.360*	.113	1.000	.326*	.306*
	Sig. (2-tailed)	.918	.135	.620	.672	.000	.116	.038	.571	.010	.016	.465	.	.031	.044
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00024	Pearson Correlatio	.321*	.304*	.393**	-.119	.365*	.547**	.513**	-.192	-.007	.278	.248	.326*	1.000	.372*
	Sig. (2-tailed)	.034	.045	.008	.443	.015	.000	.000	.212	.963	.068	.105	.031	.	.013
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00025	Pearson Correlatio	.367*	.457**	.282	-.138	.448**	.101	.467**	.221	.388**	.173	.283	.306*	.372*	1.000
	Sig. (2-tailed)	.014	.002	.063	.371	.002	.516	.001	.149	.009	.262	.062	.044	.013	.
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Analysis of correlation between hypothesis 1 – hypothesis 4 – hypothesis 5

Correlation analysis of hypothesis 1 and hypothesis 4 and hypothesis 5



Results: Correlation between hypothesis 1 – hypothesis 4 – hypothesis 5

Correlations

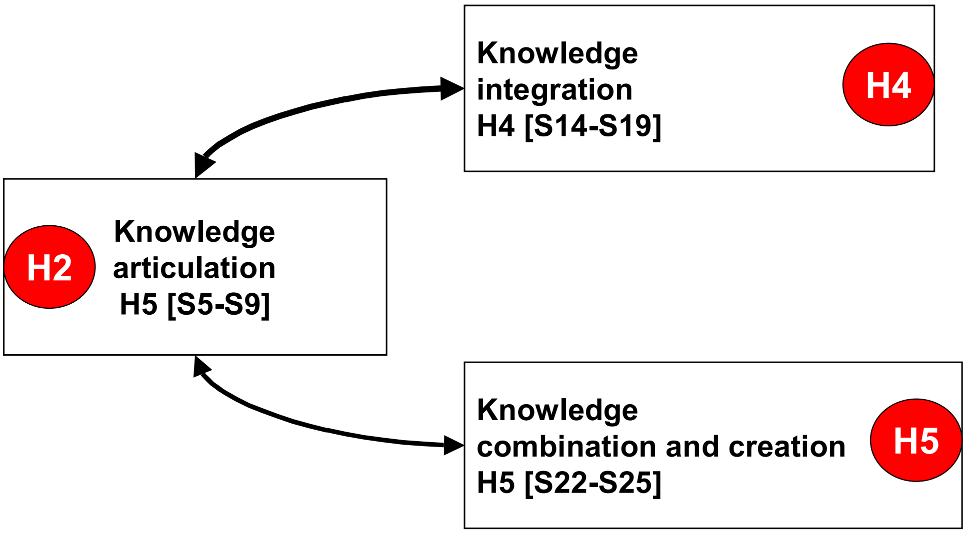
		VAR00001	VAR00002	VAR00003	VAR00004	VAR00014	VAR00015	VAR00016	VAR00017	VAR00018	VAR00019	VAR00022	VAR00023	VAR00024	VAR00025
VAR00001	Pearson Correlation	1.000	.513**	.202	.431**	.385**	.075	.548**	.449**	.244	.067	.234	.185	.305*	.383*
	Sig. (2-tailed)	.	.000	.190	.003	.010	.629	.000	.002	.110	.665	.127	.228	.044	.010
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00002	Pearson Correlation	.513**	1.000	.170	.413**	.135	.204	.468**	.244	.193	-.168	-.004	.121	.321*	.335*
	Sig. (2-tailed)	.000	.	.271	.005	.384	.185	.001	.111	.209	.277	.978	.433	.034	.026
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00003	Pearson Correlation	.202	.170	1.000	.389**	.004	-.081	-.056	.182	.497**	-.180	.075	.121	-.028	.250
	Sig. (2-tailed)	.190	.271	.	.009	.981	.602	.716	.238	.001	.242	.630	.436	.858	.102
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00004	Pearson Correlation	.431**	.413**	.389**	1.000	.147	.330*	.572**	.092	.263	-.098	.067	.280	.421**	.518*
	Sig. (2-tailed)	.003	.005	.009	.	.341	.029	.000	.555	.084	.528	.665	.066	.004	.000
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00014	Pearson Correlation	.385**	.135	.004	.147	1.000	.111	.327*	-.124	.231	.367*	.188	.564**	.365*	.448*
	Sig. (2-tailed)	.010	.384	.981	.341	.	.472	.030	.424	.131	.014	.221	.000	.015	.002
