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Automotive engineering designers' unconscious decision making

Master's thesis in Learning and Leadership

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Abstract

In this study knowledge from engineers working with product development is captured, verified and analysed using the engineering check sheet method.

The engineering check sheet method applies iterative interviews to capture knowledge from experienced engineers. The captured knowledge is analysed and put into a checklist and categorised using the categories 'Know-What', 'Know-Why' and 'Know-How'.

Through additional interviews with engineers, it was found that the engineering check sheets to a high degree reflect their work process, even if there were some deviations due to information being outdated.

When the engineering check sheets were analysed, 15 reoccurring themes were identified. Of these, more than half presents knowledge on how to thin slice the available information in product development.

Keywords: Checklist, Knowledge Reuse, Knowledge Management, Engineering Check Sheet, Thin slice, Production Development

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Introduction

As society has changed from an industrial society towards a knowledge society, so has the industry (Nonaka, 1994). In the 1960s it was commonplace for newly graduated engineers to be hired as apprentice and to remain with the same company until retirement, a career spanning 40 or more years with the engineer often becoming experts in particular areas. Knowledge was passed along from master to apprentice and between colleagues often through informal communication (Wallace & Ahmed, 2003).

Today, “organisations are becoming more knowledge intensive, they are hiring ’brains’ rather than ’hands’ and the needs for leveraging the value of knowledge are increasing [Yew Wong, 2005, page 261]”. To manage knowledge effectively is important for companies, large and small, to sustain and improve their competitiveness (Yew Wong, 2005).

In the automotive industry, the Japanese company Toyota became famous for their ability to respond to a changing world, be it customers or new markets and to rapidly develop new products (Nonaka & Takeuchi, 2007). Toyota has successfully managed to use the strategy “learn local, act global” (Ichijo & Kohlbacher, 2008). One of the tools for knowledge management used by Toyota is engineering check lists. The engineering check lists are design guidelines of “what can or cannot be done or should or should not be done – based on past experience, analysis, experimentation and testing (Sobek, Ward, and Liker, 1999, page 73)”.

Despite the evidence of success from Japanese firms in general and Toyota in particular, many firms fail to successfully adopt knowledge management methods, such as engineering check list.

1.1 Case description

The case company in the present study is a larger company in the automotive industry. The company reports that it has lost valuable experience due to high staff turnover in their product development projects, as they employ large amount of consultants during the projects which are let go when the project is finished. Another problem the company is facing is the geographical distribution, as they have development in Sweden, France, USA, India and Japan. The conclusion from the line organization is that they need a way to document experience gained from completed projects so it can be reused for future projects. To answer this need the case company implemented “engineering check sheets”, which is their version of the engineering check lists of Toyota, as a part of their knowledge management strategy. The idea was that by using engineering check sheets, the knowledge amassed by the case company's engineers can be captured and shared throughout the organization.

Before the present study was initiated, a knowledge management specialist ran a small pilot project, creating engineering check sheets for two components through a cycle of iterative interviews. As part of this study these engineering check sheets was improved upon and used as templates for creating additional engineering check sheets for a wide selection of components.

1.1.1 Project timeline

The engineering check sheets newly were introduced as a knowledge management tool at the case company at the start of this study. It was therefore deemed necessary to let the engineers of the case company use them for a while before it would be possible to do a meaningful evaluation of their usefulness. This time is necessary so that the engineers have a chance to use the engineering check sheets as part of their work routine or hand-over to their successors. This study has therefor been carried out as a longitudinal study (Yin, 2017).

The study was divided into two separate parts. The first part took part during the summer of 2014, and continued the work started with the pilot project. The pilot project had resulted in 2 engineering check sheets as well as a basic method for how to create the engineering check sheets. During this period an additional 6 engineering check sheets were created.

The second part was performed almost one year later, during the spring of 2015. During this part the focus was to evaluate the usefulness as well as the correctness of the engineering check sheets. For this purpose in depth interviews were performed with engineers responsible for 3 of the engineering check sheets.

1.2 Purpose

The purpose of this Master's thesis is to explore what kind of knowledge is used by design engineers in product development projects, but also to investigate the usefulness of checklists as a tool to elicit, document and promote reuse of knowledge.

1.3 Research questions

The study aims answer the following questions regarding the content of the engineering check sheets:

- What are the knowledge in the engineering check sheets about?
- Is the identified knowledge used and needed by the designers during the concept development?

