7 TRANSFER OF SERVICE KNOWLEDGE: A CASE FROM THE OIL INDUSTRY

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The general trend in engineering design is to consider issues related to the product lifecycle during the design of a product. Hence, the capture of knowledge arising during the operation phase (service) and the feedback of this to engineering designers is an important aspect of complex products. The reuse of this knowledge is even more critical when customized machines are involved. The aim of this paper is to investigate the knowledge arising during the later phases of a product's lifecycle focusing in particular upon the transfer of experience between projects and between different user groups. A case study of drilling machinery for offshore oil rigs has been selected. This choice arose from the unique characteristics of this industry where solutions are specific for each rig, so re-design or adaptation of machineries and assembly is required in each project and it's imperative to have a correct set of requirements and design. As the drilling machines are one-off machines, the transfer of experience between projects and knowledge from operational experience is essential. Interviews with the project team from the company owning the rig (drilling contractor), and the service engineers from the supplier of drilling equipment have been carried out focusing upon mechanisms, initiators, barriers and drivers of experience transfer between projects. The analysis of the interviews shows the importance of cross-project experience transfer and the results can be used to support and organize the communication between projects in a more efficient and systematic manner. The results also show that communication is one way- from design to service only.

Keywords: Product Lifecycle Management, Design Knowledge Management, Information Management, Service, One-Off machinery, oil industry.

1. INTRODUCTION

The general trend in engineering design is to consider issues related to the different phases of product lifecycle during the design of a product. Hence, the identification of the knowledge arising throughout the lifecycle and its feedback to engineering designers plays an important role in product development. Variant industries, such as the aerospace industry, have begun to understand the importance of service knowledge as they move towards selling a Product Service System, where Power by Hour rather than an engine is sold. Even in industries which have not moved towards a PSS, the knowledge of how the product behaves in service is still relevant, e.g. the trend of user-driven innovation for consumer products. In the case of the research presented here, the focus is upon complex business to business industry, specifically design of oil drilling equipment and rigs. In the oil industry, drilling systems are specific for each rig or set of rigs, so re-design or adaptation of machineries and assembly is required for each project, hence having well-defined set of requirements is important. As the drilling machines are one-off machines, the transfer of experience between projects is essential as reusing design (as which may be possible in the case in variant industries) is not always an option.

2. AIMS

The purpose of this paper is to investigate the knowledge arising during the later phases of a product's lifecycle and in particular focuses upon its transfer within and across projects and between different user groups. The paper specifically aims to understand:

1. To which extent knowledge in one-off industries is relevant to be shared across projects despite their customized nature.
2. The mechanisms for transferring knowledge both within a project and across projects.

3. BACKGROUND

The transfer of knowledge has captured the interest of many different research areas, each with its own specific interests. Initially research in cognitive psychology focused upon the analysis of the phenomenon of knowledge transfer at the individual level. Researchers from this field investigated how knowledge is generated, Anderson[1] claims that analogous learning mechanisms are involved in a wide range of skill acquisitions and propose a theory on acquisition of cognitive skills that divides the cognitive process into three stages: (1) a declarative stage when the learner obtains information about the skill; (2) during the compilation stage the information is interpreted and converted into a procedural form and; (3) at the procedural stage, the use or the acquired skill is applied more and more appropriately. Furthermore Anderson identifies problem solving as the basic mode of cognition. Further studies[2] extend these results proposing methods to evaluate training based on learning outcomes and acquired skills.

During the 1990's management research approached the topic at an organizational level to understand how a firm's own knowledge can be turned into a competitive asset. Several empirical studies on the subject claim that firms with clear strategies in knowledge transfer are more successful than the others. Zander and Kogut, for example, argue that a company's success is connected with the speed of transferring internal knowledge and measure this in the form of production capability.[3]

At a higher level of analysis, macro organizational theory sees efficient knowledge transfer as a driver for the variation of the organizational form and the growth of inter-organizational collaborations, as in complex areas innovation is generated in networks of learning rather than individual firms.[4]

In engineering research the interest in knowledge management issues is motivated by the growing amount of information that company need to deal with and the consequent need of capturing, structuring and organising it in a way to allow its retrieval and reuse during the development process. Additionally the current flexibility of the job market reduces the probability for an engineer to grow up within a company. This impedes the reuse of personal expertise across projects and results in companies adopting innovative approaches to accelerate the learning process and facilitate the reuse of past experience, including changes in organization and introduction of IT tools.[5] The range of solutions extends from systems to support engineers through supplying experience from past projects[6] to the creation of networks to support informal communication and learning;[7] the choice of the appropriate approach is influenced by the type of organization.