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00015	Pearson Correlation	.075	.204	-.081	.330*	.111	1.000	.370*	-.127	.096	.148	.259	.240	.547**	.101
	Sig. (2-tailed)	.629	.185	.602	.029	.472	.	.014	.411	.534	.339	.089	.116	.000	.516
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00016	Pearson Correlation	.548**	.468**	-.056	.572**	.327*	.370*	1.000	.105	.112	.142	.301*	.313*	.513**	.467*
	Sig. (2-tailed)	.000	.001	.716	.000	.030	.014	.	.497	.469	.358	.047	.038	.000	.001
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00017	Pearson Correlation	.449**	.244	.182	.092	-.124	-.127	.105	1.000	.338*	.085	.014	.088	-.192	.221
	Sig. (2-tailed)	.002	.111	.238	.555	.424	.411	.497	.	.025	.582	.926	.571	.212	.149
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00018	Pearson Correlation	.244	.193	.497**	.263	.231	.096	.112	.338*	1.000	.387**	.199	.382*	-.007	.388*
	Sig. (2-tailed)	.110	.209	.001	.084	.131	.534	.469	.025	.	.009	.196	.010	.963	.009
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00019	Pearson Correlation	.067	-.168	-.180	-.098	.367*	.148	.142	.085	.387**	1.000	.214	.360*	.278	.173
	Sig. (2-tailed)	.665	.277	.242	.528	.014	.339	.358	.582	.009	.	.163	.016	.068	.262
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00022	Pearson Correlation	.234	-.004	.075	.067	.188	.259	.301*	.014	.199	.214	1.000	.113	.248	.283
	Sig. (2-tailed)	.127	.978	.630	.665	.221	.089	.047	.926	.196	.163	.	.465	.105	.062
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00023	Pearson Correlation	.185	.121	.121	.280	.564**	.240	.313*	.088	.382*	.360*	.113	1.000	.326*	.306*
	Sig. (2-tailed)	.228	.433	.436	.066	.000	.116	.038	.571	.010	.016	.465	.	.031	.044
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00024	Pearson Correlation	.305*	.321*	-.028	.421**	.365*	.547**	.513**	-.192	-.007	.278	.248	.326*	1.000	.372*
	Sig. (2-tailed)	.044	.034	.858	.004	.015	.000	.000	.212	.963	.068	.105	.031	.	.013
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00025	Pearson Correlation	.383*	.335*	.250	.518**	.448**	.101	.467**	.221	.388**	.173	.283	.306*	.372*	1.000
	Sig. (2-tailed)	.010	.026	.102	.000	.002	.516	.001	.149	.009	.262	.062	.044	.013	.
	N	44	44	44	44	44	44	44	44	44	44	44	44	44	44