To evaluate the engineering check sheet as a tool and understand if the usage of them add value (e.g. higher quality, shorter time to market, lower product cost) they will be compared to checklists from other fields (i.e. aviation and grocery shopping) were checklists are efficiently implemented and used. By looking at how different checklists are used and the benefits of them in their corresponding fields, this study aims to answer the following questions:

- What are the similarities and differences between the engineering check sheets and other the checklists?
- Are the differences valuable or needed for the efficiency of the engineering check sheets?

In addition, the study will evaluate the method used for creating the engineering check sheets as well as their current usage.

1.4 Limitations

The project is limited in several ways due to time constraints and available resources. The following limitations will be applied:

- Only engineers within the automotive industry are considered
- The interviewed engineers work in one project
- The engineers observed will be working on components that are at the same development level
- Only one method for identifying the engineers knowledge is used.

2

Theoretical framework

Knowledge and experience acquired by automotive engineers over several years is relied on to make decisions on how to fulfill project goals and requirements for their component. When developing a new concept, engineers are faced with many decisions, which all can have an impact on cost, durability, customer satisfaction and manufacturability. The tools available for engineers are both their experience and large amounts of information and data in the form of technical standards, requirements, specifications, material properties and so on. To be able to complete the development on time, successfully and without too much expensive testing they need to use some kind of strategy for development, unconsciously or consciously, based on their experience and knowledge.

2.1 Knowledge creation

Ackoff (1989) put the concepts data, information, knowledge and wisdom in a hierarchy, illustrated as a pyramid with data as its foundation, information and knowledge a the mid-layers and wisdom at the top. Each level of the pyramid builds on the previous, as we can not have information without data, or knowledge without information (Ackoff, 1989).

According to Yuan Fu, Ping Chui, and Helander (2006) data are measurements of variables, i.e. raw figures, and information processed data in and for a specific context, e.g statistical analysis of the data (Yuan Fu et al., 2006). Together data and information provide answers to the questions “who”, “what”, “when” and “where” such as what was the car’s speed, when did the accident occur and so on. Data and information when organised and put into a specific context becomes knowledge (Nonaka, Toyama, & Konno, 2000). Knowledge is answers to “how” questions but it is also actions (Zeleny, 2005). As Aven (2013) put it, if the temperature of the room is information then how to control the temperature is knowledge.

Knowledge can be divided into tacit knowledge and explicit knowledge (Polanyi, 1966; Nonaka & Takeuchi, 2007). Tacit knowledge is knowledge that can not be explicitly expressed, in the sense that possession of the knowledge (the know-how) does not mean the ability to explain or even have the slightest idea of how it really works (Polanyi, 1966). Polanyi (1966) uses the example of riding a bike, since the ability to ride a bike does not mean that we can communicate how we do it; it is something we have to embody, making it impossible to break it down into specific articulated steps. Explicit knowledge is, on the other hand, knowledge that readily can be articulated and shared (Yuan Fu et al., 2006), much like how a teacher explains the solution of a math problem to the class, but not necessary understood.

2.1.1 The SECI-model

According to the SECI-model put forward by Nonaka et al. (2000), individuals create new knowledge through interactions called knowledge conversions. The conversion process expands the quality and quantity of both explicit knowledge and tacit knowledge (Nonaka et al., 2000). The four different knowledge conversion modes are socialisation (from tacit knowledge to tacit knowledge), externalisation (from tacit to explicit), combination (from explicit to explicit), and internalisation (from explicit to tacit) (Nonaka et al., 2000). Later, Nonaka et al's model has been criticized, as though it is called 'knowledge conversion' it should be noted that the knowledge is not converted from tacit to explicit or from explicit from tacit but rather a process where knowledge possessed is used to create new knowledge (for an individual or group) (Powell, Thomas, & McGee, 2007).

Socialisation

By sharing an experience through a organization, tacit knowledge can be tacitly shared between individuals and groups (Nonaka et al., 2000). It requires time spent together in the same environment and the knowledge is often shared through observation, imitation and practice (Nonaka & Takeuchi, 2007). Sharing the knowledge in this way creates tacit knowledge for the recipient.

Polanyi describes this as "A novice, trying to understand the skill of a master, will seek mentally to combine his movements to the pattern to which the master combines them practically (Polanayi, 1966, page 14)". According to Nonaka and Takeuchi (2007), this process is characterized by that neither the master or the novice gain any systematic insights of the knowledge and the knowledge shared is rather limited.

Externalisation

Externalisation is the process of piecing together pieces of tacit knowledge so that it can be expressed explicitly. The process is unconscious (due to the nature of tacit knowledge), but can often end with a "heureka moment" when the new knowledge becomes tangible. The story of Archimedes in the bath is a prime example of how pieces of tacit knowledge can come together and be externalised as new knowledge.