Only a limited number of studies have been conducted in the engineering field to understand what actually constitutes the knowledge arising during the service of products and how this can be reused during the lifecycle of a product or to support designers during the design of similar products. Jagtap's study investigated the service phase from a design perspective and identified which requirements from service are taken into account by designers and what service information designers would like to access.[8]

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 strategy while considering the characteristics of the company. Hence this paper focuses

Table 1. Participants interviewed.

	Drilling Contractor		Supplier of Oil Drilling Equipment		Other Suppliers
User Group	Project Team	Operators of Equipment	Designers of Equipment	Service Engineers	Service Engineers
Participants	4	3	2	2	1

on the analysis of motivation, mechanisms, and dimensions of knowledge transfer in an engineering context.

4. METHODS

4.1. Case Selection and Data Collection

A case study of drilling machinery for offshore oil rigs has been selected. The chosen case consists of a series of four oil rigs to be completed with six month delay between them. The rigs, from a construction point of view, are to be considered copies; the intention of both the drilling contractor and the supplier of the equipment is to reuse the rig design and the experience arising from installation and commissioning of the first rig in the others. The research presented here was carried out at the end of the commissioning phase of the first rig whilst the others were under construction.

A total of twelve interviews were carried out at the yard with various stakeholders involved in commissioning and operation. The participants represented the project team, the equipment designers, the service engineers and the operating crew, see Table 1. The interviews were semi-structured, with questions asked related to: communication, knowledge required during commissioning and service and transfer of experience. Not all participants were asked all the questions (only certain groups of questions were relevant for some of the interviewees). All interviews lasted between 20–45 minutes, and were audio-recorded. The interviews were transcribed, resulting in 1872 segments, and coded by two coders, using a pre-determined coding scheme, described in detail in Chapter 4.2. A coder-reliability check was conducted and kappa found to be 0.98; all disagreements were checked and an agreement reached.

The findings from the interviews have been coupled with the change documentation arising from the different rigs, to investigate whether the number of changes is decreased from one rig to the next and whether repeated problems occurred. The number of requests arising from each rig has in fact been used as an indicator of the experience transfer between rigs with the assumption that if the number of change requests significantly decreases from one rig to the next then this implies that some transfer of experience has occurred.

4.2. Data Analysis

4.2.1. Interviews

The transcriptions from the interviews have been coded according to a scheme elicited from existing literature on knowledge management, particularly on knowledge transfer. The scheme includes different categories, each one embracing codes and subcodes. Subcodes within a code are mutually exclusive. An overview of the categories and the main codes is shown in Table 2.

4.2.2. Change documentation

The change documentation from the four rigs has been analysed quantitatively. This documentation is used to report changes throughout all the lifecycle of the rigs, from the design phase to operation and service. The change reports from each rig have been grouped according to the date of their initiation. Each group covers a 6 month period starting from the date the first report from the first rig has been submitted. As the four rigs have a 6 month delay between each other, the number of changes for the four rigs is compared by analogous phases of their lifecycle, rather then by total number of changes.

Table 2. Coding scheme.

