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KNOWLEDGE TRANSFER BETWEEN SERVICE AND DESIGN PHASES IN THE OIL INDUSTRY

Giovanna Vianello, Saeema Ahmed
Technical University of Denmark, Denmark

ABSTRACT
Communication between departments in any company involved in the different phases of product lifecycle is crucial in order to correct faults from previous products. This paper illustrates a case study from the oil industry where knowledge transfer across departments is analysed. Interviews with engineering designers and service engineers were carried out. Knowledge arising from the operation of drilling machineries was investigated and compared to that relevant for the engineering designers; furthermore the mechanisms involved in the transfer of knowledge between service and design were investigated.
Differences in knowledge needs were observed in the two departments: engineering designers were more orientated towards knowledge of machinery at a component level while service engineers were interested in obtaining an overview of the systems. The study showed that communication between the departments consisted prevalently of information pushed by service engineers to engineering designers. If information flowed in the other direction, i.e. from design to operation, this was likely to be pulled by service engineers. These observations have implications on the structuring and capturing of knowledge for the different user groups.

Keywords: Knowledge management, experience transfer, service, product lifecycle.

1 INTRODUCTION
The general trend in engineering design is to consider issues regarding different phases of the product lifecycle during the design of a product. Knowledge from the later phases and its feedback to the engineering design phases is important in product development as the transfer of operational experience to engineering designers facilitates the correction of product flaws and suggests directions for future improvements. To enable companies to effectively reuse operational experience it is necessary for them to adopt an effective knowledge management strategy, which is designed considering the characteristics of the company in order to facilitate internal learning.
In the case study presented here, the focus is upon a complex business to business industry, specifically the design of drilling equipment for the oil industry. The configuration of the drilling system is specific for each series of rigs (usually between 2 and 4), so re-design or adaptation of machineries and assembly is required for each project. The company designing the drilling equipment is involved throughout all of its lifecycle, first with responsibility for installation and commissioning of the drilling package, secondly providing training to the rig crews and finally supplying service and maintenance during the operation phase. This results in knowledge covering the different phases of the lifecycle that is available inside the company both as documentation and as experience of those working in the different phases.
As drilling machines are customized machines, the prototype and testing phase is limited compared to a serial product; hence the transfer of experience between projects and reuse of knowledge from operation is essential to design the machineries correctly the first time. The aims of the research, together with the case study based on interviews with engineering designers and service engineers for the collaborating company, are presented in the following sections.

2 AIM
This research focuses upon how technical knowledge is perceived from the point of views of engineering designers and service engineers and investigates knowledge transfer between the two

groups. The case study is conducted within the context of drilling equipment for the oil industry. The main research questions were: 1) to understand which types of knowledge are relevant for service engineers and engineering designers, 2) to investigate which of the identified types of knowledge are likely to be reused across departments, particularly from operation to design, and finally 3) to analyse current knowledge transfer mechanisms across departments and recognize possible boundary objects that can facilitate this transfer.

3 BACKGROUND

Knowledge definition and classification is a topic of common interest to various disciplines with entire areas of philosophy specifically dedicated to debate this topic. The discussion of defining knowledge is beyond the scope of this paper; where a more general approach towards the topic has been adopted and knowledge includes both explicit and tacit elements, in line with the view from Von Krogh and Nonaka[1]. They introduced the concept of knowledge domain, consisting of the set of relevant data, information, articulated and tacit knowledge in relation to a particular subject.