Externalisation is important as it allows for ideas and concepts to be shared and discussed with others, allowing for more knowledge to be created (Nonaka et al., 2000). Being able to express the knowledge is a key part of efficient knowledge sharing.

Combination

By combining explicit knowledge, either as an individual or in a group, new explicit knowledge can be created (Nonaka & Takeuchi, 2007). The process can be helped by building prototypes, collaborations, workshops or by experimentation. For example, at the case company there are recurring workshops where engineers from different areas of expertise attack particularly hard problems, such as integration of several subsystems.

Internalisation

By using explicit instructions, following and reflecting upon them we can internalise the knowledge. As Nonaka et al. (2000) say "Internalisation is closely related to 'learning by doing' [Nonaka et al., 2000, page 10]". Explicit knowledge can not transform into tacit knowledge without action. So to internalise explicit knowledge, the knowledge needs to be actualised through action and practice (Nonaka et al., 2000) which in turn creates the requirement of a personal commitment (Nonaka & Takeuchi, 2007).

When a student is learning mathematics, the student is given a set of explicit instructions. These instruction should be imitated and combined to solve the different problems. It is not until the student commit herself to the problems presented and apply the instructions she can internalise the explicit knowledge.

2.1.2 Learning

Knowledge conversions create creates a spiral of knowledge creation for both the individual and the group (Nonaka & Takeuchi, 2007). Once again, it should be understood that it is not a question of converting knowledge from one category to another, but rather using existing knowledge to aid the creation of new knowledge (Powell et al., 2007). This is similar to how Vygotsky (1978) describes how "the zone of proximal development" grows with new experience. The zone of proximal development is the second of three zones. The first being what the learner can do herself, the second what the learner can do with guidance and the third zone contain what the learner can not do even with help (see figure 2.1) (Vygotsky, 1978). According to Vygotsky (1978) very little learning occurs in the first zone, since the challenge to the learner is to small, and in the outermost zone, since the challenge is to great and the learner is discouraged and will not be engaged.

However, faced with a challenge from the zone in the middle, the zone of proximal development, the learner can with help from a facilitator both be engaged by the challenge and learn from the new experience. The facilitator will assist the learner to identify the needed knowledge and through the action of solving the problem and experience new knowledge will be created for the learner. Vygotsky (1978) puts a heavy emphasis on social interaction between individuals and describes diminishing results from using written

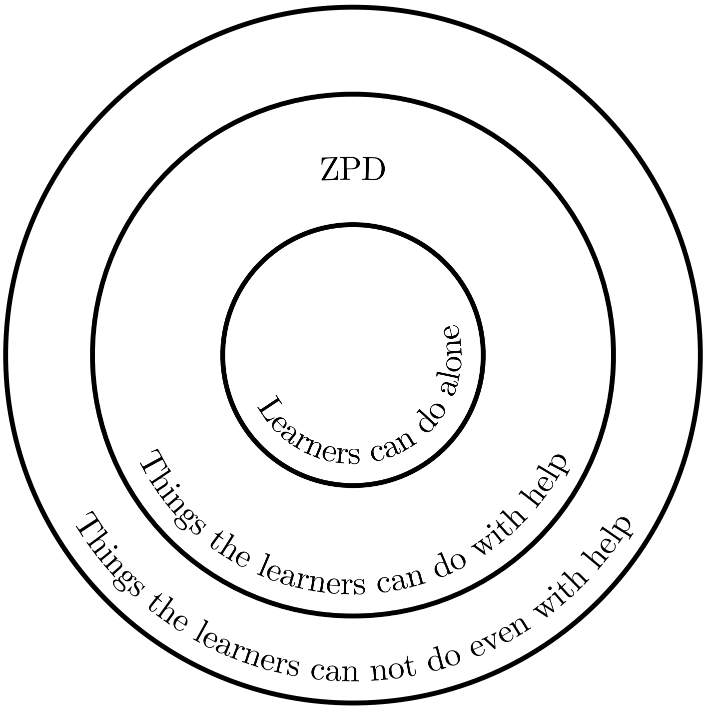


Figure 2.1: The zone of proximal development is the second zone. If the learner is faced with a problem in this zone and is given support, she can both solve the problem and gain new knowledge. Challenges in the innermost circle are to easy and the learner seldom gains any new knowledge. In the outermost circle, the problems are to challenging and the learner can not solve them even with support. The learner will not gain new knowledge and can in many cases be discouraged from expanding her knowledge in that direction (Vygotsky, 1978).

documentation. By constructing the written documentation in a way that closer mimic the interaction between a learner and a facilitator (using the question “what”, “how” and “why”) I argue that even if the result will be diminished, the written documentation will provide benefits similar to a human facilitator.