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Analysis of correlation between hypothesis 2 – hypothesis 4 – hypothesis 5

Correlation analysis of hypothesis 2 and hypothesis 4 and hypothesis 5



Results : Correlation between hypothesis 2 – hypothesis 4 – hypothesis 5

Correlations

	VAR00005	VAR00006	VAR00007	VAR00008	VAR00009	VAR00014	VAR00015	VAR00016	VAR00017	VAR00018	VAR00019	VAR00022	VAR00023	VAR00024	VAR00025
VAR00005	1.000	.167	.366*	-.056	-.365*	.171	.168	.234	.182	.321*	.296	-.018	.242	.322*	.124
	.	.277	.014	.716	.015	.268	.275	.126	.237	.034	.051	.909	.114	.033	.421
	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00006	.167	1.000	.214	-.020	.043	.244	.137	.034	.075	.185	.045	.097	.115	-.035	.211
	.277	.	.164	.899	.783	.110	.374	.825	.629	.229	.773	.530	.458	.823	.169
	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00007	.366*	.214	1.000	-.213	-.102	.097	.069	.257	.080	.044	-.316*	-.321*	.192	.267	.185
	.014	.164	.	.165	.509	.529	.658	.093	.605	.776	.037	.034	.212	.079	.230
	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00008	-.056	-.020	-.213	1.000	.630**	.112	.313*	.061	-.046	-.134	.251	-.117	.324*	.223	-.014
	.716	.899	.165	.	.000	.471	.039	.693	.768	.387	.100	.448	.032	.145	.928
	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00009	-.365*	.043	-.102	.630**	1.000	.131	.057	-.106	.168	-.070	.176	-.134	.214	.038	.094
	.015	.783	.509	.000	.	.396	.714	.494	.276	.652	.253	.387	.163	.808	.543
	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00014	.171	.244	.097	.112	.131	1.000	.111	.327*	-.124	.231	.367*	.188	.564**	.365*	.448**
	.268	.110	.529	.471	.396	.	.472	.030	.424	.131	.014	.221	.000	.015	.002
	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00015	.168	.137	.069	.313*	.057	.111	1.000	.370*	-.127	.096	.148	.259	.240	.547**	.101
	.275	.374	.658	.039	.714	.472	.	.014	.411	.534	.339	.089	.116	.000	.516
	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00016	.234	.034	.257	.061	-.106	.327*	.370*	1.000	.105	.112	.142	.301*	.313*	.513**	.467**
	.126	.825	.093	.693	.494	.030	.014	.	.497	.469	.358	.047	.038	.000	.001
	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00017	.182	.075	.080	-.046	.168	-.124	-.127	.105	1.000	.338*	.085	.014	.088	-.192	.221
	.237	.629	.605	.768	.276	.424	.411	.497	.	.025	.582	.926	.571	.212	.149
	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00018	.321*	.185	.044	-.134	-.070	.231	.096	.112	.338*	1.000	.387**	.199	.382*	-.007	.388**
	.034	.229	.776	.387	.652	.131	.534	.469	.025	.	.009	.196	.010	.963	.009
	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00019	.296	.045	-.316*	.251	.176	.367*	.148	.142	.085	.387**	1.000	.214	.360*	.278	.173
	.051	.773	.037	.100	.253	.014	.339	.358	.582	.009	.	.163	.016	.068	.262
	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00022	-.018	.097	-.321*	-.117	-.134	.188	.259	.301*	.014	.199	.214	1.000	.113	.248	.283
	.909	.530	.034	.448	.387	.221	.089	.047	.926	.196	.163	.	.465	.105	.062
	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00023	.242	.115	.192	.324*	.214	.564**	.240	.313*	.088	.382*	.360*	.113	1.000	.326*	.306*
	.114	.458	.212	.032	.163	.000	.116	.038	.571	.010	.016	.465	.	.031	.044
	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00024	.322*	-.035	.267	.223	.038	.365*	.547**	.513**	-.192	-.007	.278	.248	.326*	1.000	.372*
	.033	.823	.079	.145	.808	.015	.000	.000	.212	.963	.068	.105	.031	.	.013
	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44
VAR00025	.124	.211	.185	-.014	.094	.448**	.101	.467**	.221	.388**	.173	.283	.306*	.372*	1.000
	.421	.169	.230	.928	.543	.002	.516	.001	.149	.009	.262	.062	.044	.013	.
	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44