Several studies on knowledge management and organizational learning claim that firms with clear strategies in knowledge transfer are more successful than those without these [2] and propose frameworks to better analyse the phenomenon. Two of these frameworks were reviewed in detail: 1) Argote *et al.*[3]; 2) Gilbert *et al.*[4] and are discussed here. Argote and Ingram proposed a framework based upon empirical evidence to describe the phenomenon of knowledge transfer [3]. At the organizational level three basic elements –members, tools and tasks - and the networks formed by their combination are identified as the reservoirs of the organization's knowledge. Tools represent the technological elements within the organization; tasks represent the goal and purpose, while members are the individuals who form the organization resources. The framework proposes that knowledge transfer can take place following two distinct mechanisms: the moving of a knowledge reservoir into different context or the modification of a reservoir at the recipient side. To have a positive impact on organizational performance the networks formed by pairs of the three basic elements of the reservoirs must be compatible both internally and externally with other networks within the organization. From a management perspective the aim of knowledge transfer is to increase the competiveness of a company, hence the ideal objective of the process is to enhance the company's internal knowledge so that it is difficult to replicate for other companies. Argote *et al.* identified the network member-to-member as the reservoir that best fulfils this need, as the interactions between members of an organization may be transferred within the organization, although not easily, and they are not likely to be adapted to other organizations as they are influenced by the characteristics, routines and culture specific of the company. Additionally the member-to-member network benefits from the ability of individuals to adapt to different environments.

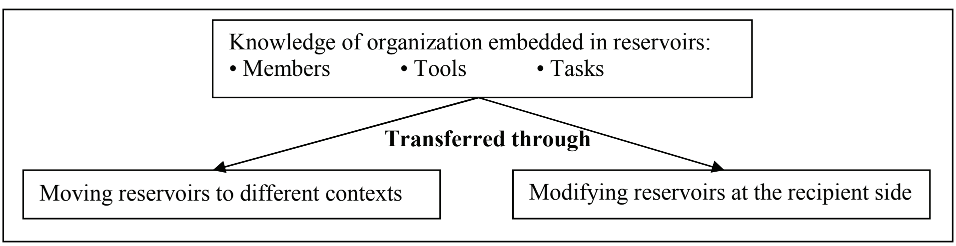

Figure 1 Argote's framework on transfer of knowledge reservoirs

The framework described above and summarized in Figure 1 provides a general description of possible knowledge transfer mechanisms, however it does not describe the different stages that constitute the knowledge transfer process or the contents of the knowledge that are relevant to transfer in order to increase the competitiveness of the company.

Other authors propose frameworks that describe how knowledge transfer occurs over time. Specifically Gilbert *et al.* focus on subsequent phases of knowledge transfer, namely acquisition, communication, application and assimilation [4] and state that true learning occurs only in the last stage where the process results in the development of core organizational routines and practices, although the transfer of knowledge is effective already in the application phase. This framework mirrors, at the organizational level, that described by Anderson [5] for individuals with the integration of a communication phase. This vision of knowledge transfer is complementary to Argote's model when transfer occurs though modifying knowledge at the receiver's side, but excludes transfer through moving knowledge reservoirs to other contexts.

Focusing on the communication aspects of knowledge transfer, knowledge sharing may be symmetric or asymmetric [6]. When asymmetric sharing occurs, the transfer process can be analysed through a sender-receiver framework that includes motivational issues, trust between parties involved and completeness of the shared information.

The process of transferring knowledge which is not from a single discipline but across disciplines facilitates innovation as dissimilarity is a condition for learning and a variety of beliefs support exploration of new solutions [7]. However this involves more complex mechanisms than the simple transfer of knowledge within a homogeneous group. According to Carlile's framework for managing knowledge across boundaries [8], when a pragmatic boundary is present, that is when the parties have different interests, the simple transfer of available knowledge is not enough; it has to be translated according to the receiver's needs in order to be successfully shared. Hence this is expected to be the case for this study and for the transfer of service to engineering knowledge.