For example, when an apprentice is working with a master, the master shows the apprentice how to perform a task. If the knowledge required for the task is in the zone of proximal development, learning can occur and new knowledge can start to be created by sharing the master’s internalised tacit knowledge to the apprentice by socialisation. This process will not result in any systematic insights for the apprentice (Nonaka & Takeuchi, 2007), but it will increase her zone of proximal development (Vygotsky, 1978). By using this small amount of socially learnt tacit knowledge, the apprentice can articulate questions and reflect upon the actions she takes, externalising the tacit knowledge and creating new explicit knowledge in the process (Nonaka et al., 2000). This can prompt her to gain explicit knowledge for what to look for when observing the master and what questions to ask. This makes it possible for her to expand her zone of proximal development even further, combining her explicit knowledge with that of the master. By applying this new knowledge in her work, the apprentice can internalise the new knowledge and in turn use it to tacitly make new observation, learn more and making her knowledge spiral towards mastership.

In the meeting of two masters , the same process takes place. They will use their tacit knowledge and explicit knowledge to make observations, to make inquires and discuss their work. They might be able to create a new knowledge by combination of their explicit knowledge, and by applying it, they will learn to understand it tacitly.

In the cases above, very similar learning cycles takes place. The learner, be it a novice or a master, uses prior experience (in the form of tacit or explicit knowledge) as a reference or starting point to build their new knowledge (Nonaka & Takeuchi, 2007). Through collaboration the learner can rely on another's experience to expand what learning that is possible (Vygotsky, 1978). The knowledge created might be completely new in such way that no party in the collaboration possessed it before, neither explicitly or tacitly, but the new knowledge will not exist without the context of the earlier knowledge (Nonaka et al., 2000). That is, all new knowledge will be related in one way or another to old knowledge.

2.1.3 Formal and informal learning

The knowledge and experience a skilled engineer possesses comes both from formal and informal learning. The formal learning comes from education, workplace training or similar and is to a high degree made up of explicit knowledge (Kavakli & Gero, 2003; Nonaka et al., 2000). Common factors for the different kinds of formal learning situations are that it has an outspoken goal and is organized for the learning. In contrast, informal learning is more difficult to account for. The informal learning can come from a number of sources, the main trait is that the main purpose of the activity is not learning (Kavakli & Gero, 2003). Attending a seminar about a new tool would be formal learning while finding out that a certain material will not fulfill the requirements by testing it is informal learning. Formal knowledge can be passed on as informal and informal as formal and so on (Kavakli & Gero, 2003).

2.1.4 Difference in experience among engineers

An engineer with less than 5 years of experience is often seen as a novice while an engineer with more than 8 years of experience is seen as experienced. The main difference in knowledge between the novice engineer and the experienced engineer comes from work experience, which would mostly consist of informal learning (Kavakli & Gero, 2003).

One of the main differences between the groups are that novice engineers tend to implement a solution and then evaluate it, while the experienced engineers tend to evaluate solutions prior to implementation (Kavakli & Gero, 2003). The experienced engineer try to evaluate the solution both often but more importantly, earlier. This in contrast to the novice engineer, who trust the numerical data to be accurate enough to use to evaluate the solution rather than to perform prototype testing (Kavakli & Gero, 2003).

2.2 Decision making

Decision making strategies can roughly be divided in three categories of strategies: logical strategies , strategies based on probability and strategies based on intuition (Gigerenzer, 2008). Gigerenzer (2008) defines strategies as logical if the decision is reached by reasoning, based on probability if the decision is made using statistical analysis on historical data, and intuition as following gut feeling.

Design tasks are often ill-defined and have conflicting requirements. This means it is almost impossible to find an optimal solutions using strategies based on logic or probabilities (Gigerenzer, 2008; Ahmed, Wallace, & Blessing, 2003). Intuition on the other hand ignores part of the available information, do not try to optimise but rather finds good-enough solutions (Gigerenzer, 2008). To know what information to ignore becomes important, and heuristics (rules that are govern by intuition), created from experience, which order cues by importance and employ limited search helps with this (Gigerenzer, 2008).

2.2.1 Biases

The decision taken based on heuristics is influenced not only by the available information and the decision takers' experiences, but also by the biases they have (Tversky & Kahneman, 1974). Even an experienced professional runs the risk of unknowingly applying biases, or as Tversky and Kahneman put it: "The reliance on heuristics and the prevalence of biases are not restricted to laymen. Experienced researchers are also prone to the same biases – when they think intuitively (Tversky and Kahneman 1974, page 160)".