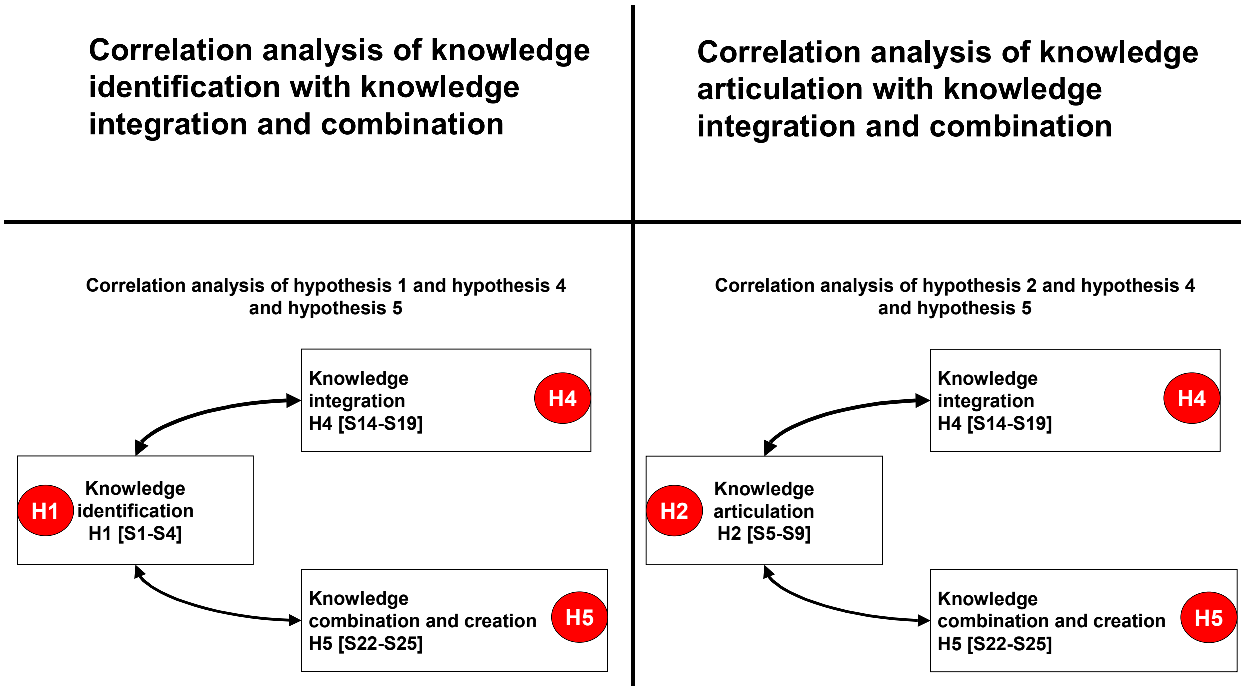
*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Results: Correlation analysis of knowledge integration and articulation to integrate and combine knowledge in the product development process

The following figure shows the tested associations between knowledge identification [H1] and knowledge articulation [H2], and knowledge integration [H4] and knowledge creation and combination [H5].

Figure: Tested associations of knowledge identification and articulation in relation to knowledge integration and combination



All significant correlations are shown and discussed in chapter 4.5.3 pages 137 - 141

Results: N=44 Master score

Results: N=44 Master score			Master Score N= 44 [%]	Hypothesis Mean [%]	Note
Hypothesis 1: Knowledge identification	**S1**	It is uncomplicated for the receiver to identify source personnel who could help them reconfigure and implement requested design expertise.	63	65	
	S2	It is uncomplicated for the receiver to identify the source personnel to spot necessary design requirements and understand the technologies related to this expertise.	60		
	S3	It is uncomplicated for the receiver to identify which tools (CAE; CAD) to use to perform design tasks on provided knowledge.	74		
	S4	It is easy for the receiver to locate and extract the information needed to understand design relevant expertise.	64		
Hypothesis 2: Knowledge articulation	**S5**	New engineers can easily learn this know-how by studying a complete set of technical specifications, documents or plans.	44	58	
	S6	New engineers can easily learn this know-how by talking to experienced personnel	60		
	S7	Educating and training new engineers regarding this know how is a quick and easy job	30		
	S8	The engineering tasks require that personnel have long experience in this industry sector to achieve high product development performance	83		
	S9	The engineering tasks require that new engineers have to work with experienced engineers as apprentices for a long time (2-3 years) to learn their jobs within important areas. (BIW engineering, Interior engineering for example)	76		
Hypothesis 3: Knowledge gaps	**S10**	Given the overlap of the source and receiver knowledge bases, source personnel could easily independently solve the same design tasks as the receiving engineers.	67	67	
	S11	The receiver had the knowledge base necessary to easily understand and put to use the provided know-how.	75		
	S12	The source had the knowledge base necessary to easily understand how the recipient planned to use the transferred know-how.	64		
	S13	Differences in the knowledge bases made integration of provided know-how in the receiving unit very difficult.	63		
Hypothesis 4: Knowledge integration	**S14**	The receiving unit feels a sense of responsibility for how this know how gets used	77	70	
	S15	Both parties, sender and receiver, really care about the implementation of the provided know-how.	71		
	S16	Both parties have had sufficient interaction with this know-how to develop an intimate understanding of it.	63		
	S17	The receiver developed a high degree of ownership of provided know-how.	76		
	S18	Sender and receiver refer to this know-how in the teams, as important to the development process.	74		
	S19	People have invested significantly their time, ideas, skills and physical and intellectual energies in the know-how transferred between sender and receiver.	58		