In the engineering field the interest in knowledge management issues is motivated by the growing amount of technical knowledge that a company has to capture [9], structure and organise to facilitate its retrieval and reuse during the development process. For example in the case of variant design up to 70% of information is reused from previous solutions [9]. Furthermore current trends in engineering design include the consideration of issues related to the later phases of product's lifecycle during the design process, resulting in the need to organize information from the lifecycle in accessible way for engineering designers. The current flexibility of the job market reduces the probability for an engineer to have a lengthy career within anyone company. This limits the reuse of personal expertise across projects and motivates companies to implement new approaches to facilitate the learning process and the reuse of past experience. Empirical studies have shown the difficulties for novices to formulate questions and define what they are looking for, hence highlighting the need for knowledge [10]. The range of solutions extend from strategies focused on personalization [11] aiming to support the sharing of information within the organization [12] by building of personal networks amongst employees to codification strategies [11] which try to solve issues connected with knowledge management through information and communication technologies. Selecting the appropriate approach is influenced by the type of organization and product.

A limited number of studies have been conducted in the engineering field to understand the knowledge arising during the service of products and how this can be reused during the lifecycle of a product or to support engineering designers during the design of similar products. Jagtap *et al.*'s research [13] investigated the service phase from a design perspective through a case study from the aerospace industry. They identified the main requirement for service knowledge from engineering designers as: maintenance and failure data, reliability, service instructions and lifecycle costs as the main requirements from service taken into account by engineering designers. Additionally the research identified the information engineering designers would like to access. Failure, operating and maintenance data together with design information, lifecycle costs and life of component were identified as the main types of information to be included in a service information system for the aerospace industry. The structuring of service information available from different repositories was found to be critical for the reuse of service information by engineering designers as quick retrieval of available documentation is imperative in order to achieve systematic reuse of information from service.

Wong *et al*s case study, also from the aerospace domain, resulted in a proposal for organizing service knowledge and incorporating it into the design phase based upon a service oriented architecture perspective. They proposed to integrate different knowledge repositories [14] through defining an ontology.

This literature review shows that studies from different research fields agree on the importance of knowledge transfer. Management and organizational research see it as a key factor for a company's success; while psychology considers it as a fundamental mechanism for learning and skill acquisition. The investigation of knowledge transfer in an engineering context is a field that needs further research as the authors believe a better understanding of its mechanisms is crucial to develop a sound knowledge management system that fits a company's characteristics. For this reason this paper focuses on the analysis of contents and mechanisms of knowledge transfer in an engineering context.

4 METHODS

4.1 Case selection and data collection

A case study of a company supplying drilling machinery for offshore oil rigs has been selected. The collaborating company is involved from design to operation; hence the company's internal knowledge covers the lifecycle of the equipment. In these conditions extensive information from service is available in-house and the transfer of knowledge between people involved in the service phase and engineering designers may take place at organizational level without the involvement of other stakeholders. The availability of in-house knowledge from all the phases of the lifecycle facilitates the investigation of knowledge transfer mechanisms between operation and design as the number of influencing factors is reduced compared to cases when knowledge transfer occurs across organizations. Barriers in knowledge sharing related to competitive reasons or as a result of differing companies practices are not included in this study.

Table 1 Participants Interviewed

	Engineering designers		**Service engineers**	
Location	Headquarters	Rig	Headquarters	Rig
No. of participants	10	2	7	2

A total of 21 interviews with engineering designers and service engineers were carried out at the company headquarters in Norway and on a jack-up oil rig during its commissioning phase, see Table 1. The interviews were semi-structured with questions asked related to: communication, knowledge required by the participants and reuse of experience from operation of previous machinery. All interviews were audio-recorded and lasted between 20-60 minutes, with interviews carried out on the rig shorter due to the limited time available. The interviews were transcribed, resulting in 4750 segments, and coded using a pre-determined coding scheme, described in detail in section 4.2. A coder-reliability check was conducted and kappa found to be 0.91; all disagreements were checked and an agreement reached.

4.2 Data analysis

The interviews transcripts were coded with a coding scheme developed from literature on service knowledge, knowledge management, organizational learning and was completed following a bottom-up approach. The scheme included different categories, each one embracing codes and subcodes. The subcodes within any of the codes are mutually exclusive. An overview of the categories and the main codes is shown in Table 2. A sample of the collected data and of how they were analysed using the coding scheme is presented in Table 3.