Categories	Codes (Subcodes)	Definition	Literature
Knowledge Characteristics	Stage (Capture, retrieve/reuse, transfer)	Phase of the knowledge transfer process	Wallace, *et al.*[9]
Knowledge Transfer	Type of capture (Personal, codified)	Transfer through structured (codified) ways or relying on human factors	Hansen *et al.*,[10]
	Context (Across projects, across rigs, within rig)	Transfer within a rig, across rigs part of the same project, or across projects	
	Initiation mechanism (push/pull/fixed)	Transfer pulled by the receiver, pushed by the sender or initiated by fixed means	McMahon *et al.*,[5]

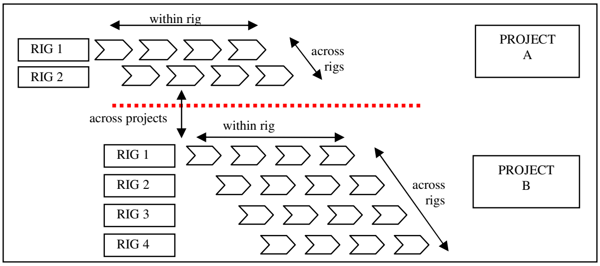

Figure 1. Transfer within rig, across rigs and across projects.

5. RESULTS

The transfer of knowledge from the rig during commissioning and operation has been investigated throughout interviews with operators, project managers from the drilling contractor, designers and service engineers from the supplier of drilling equipment and other third parties. From the interviews three dimensions of knowledge transfer have been elicited (illustrated in figure 1):

- *within a rig*: transfer of information related to the progress of that rig or the lifecycle of the rig (e.g. through handover, records, talk among colleagues)
- *across rigs*: that are part of the same project: reuse of experience from the first rig into the next ones of the same series (e.g. through moving the crews from one rig to another, transfer of change records, reuse of procedures)
- *across projects*: experience gathered through lessons learnt, personal experience, maintenance records and reused in subsequent projects (i.e. a different series of rigs).

These dimensions were considered in relation to knowledge transfer during the analysis of the interviews and are reported in Section 5.2.2

5.1. Change Documentation

The change documentation arising from each of the four rigs was analysed quantitatively, to investigate whether the number of changes is decreasing from one rig to the next one. The results of this analysis are shown in Table 3 the changes of the four rigs are compared with each other for similar stages of their lifecycle, where the first stage starts with the design phase and the fourth stage includes the rig entering into operation. Due to the 6 month delay between one rig and the next one, only rig 1 was in operation when the data were collected and the interviews carried out.

The reduction of changes between the first and the second rig is significant, particularly in the first two stages when the number of changes in the second rig drop by 75% and 90% respectively compared to the changes from the first rig. These data confirm that transfer of experience has taken place across

Table 3. Number of changes for similar stages of the lifecycle for the four rigs.

		Stage 1	Stage 2	Stage 3	Stage 4
Number of Changes	Rig 1	22	79	32	48
	Rig 2	5	8	25	
	Rig 3	6	10		
	Rig 4	6			

Table 4. Types of transfer of knowledge identified

Knowledge transfer	Push	Pull	Planned meetings	Planned other	Total
No. of instances	31	18	7	6	62
Percentage	50%	29%	11%	10%	100%

the rigs. The first data arising from the later rigs of the family seem to confirm the distribution of changes emerging with the second rig and indicate that a further reduction of the number of changes from the last rigs is not likely to happen.

The distribution of changes throughout the lifecycle of the first two rigs seems contrasting: rig 1 has a peak in the second semester while rig 2 shows a constant increase of the number of changes per semester throughout its lifecycle. A qualitative analysis of change documentation is needed to better understand the type of changes emerging from the different phases; additionally data from the later rigs are requited to investigate more in depth the knowledge transfer across rigs.

5.2. Interviews

5.2.1. Push/pull. What triggers the exchange of information?

The motivation for knowledge transfer was analysed to investigate whether knowledge was pulled, that is driven by a request for information from the receiver that actively seek it out, or pushed, when the sender makes information available before a specific need for it has arisen. An intermediate stage was also identified: planned transfer due to fixed meeting or standard reports, i.e. there is no specific need or request, but an organized process to share knowledge.