Continuous results: N=44 Master score

Results: N=44 Master score			Master Score N= 44	Hypothesis Mean	Note
Explicit domain	**S20**	The knowledge that I use to solve design tasks is embedded and collected out of technical description, technical specification and specific literature.	38		See Page 12
Tacit domain	**S21**	The knowledge that I use to solve design task comes mainly from previous projects and my work experience.	82		See Page 12
Results: N=44 Master score					
			Master Score N= 44	Hypothesis Mean	Note
Hypothesis 5: Knowledge combination and creation	**S22**	We systematically use knowledge generated in previous projects as a knowledge platform for new projects.	80	75	
	S23	We use intensive collaboration with our partners to generate new knowledge for new applications in new product development projects.	74		
	S24	We use intensive collaboration with our partners to define objectives and targets to deliver requested design solutions for new products.	69		
	S25	The knowledge generated in previous projects is existing and available for application, if we start with new projects.	75		

On following page is the questionnaire that was used in project three, where all results are discussed in detail. The research took place in Munich, Germany, and therefore the original questionnaire is in German, but for discussion and analysis of results it is translated into the English language, sees results and statements S1-S25.

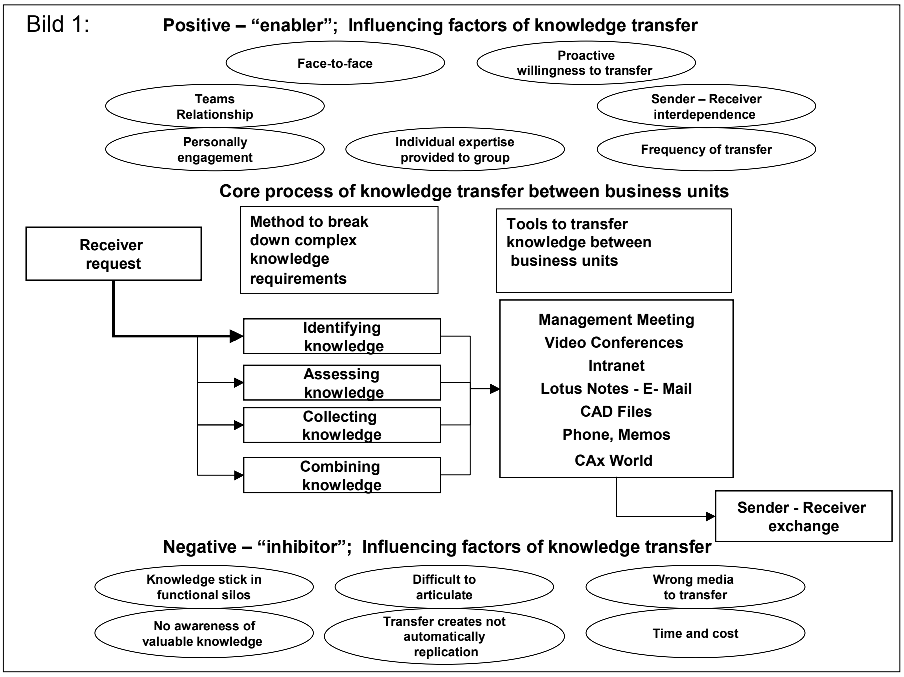
Used Questionnaire -- Verwendeter Fragebogen:

Title of DBA Research:

An explorative study of knowledge transfer processes in new product development in the automotive industry

Die Dissertation, beschäftigt sich mit Wissenstransfer in Produktentwicklung - Teams. Die Studie brachte zum Vorschein, das Wissenstransfer durch verschiedene Faktoren beeinflusst wird, welche in der Studie als Enabler – positive Faktoren und Inhibitors, negative Faktoren des Wissenstransfer identifiziert und klassifiziert wurden, *(Bild 1).*

Im allgemeinen beinhaltet die Aufgabenstellung in der Produktentwicklung, Wissen welches durch Formeln, Lastenhefte und Normen vorhanden ist; " Explizites Wissen ". Eine erfolgreiche Produktenwicklung ist jedoch komplexer, das "*Know how"* von Ingenieuren ist nicht in Datenbanken abrufbar, es ist eine Kombination von technischem Wissen, Erfahrungswerten und richtiger Anwendung von verschiedenen Support Tools, wie (CAD, CAE, FEM, usw.).