Table 2 Coding scheme

Categories	**Codes (subcodes)**	**Definition**	**Literature**
Knowledge characteristics	Content of knowledge (product, process, etc.)	The object of the knowledge	Jagtap *et al.*[13], Ahmed[15]
Knowledge transfer	Sender/receiver	Parties involved in knowledge transfer	Lin *and al.*[6]
	Initiation mechanisms (Push , pull, fixed)	Transfer pulled by the receiver, pushed by the sender	McMahon *et al.* [11]
	Type of capture (Personal, codified)	Transfer in codified ways or relying on people	Hansen [16], McMahon *et al.* [11]
	Context (within, across projects)		Bottom up approach

Table 3 Example of collected data and their analysis through the coding scheme.

		Missing	Wanted	Object	Type of capture	Initiation: sender	Initiation: receiver	Mechanism
	Do you receive reports of service interventions?							
A	No I would say not, but they ARE available. Eehm, there are some SPS sites, that we can jump into, and try to find out. But we don't do that.	1		Operation, lifecycle and service	Codified	Operation	Equipment	Pull
	Where we have problems, we might do that directly ourselves, but we usually go through service, senior service. The senior service group, if we need to have some experience transfer, from a special rig.			Changes, issues and improvements	Personal	Operation	Equipment	Pull
	When does the senior service group contact you?							
A	If they have a problem that they either don't have resources for handling or technical experience, or if they sort of getting into design issues, then they contact us			Changes, issues and improvements	Personal	Equipment	Operation	Pull

All the instances were coded against two additional binary codes: desired conditions and needs not fulfilled, these were separated from statements describing the current situation.
First the knowledge relevant for the two groups was investigated, the initial coding scheme included four subcodes: product, process, issues and function [15]. While analyzing the data more subcodes were added following a bottom-up approach to cover the entire span of knowledge emerging from the interviews. The final subcodes describing the types of knowledge were:

- *Product*: including its design and its functionalities. The behavior during operation was not categorized here with the only exception being issues from operation that led to changes in design.
- *Process and procedures* related to how to accomplish a task.
- *Changes, issues and improvements* associated with variations to the original design of the product, motivated by the correction of a previous flaw or the need to increase performance.
- *Project:* providing an overview of a drilling system for a specific rig throughout its lifecycle, including set up of requirements, reviews of the different phases, interaction with client and suppliers, time schedule, results from tests, etc.
- *People and organization* related to the organizational structure and the awareness of who knows what.
- *Operation and lifecycle* including knowledge on a drilling system after the design phase was completed: its commissioning, use, maintenance and service.
- *Function:* representing the task of a particular component or assembly has to fulfill.
- *General knowledge* including background knowledge on electronics, hydraulics, computer programming, oil industry, drilling methods etc.

After the investigation of the types of knowledge relevant for service engineers and engineering designers the focus moved to the knowledge transfer mechanisms and how this can be related to the two groups involved and their knowledge characteristics.

5 RESULTS

5.1 Knowledge relevant for engineering designers and service engineers

First the interviews were analysed according to the coding scheme described in 4.2 to identify the knowledge that is relevant for the two groups, the results are illustrated in Table 4.

Table 4 Knowledge relevant for engineering designers and service engineers.

	Engineering designers % (311 instances)	**Service engineers %** (127 instances)
Product	25	14
Process and procedures	17	7
Changes, issues and improvements	29	34
Function	1	0
Project	12	22
People and organization	3	3
Operation, lifecycle and service	12	16
General	2	4
Total	100	100

From the distribution of the types of knowledge relevant for service engineers and engineering designers, both groups were interested in *changes, issues and improvements*. Knowledge particularly relevant for engineering designers was *product* knowledge whilst service engineers were interested in knowledge about *projects* over time.