Table 4 shows that only 21% of the total instances on transfer of knowledge identified was due to a planned procedure, i.e. a planned meeting or a report. Around a quarter of the transfer was pulled whilst the majority of cases (50%) were cases of pushing knowledge, with. the sender passing on knowledge without the receiver actively requesting this knowledge. Hence, we can see that the knowledge pushed is not necessarily reused, whereas the knowledge that is pulled i.e. requested or actively sought identifies that there is a need for this knowledge.

All the examples of planned knowledge transfer were related to either the status of the project within the current rig, or lessons learnt which maybe relevant to the next three rigs.

A qualitative analysis was carried out to understand this better and is described below. The push/pull mechanisms are studied in relation to the type of sender and receiver of information, particularly people involved in the design phase and those involved in the service phase. The analysis highlighted that all communication between the service and design phases is one way- from service engineers to design, where the service engineers are pushing the knowledge to the equipment designers. The knowledge that is pushed to the engineers includes: reporting of changes and feedback of problems. The preferred media of feedback was personal contact; with only one instance (from seven) where the knowledge captured into documentation was identified. No feedback of service knowledge across project, i.e. could be used for the design of the equipment on the next set of rigs, was identified.

Table 5. Where Knowledge is Transferred.

Type of Knowledge Transfer	No. of Instances	Percentage
Across/Within Rigs	3	2%
Across Projects	22	12%
Across Rigs	128	70%
Within Rig	31	17%

Table 6. Capture and retrieval of projects.

	Across or Within Rigs	Across Projects	Across Rigs	Within Rig
Capture	5%	10%	67%	19%
Reuse/Retrieve	0%	35%	52%	13%
Transfer	4%	7%	59%	30%

5.2.2. Transfer of knowledge across projects, across rigs, within rig

In the analysis of the interviews it became clear that the knowledge transfer follows different trends in respect to the context when it occurs. The majority of instances on knowledge transfer focused upon transfer from the first rig to the remaining three, i.e. *within project* (70%), with very few instances (12%) of *across projects* knowledge (from this series of rigs to another) identified. In total 22 instances of *across project* knowledge were identified, as opposed to 128 *across the rigs* (see Table 5). Hence, the majority of reuse is focused upon transfer of knowledge from one rig to the next ones within the same project, and around 17% of transfer of knowledge related to *within rigs*. This trend is confirmed by the quantitative analysis of change documentation, where a significant reduction of the number of changes emerged between the first and the second rig that implies that an effective transfer of knowledge across rigs has actually occurred.

The stages of the knowledge characteristics, i.e. creation, capture, etc refer to Refs. 9 and 10 were examined against the type of knowledge transfer. The relevant findings are presented in Table 6. It is clear that the majority (67%) of knowledge formally captured during the commissioning and installation phase of the rigs is knowledge that is relevant *across rigs* rather than *across projects*, i.e. not much knowledge that could be reused across projects is being captured (around 10%). However, when reuse and retrieval of knowledge is considered, knowledge of previous rigs is relevant as 35% of that retrieved or reused is from rigs from past projects, whilst knowledge across the rigs is still the most pre-dominant category. A second way to understand if knowledge across projects is relevant in the one-off drilling equipment is to see if problems that have been seen on this rig are similar to the ones that have been seen before, i.e. are repeated, hence knowledge related to these past problems could have been relevant to the current problem. 24 instances of repeated problems were identified during the commissioning/installation phase, i.e. the participants are aware of the problem from a previous project that they have worked on. These repeated problems show that lesson learnt in past rigs could have been used in the current rig, however little knowledge is captured with this intention.

The category of *Transfer* in Table 6 refers to transfer of knowledge through people (either through people with relevant knowledge being employed in teams on related projects, or communicating informally with people). The transfer of knowledge was used for sharing knowledge across rigs (through transfer of crew experience by having the same people as part of the crew and project management team of the next rig, and hence knowledge related to the use of the equipment and project management was transferred through these people. Transfer through communicating directly with people was the main way of transferring knowledge within a rig, i.e. during the handover phase from equipment design to operation, and from project management to operators. Previous studies[11] showed that testing and installation phase, followed by the service phase are the most critical phases in a product's lifecycle with respect to engineering changes. Hence, the transfer of the experience from the first rig becomes crucial for the reduction of the number of changes arising from the other rigs.