Die Kombination von Personen, Tools und verschiedenen Wissensbereichen erzeugt die Kompetenz für eine erfolgreiche Produktentwicklung. Die Komplexität dieses kombinierten Wissensbereich ist eine klare Herausforderung an den Wissensaustausch zwischen den Entwicklungspartnern.

Im Projekt drei, möchte ich erfassen wie zufrieden Ingenieure in der Fahrzeugentwicklung mit dem Wissensaustausch zwischen Entwicklungspartnern sind. Dieser Fragebogen ist ein wichtiger Baustein meiner Dissertation und daher möchte mich bei Ihnen für die Beantwortung der Fragen auf nachfolgenden Seiten herzlich bedanken.

Fragebogen

Dieser Fragebogen auf Seite drei bis fünf beinhaltet verschiedene Klassifizierungen über Wissensaustausch. Bitte bestimmen Sie aufgrund Ihrer Erfahrung in Produktenwicklungsprojekten den Übereinstimmungsgrad mit den Stellungsnahmen S1- S25 anhand der Bewertungsskala, welche eine Bandbreite von 0 keine Übereinstimmung bis 4 sehr starke Übereinstimmung als Abschätzung zur Verfügung stellt.

Bewertungsskala der Übereinstimmung:

Keine Übereinstimmung **Übereinstimmungsgrad 1- 4**

0	1	2	3	4
Keine Übereinstimmung	**Sehr geringe Übereinstimmung**	**Geringe Übereinstimmung**	**Starke Übereinstimmung**	**Sehr starke Übereinstimmung**

Beispiel Beantwortung der Stellungsnahmen

	Wissensaustausch in der Produktentwicklung **Stellungsnahmen 1 - 25**	**0** Keine Übereinstimmung	**1** Sehr geringe Übereinstimmung	**2** Geringe Übereinstimmung	**3** Starke Übereinstimmung	**4** Sehr starke Übereinstimmung
S	Leute haben Zeit, Energie, Ideen und Können in das transferierte Know how investiert.					**X**

Bitte den Übereinstimmungsgrad ankreuzen laut Bewertungsskala
Stellungnahmen 1 – 25 auf nächsten Seiten;
Danke

Stellungsnahmen 1 – 25						
	Wissensaustausch in der Produktentwicklung **Stellungsnahmen S1 - S2**	0 Keine Überein-stimmung	1 Sehr geringe Überein-stimmung	2 Geringe Überein-stimmung	3 Starke Überein-stimmung	4 Sehr starke Überein-stimmung
S 1	Es ist für den Empfänger *(SIE)* einfach, den Sender zu kontaktieren und bei etwaigen Fragen Information zu erhalten.					
S 2	Es ist für den Empfänger *(SIE)* einfach beim Sender zusätzliche Information zu bekommen, um etwaige Problemlösungen im Entwicklungsbereich abzudecken.					

Stellungsnahmen 3 – 11						
Wissensaustausch in der Produktentwicklung **Stellungsnahmen: S3 – S11**		0 Keine Überein-stimmung	1 Sehr geringe Überein-stimmung	2 Geringe Überein-stimmung	3 Starke Überein-stimmung	4 Sehr starke Überein-stimmung
S 3	Es ist für den Empfänger *(SIE)* unkompliziert, zu entscheiden, welche Computer unterstützte Tools er anwenden soll aufgrund des vom Sender zur Verfügung gestellten Informationsmaterials.					
S 4	Es ist für den Empfänger *(SIE)* einfach den Sender zu kontaktieren um das zur Verfügung gestellte Know-how in den Entwicklungsprozess zu integrieren.					
S 5	Neue Ingenieure können das notwendige Know-how, in Lastenheften, Normen und technischen Beschreibungen leicht nachlesen und lernen.					
S 6	Neue Ingenieure können sich das Know-how leicht durch die Diskussion mit erfahrenen Ingenieuren aneignen					
S 7	Die Ausbildung von neuen Ingenieuren für die Fahrzeugentwicklung ist ein einfacher und schneller Prozess.					
S 8	Die Komplexität der Konstruktionsaufgaben benötigt, dass Ingenieure eine langjährige Berufspraxis haben um erfolgreich in der Fahrzeugentwicklung zu agieren.					
S 9	Die Komplexität der Konstruktionsaufgaben, haben zur Folge, dass neue Ingenieure, mit erfahrenen Ingenieuren, in einer Art Aufbauschulung, länger Schulter an Schulter zusammenarbeiten.					
S 10	Aufgrund des gleichen Fachwissens von Sender und Empfänger *(SIE)* ist der Informationsaustausch unkompliziert.					
S 11	Der Empfänger *(SIE)* hat die Wissensgrundlage das empfangene Know-how problemlos zu verstehen und in den Produktenwicklungsprozess zu integrieren.					