The interviews also investigated which type of knowledge the two groups would have liked to have access to and which knowledge was perceived as missing. Table 5 and

Table 6 illustrate the results. Different trends were observable for service engineers and engineering designers. The former would like more knowledge about the project to be available, whilst the latter would like to have greater access to process knowledge. Differences between the two groups stood out particularly from the analysis of the type of knowledge perceived as missing. Engineering designers mentioned the lack of available knowledge only twice, while service engineers mentioned missing knowledge in 45 instances. This perception of missing knowledge from service engineers was not linked to a particular type of knowledge but included changes and issues, project, operation, procedures, etc.

Table 5 Knowledge desired by engineering designers and service engineers.

	Engineering designers % (37 instances)	**Service engineers %** (16 instances)
Product	14	19
Process and procedures	41	19
Changes, issues and improvements	19	6
Project	3	31
People and organization	11	6
Operation, lifecycle and service	14	19
Total	100	100

Table 6 Knowledge missing for engineering designers and service engineers.

	Engineering designers % (2 instances)	**Service engineers %** (45 instances)
Product	0	13
Process and procedures	0	16
Changes, issues and improvements	50	24
Project	0	22
People and organization	0	2
Operation, lifecycle and service	50	16
General	0	7
Total	100	100

From the analysis of knowledge relevant for service engineers and engineering designers it appeared that the two groups viewed the same object from two different perspectives. Engineering designers approached the drilling systems at the component level and saw them as composed by a number of components. On the other hand service engineers tended to see the drilling system as a whole; they were interested in getting an overview of the interactions between components and of the history of the project while they were assigned to a job. This difference in approaches was also visible at organizational level, as the two departments adopted different strategies. The design department was organized by product in a functional way; each engineering designer specialized in the development of electrical, mechanical or software part of a specific component under the coordination of the product responsible. In contrast, the service engineers in operation were divided only by their specialization as mechanical-hydraulic or electrical, since the priority of the department was to assure the availability of technicians able to perform a given job at any time and aim to create service engineers with general competences.

5.2 Knowledge reused across departments

The research focused upon understanding to what extent the company's internal knowledge is of interest and eventually reused across departments. Table 7 illustrates, according to a sender-receiver framework, who initiates the transfer of knowledge between service and operation and identifies the transfer mechanisms. The first column of the table shows that 76% of instances describing knowledge made available to the design department consisted of knowledge from operation. These data are influenced by the type of questions asked, with a prevalence of questions related to service knowledge, nonetheless they show that most of this information was pushed to engineering designers, i.e. it was made available to them without implying that the information was actually reused. The second column of Table 7 represents the distribution of instances describing knowledge addressed to the service phase. There was a less clear predominance of a single transfer mechanism, with only a slight prevalence of pull for information from the design phase which is made available to service.

Table 7 Knowledge transferred within and across departments analysed according to a sender-receiver framework.

	Receiver	
Sender	**Design Phase** % (72 instances)	**Service Phase** % (36 instances)
Design phase	**24**	**47**
Push	4	19
Pull	3	25
Fixed	6	0
Personal contact	7	3
Supervision	4	0
Service Phase	**76**	**53**
Push	44	25
Pull	21	11
Fixed	6	8
Personal contact	6	8
Total	**100**	**100**

Knowledge transfer from service to design was further analysed by pairing the transfer mechanisms with the content of knowledge; the results are illustrated in Table 8. Personal knowledge was directly transferred to the receiver whilst codified knowledge was captured by pushing it into knowledge repositories and then retrieved by the receiver mainly through pulling it. The number of instances related to information pushed through codification was higher than that for information pulled, indicating that a relevant amount of service information made available into knowledge repositories was not retrieved by engineering designers. The main codified knowledge that was transferred across departments was about *changes, issues and improvements*; this was primarily pushed by service engineers (more than 50% of total instances) and, to a lesser extent, pulled by engineering designers. Transfer through personalization was equally initiated by service engineers pushing knowledge to engineering designers and vice versa, by engineering designing pulling knowledge from operation. Knowledge pushed to engineering designers by service engineers mainly concerned changes, whereas engineering designers were also interested in obtaining information about operation and, to a lesser extent, project and product. From this analysis *changes, issues and improvements* arising during operation emerged as the main knowledge transferred to engineering designers, confirming the results from the investigation of the types of knowledge relevant for the two groups. However it is evident that no clear strategy for transferring this type of knowledge was followed as transfer occurred both through codification and personalization.