Table 7. Codified or personal knowledge.

	Across Projects	Across Rigs	Within Rig
Codified	44%	62%	61%
Personal	56%	38%	39%

The data was also analyzed to understand if there was a difference in the type of knowledge sharing. Hence instances were examined to see what percentages of knowledge transferred (*within a rig*, *across rigs* and *across projects*) is codified or personal. It was found that *across rigs*, and *within a rig* the majority or knowledge is codified, whereas in the case of sharing *across projects*, this was predominantly personal approaches to capture, retrieve and share knowledge (refer to Table 7) this is inline with the finding relating to transfer of knowledge and illustrates the heavy reliance on personal knowledge and experience to reuse knowledge across projects.

5.2.3. Types of Knowledge

A qualitative analysis was carried out to understand better how the different types of knowledge sharing took place, and this is identified below:

- Across Projects: one series of rigs to another series

Examples of knowledge reused from previous projects included knowledge related to common problems that occurred in the past or related to component life for preventative maintenance. In relation to software, some of the suppliers also adopted module based approaches to reuse modules from past projects. The findings show that not much knowledge is captured or structured with a focus upon across project capture, and much of this is reliant on personal, hence heavily reliant on people. Examples of repeated problems were seen and highlighted the need to capture such knowledge.

- Within project: across the four rigs

67% of all instances identified were related to knowledge transfer across the four rigs. Two main reasons are identified: (1) change due to error/improvement, and secondly (2) transfer of peoples, operators and project teams. Often the design is transferred and not necessarily the knowledge, i.e. software errors are rectified and copied across the four rigs, and mechanical problems may result in change requests for the next rigs. In relation to improvements, changes needed to be justified before they could be implemented. The procedural knowledge of how to operate the equipment was transferred primarily through people and was not codified.

- Within rig: throughout the lifecycle

The majority of knowledge transferred within the rig, i.e. during the handover between development and operation was transferred through the category 'transfer' i.e. through people informally communicating with one another. These transfers occurred between client and supplier, involving training of equipment, etc. and also between the client's project team and operators.

6. CONCLUSIONS

A study has been carried out during the installation/commissioning phase of an oil rig to understand if knowledge in one-off industries is relevant to be shared across projects despite their customized nature. Interviews were carried out with various stakeholders, and combined with document analysis to understand experience transfer in complex one-off industries. The analysis of the interviews shows the importance of cross-project experience transfer and the results can be used to support and organize the communication between projects in a more efficient and systematic manner. The document analysis highlights that experience transfer does take place due to the reduction in number of changes from one rig to the next rigs in a series of rigs.

The findings show that in the design of one-off products, knowledge is shared in three ways: within the rig, across the rigs, across projects. The findings show that emphasis is placed upon sharing knowledge across rigs (i.e. rigs that are part of the same project), and within a rig, with little focus on sharing across projects, i.e. across different series of rigs. The mechanisms identified for each of these are different; i.e. *across rigs* the knowledge is transferred through codified manners, while *across projects* is heavily reliant on people and their personal knowledge and experience. Although there is evidence that across project knowledge is relevant through instances of reuse identified and through examples of problems seen which have occurred on past projects, the focus is still very much upon reuse of design through fixing errors within one project (i.e. across rigs), and reliance on people to transfer operational and process knowledge.

In relation to the second aim of the project (to understand if knowledge is pushed or pulled), it was found that transfer of experience is often pushed (50%), and there are some formal procedures (around 21%) which are planned transfer. It was found that knowledge is also pulled, which indicates that knowledge is required and needed. This was supported by the observation of repeated problems identified on this rig that have been observed in past projects.

The findings show that knowledge from past projects in one-off industries is both relevant and actively sought in new projects, however current mechanisms are heavily reliant on personal experience and knowledge. The findings also show that in this industry reuse has focused upon reuse of design solutions, and not of knowledge, hence a focus upon fixing errors, and improving designs within a project, from one rig to the next.

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