Stellungsnahmen 12 - 21						
Wissensaustausch in der Produktentwicklung **Stellungsnahmen: S12 – S21**		0 Keine Überein-stimmung	1 Sehr geringe Überein-stimmung	2 Geringe Überein-stimmung	3 Starke Überein-stimmung	4 Sehr starke Überein-stimmung
S 12	Der Sender hat die Wissensgrundlage: *"Das Produktentwicklungs- Know-how",* so zu konzipieren, dass es beim Empfänger *(IHNEN)* problemlos angewendet werden kann.					
S 13	Verschiedene Wissensgrundlagen erschweren Ihnen und den Entwicklungspartnern, die Kombination und Anwendung des transferierten Wissens.					
S 14	Der Empfänger *(SIE)* fühlt sich verantwortlich, das gesendete Know-how auch anzuwenden.					
S 15	Sender und Empfänger *(SIE)* sind sehr aktiv und achten darauf, das Know-how gesendet auch angewendet wird.					
S 16	Sender und Empfänger *(SIE)* haben sich intensive mit dem Know-how beschäftigt, so dass es bei beiden Entwicklungspartnern verstanden und integriert ist.					
S 17	Der Empfänger *(SIE)* integriert das Know-how und implementiert es in eigene Entwicklungsprozesse.					
S 18	Empfänger *(SIE)* und Sender benutzen transferiertes Know-how, zur gemeinsamen Problemlösung von Entwicklungsprozessen.					
S 19	Sender und Empfänger *(SIE)* haben Zeit, Energie, Ideen und Können in das transferierte Know-how investiert.					
S 20	Das Wissen welches ich in der Konstruktion anwende ist in Fachbüchern, Lastenheften und technischen Produktbeschreibungen vorhanden.					
S 21	Das Wissen welches ich in der Konstruktion anwende, basiert, hauptsächlich auf meiner langjährigen Konstruktionserfahrung.					

Stellungsnahmen 22 – 25						
Wissensaustausch in der Produktentwicklung **Stellungsnahmen: S22 – S25**		0 Keine Überein-stimmung	1 Sehr geringe Überein-stimmung	2 Geringe Überein-stimmung	3 Starke Überein-stimmung	4 Sehr starke Überein-stimmung
S 22	Das Wissen aus früheren Projekten wird bei neuen Projekten angewandt.					
S 23	Durch die intensive Zusammenarbeit mit dem Kunden wird neues Wissen erzeugt und angewandt.					
S 24	Durch die intensive Zusammenarbeit mit dem Kunden werden Zielvorgaben klar definiert und abgearbeitet.					
S 25	Das Wissen aus früheren Projekten existiert und ist abrufbar und anwendbar in neuen Projekten **für den gleichen** Kunden. (“Geheimhaltungsaspekt“)					

Für die Statistik noch kurz eine Frage zu Ihrer Person auf folgenden Blatt:

Ihre Anonymität bleibt voll gewahrt, ich bitte Sie nur die Anzahl der Berufsjahre anzukreuzen.

Berufserfahrung im Produktentwicklungsbereich	**1- 3 Jahre**	**3- 5 Jahre**	**5 – 10 Jahre**	**10 Jahre plus**

Kommentar oder Anmerkungen werden von mir gerne angenommen:

Herzlichen Dank für Ihre Unterstützung, und bei spezifischen Fragen, stehe ich gerne unter angeführter Kontaktadresse zur Verfügung.

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