Table 8 Contents of knowledge transferred from operation to design.

	Receiver: engineering designers	
Sender: service engineers	**Codified %** (23 instances)	**Personal %** (27 instances)
Push	**70**	**41**
Changes, issues and improvements	52	37
Project	9	4
People and organization	4	0
Operation, lifecycle and service	4	0
Pull	**22**	**37**
Product	0	4
Changes, issues and improvements	13	15
Project	0	7
Operation, lifecycle and service	9	11
Fixed	**9**	**7**
Changes, issues and improvements	0	4
Operation, lifecycle and service	9	4
Personal contact	**0**	**15**
Product	0	4
Changes, issues and improvements	0	11
Total	**100**	**100**

From the quantitative analysis of the interviews, coupled with a qualitative study of their content, knowledge transfer between departments was a relevant issue from the perspective of operation, who experienced recurrent problems and would have liked to be involved in the design process in order to ensure that the experience from the field was taken into account. Knowledge transfer across departments was less relevant for engineering designers who were not used to including input from operation while designing a product. This explains why most of the information was pushed from operation to design. The limited interest of engineering designers for knowledge arising throughout the lifecycle of a product may be linked to the characteristics of the oil industry, which is still very conservative. In addition the provision of service and maintenance is still a source of profit, hence there is not strong motivation to focus upon product lifecycle issues which is the case when product-service systems are supplied, e.g. in the aerospace industry.

Comparing the findings from this case on knowledge transfer from service to design in relation to customised equipment with the types of service knowledge relevant for engineering designers in other industries, namely variant design of complex machinery [13], the information on failures, maintenance and lifecycle are common for both variant and customized designs whilst the importance of knowledge about current and past projects was only seen in the case of customized machines but would be expected to be relevant for variant industries.

Commonalities and differences across departments

Knowledge of changes and issues emerged as of common interest to service engineers and engineering designers and, if this knowledge was structured considering the needs of the two groups, it could be used as a boundary object able to facilitate communication across departments.

However the different perspectives of the two departments were reflected in the nature of documentation. Service documentation aimed to capture dynamic knowledge of value mainly at the moment when the documentation was issued and available in form of service reports or status descriptions; design documentation on the other hand represented more stable knowledge entailed in drawings, valid throughout the lifecycle of a product and relatively easy to reuse across projects.

5.3 Knowledge transfer mechanisms

The analysis of the interviews focused upon obtaining a better understanding of how knowledge transfer occurred between the two groups. Personalization or codification strategies for knowledge transfer as defined by McMahon [11], already mentioned in the previous paragraph, were investigated in more depth and coupled with Argote's framework of knowledge transferred through moving or modifying knowledge reservoirs [3]. All the four possible combinations were identified from the interviews as reported in Table 9.

Table 9 Examples of knowledge transfer mechanisms.

	Personalization	**Codification**
Moving reservoirs	• Job rotation part of employee development project • Support across departments in critical phases.	• Copy of software across rigs
Modifying reservoirs	• Communication with colleagues	• Reuse of documentation

Moving personnel across departments had been the focus of an employee's development project implemented by the company before the interviews were carried out. The project, although successful, was interrupted due the exponential development of the oil business that impeded the temporary allocation of engineering designers to other departments. Nonetheless the benefits of that program were still visible at the company as engineering designers who participated in it had a better vision of the lifecycle of machines and formed a network of contacts in the operation department which remained active. Temporary moving of personnel from the design department, particularly software developers, to support the most critical parts of the commissioning phase was also common practice at the company and had the unplanned positive effect to facilitate the communication across departments. Moving knowledge reservoirs in the form of design tasks occurred in the case of similar projects where solutions regarding the software package were transferred from one rig to the next.

Interviews also provided evidence of different mechanisms of modification of knowledge reservoirs; two modes of knowledge transfer across departments were identified: 1) through reuse of codified documentation and 2) through personal communication. In the case of transfer across departments, positions acting as knowledge brokers were recognized. A knowledge broker represents an intermediary who facilitates the knowledge transfer process providing links, pointing to sources or directly supplying knowledge [17]; brokering practices include crossing organizational boundaries, translating and interpreting available knowledge according to the needs of the receiver and support the transfer of knowledge across units in the organization [18]. In the analysed case study, one department tended to contact a broker from the other department rather than to look for available documentation;

this resulted in the broker supplying information in the form of personal communication, ad-hoc reports created to satisfy the receiver needs or through currently available documentation.

From the data and the viewpoint of knowledge transfer according to a sender-receiver framework, when the transfer occurs through personalization strategies the sharing of knowledge can be symmetric or asymmetric while for codified information the transfer is always asymmetric; asymmetric transfer can be either pushed by the sender or pulled by the receiver. Additionally when knowledge is captured in a codified way, a third element in the communication flow has to be taken into account, i.e. the knowledge repositories. The sender pushes information into repositories; the same information can be pulled by the receiver or pushed to him/her in the form of a notification, alert etc. The different transfer mechanisms are illustrated in Figure 2.

From the interviews it appeared that retrieval and reuse of information that is stored into knowledge repositories was the most problematic phase of the information flow, particularly when the receiver was from a different department, as: 1) there was lack of awareness of the available documentation; 2) documentation, particularly from the service phase, was scattered across different repositories and mostly unstructured and finally 3) service documentation was often created to capture dynamic knowledge related to ongoing processes, e.g. request for change, trouble shooting etc. hence not organized to reuse information in other contexts. The consequences were difficulties in situations of: 1) retrieval of documentation due to poor search criteria which were not consistent across databases; 2) obtaining a complete picture of a project, product, etc. from the documentation; 3) comparing documentation from different cases as it was not possible to assess similarity between cases without personal knowledge at the receiver side; 4) extract reusable information from available documentation.

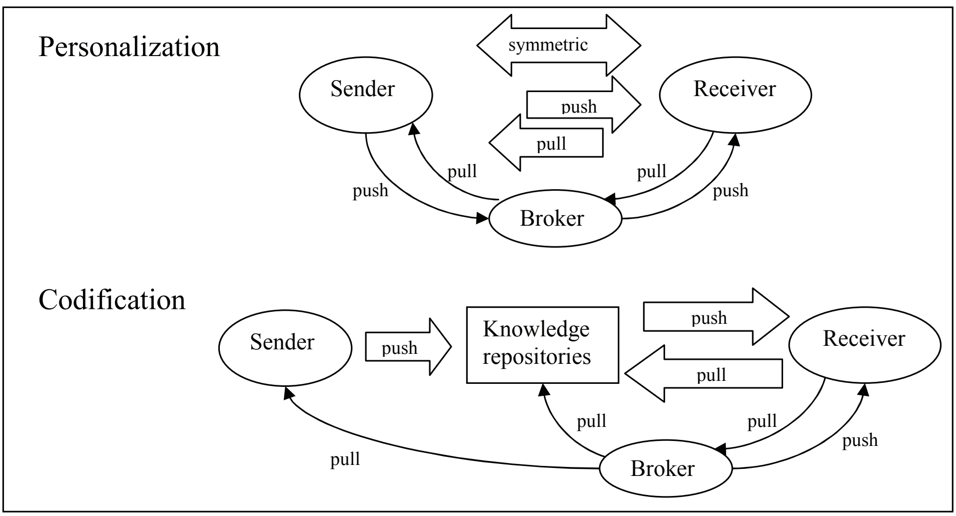

Figure 2 Modification of reservoirs through codification and personalization strategies

Although the storage of knowledge is particular to this company, the findings are in line with other research stating the difficulty for engineering designers to retrieve information from knowledge repositories and identifying colleagues as the most frequent source of information [19], with nearly 80% of information requests answered from memory. This explains the need of a broker acting as facilitator for transferring codified knowledge, particularly across departments.

6 INDUSTRIAL IMPLICATIONS

The analysis suggests that a company, when defining its knowledge management strategy, needs to consider the user of the information and the context in which information is reused, in order to ensure that information is structured in an appropriate way. This is particularly evident when information is to be reused across projects and across different user groups. In this case the company's knowledge strategy should include a translation process aiming to extract useful information from the available documentation and present it in a way suitable for the needs of the potential receivers. This may result in indexing approach to access codified knowledge differing depending on the user group. Specifically, in a context of customized equipment, efforts to facilitate knowledge transfer from service to design phases should be primarily focused on transferring information on changes and issues as this emerged to be the most relevant information to share across departments.

In the cases of a company's strategy based upon codification, the access and the reuse of service knowledge by engineering designers could be facilitated through:

- structuring service knowledge according to the perspective of engineering designers towards the product, e.g. making information retrievable down to the component level;
- translating service information into more stable forms directly applicable to the design phase.

7 CONCLUSIONS

This paper investigated the knowledge relevant for engineering designers and service engineers and to what extent this knowledge was transferred across departments in the context of a company supplying drilling systems.

The two groups approached the same product, i.e. the drilling system, from two different perspectives. Engineering designers considered it as divided into different parts and components and were mainly interested in knowledge about the product itself while service engineers had a general overview of the system and were interested in understanding how parts interact and knowing the behaviour of the system over time, hence they were more orientated towards a project dimension. This difference in approaches was reflected at the organizational level, as the design department was organized functionally by product while the structure of the operation department was focused on creating a general profile of service engineers that are able to perform a high variety of jobs for the entire drilling system. This implies that service engineers and engineering designers need to access knowledge differently; engineering designers in relation to sub-assemblies and service engineers for complete systems and over time.

The main type of knowledge relevant for both departments was about changes and issues arising during service. Although engineering designers found this knowledge relevant during the design phase they rarely retrieved available documentation from the knowledge repositories, instead preferring to contact directly senior positions at the operational side if necessary. This was caused by: 1) difficulties in retrieving relevant documentation due to poor search criteria 2) available documentation not structured according to the needs of engineering designers with reports that were not specific for the different components.

The two groups had different needs regarding knowledge sharing. Engineering designers were overloaded with information, e.g. more than 50% of instances regarding knowledge arising from service was pushed, hence made available to them, and their main interest was how to structure this in a way to facilitate its reuse during the design process. On the contrary, service engineers' requirements for information were not fully fulfilled; they expressed the need to access more information and tended to pull information from the design phase. Additionally service engineers addressed the problem of knowledge sharing across departments through a willingness to share their knowledge in order to improve the quality of machinery; in contrast engineering designers were not likely to seek information from operation while designing a product. This resulted in the service engineers being the initiators of most of the communication with engineering designers, either by pushing information from the operation of machinery to engineering designers or by pulling the information they need from the design phase.

In the analysed case study of a company supplying drilling equipment and involved throughout all the phases of the product lifecycle, despite the company investments in the development of integrated knowledge repositories, personalization strategies built upon personal networks were found to be the most effective way to transfer knowledge across departments. This suggests that a careful analysis of the different user groups is required and documentation has to be structured according to the needs of the receiver in order to make knowledge repositories an effective means for transferring knowledge across departments. Furthermore alternatives to knowledge repositories should be taken into account and a company should evaluate, according to its characteristics, whether its knowledge management strategy should be based on personalization, codification or a mix of the two before starting developing new knowledge repositories.

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Contact: Giovanna Vianello
Technical University of Denmark, DTU
Management Engineering Department
K&P Section
Produktionstorvet
Bygning 426, Room 130
2800 Kongens Lyngby, Denmark
+45 4525 4163
gvia@man.dtu.dk