Examples of biases are base-rate neglect (ignoring general information and focusing on specific information), overconfidence (Kahneman & Tversky, 1996), insensitivity to predictability (drawing conclusions for predictions from too small data sets), the illusion of validity (producing unwarranted confidence from a good fit between input information and the predicted outcome), misconception of regression (ignoring that results tend to go to the mean value, e.g. an extremely good result in one test will probably be followed by a slightly worse result next time it is tested, and vice verse) (Tversky & Kahneman, 1974).

2.2.2 Decision making strategies

To mitigate the impact of biases , decision making strategies with simple stopping rules can be applied during the decision process (Gigerenzer & Todd, 1999).

The stopping rules can be frugal or non-heuristic. The main difference between frugal rules and non-heuristic rules are the number of aspects taken in consideration. A frugal rule only looks at a limited number, while a non-heuristic rule will take all or almostall known aspects into consideration. The frugal rules can be as accurate as the non-heuristic rules but only need as little as a third of the number of cues. An example of a frugal rule is “take the best”, where the choice is made by comparing the most important cues first. If this does not result in a clear choice , the second most important cues are compared (and so on). The ordering of the cues can for example be learned by observation. Dawe’s rule is an example of a non-heuristic rule, where all known cues are weighted and all positive cues are added up and all negative cues subtracted (Gigerenzer & Todd, 1999).

Experienced engineers seem to know where to look for the better cues as well as have some intuition for how important they are and applying frugal rules rather than non-heuristic rules when choosing what information to use. This has been ascribed to the experienced engineers being able to hold a larger amount of information in their short-term memory as well as also having a better spatial memory, consider more issues at once and having knowledge from earlier projects (Ahmed et al., 2003).

2.3 Thin-slicing

Thin-slicing offers a different perspective on knowledge, and specifically tacit knowledge. Thin-slicing is the process or ability to from a very small set of information make a correct prediction or assessment of a complex system (Ambady, 2010), without requirements on being able to articulate exactly what information were used or how it was interpreted. Making quick and correct assessments from limited information has been casually observed in several other fields, such as in sports (having *court sense*) and in the military (*coup d’oeil*). In these fields, thin-slicing is being able to sum up a situation and make a correct decision, without knowing what information to use (or even to look for) on a conscious level.

In the context of evaluating teachers, humans have been shown to subconsciously apply strategies to use minuscule amount of information to assess other people. These assessments have further been shown to not significantly differ from assessments based on much more information (Ambady & Rosenthal, 1993)(Tom, Tong, & Hesse, 2010). As with the experienced engineers studied by Kavakli and Gero (2003), the participants in Ambady and Rosenthal (1993) could not articulate everything they based their decision on, indicating that they used tacit knowledge to assess the technical solution or the teacher respectively to subconsciously create frugal decision making strategies, coloured by their earlier experience in respective field.

2.4 Checklists

In lacking of existing models and definitions, for this study checklists are proposed to be viewed as a subset of instructions and are, as the name suggests, constructed as a list with elements which are to be checked as they are performed. Furthermore, a checklist’s phases are here considered to be a planning phase and an execution phase. The outcome of the planning phase is the checklist itself (as an artefact) and the activities performed are here viewed as very similar to requirement elicitation activities in requirement engineering. In the execution phase the elements of the list are performed. A more complex model could for example include how feedback from a performed execution phase is used to update an existing checklist to improve (some aspect) of the next execution phase.

For the purpose of this study it is proposed that separating execution and planning have the benefit of removing the focus from remembering what action to execute, freeing up resources to focus more on executing the actions. Further, a claim is made that, if a checklist fulfills certain qualities, the checklist gives the possibility to standardize procedures, ensure quality, and break down bigger deliveries into smaller, bite sized deliveries.

To define such qualities, it is assumed that as a subset of instructions, general guidelines for instruction should at least partly apply checklist. Li et al. (2018) define the following qualities for good work instructions in general:

- Comprehensiveness: The instructions were sufficiently comprehensive for my assembly work (contained all necessary information).
- Validity: During my assembly work, I could trust that the instructions were correct.
- Timeliness: The instructions were presented at the right time (for me to perform my assembly work).
- Accuracy: The instructions were suitable for the task (assembly).
- Relevance: The instructions represented the reality.
- Accessibility: The instructions felt accessible, e.g. physical access, simple to navigate

As these qualities are for general work instructions (which may or may not include checklists) there is a need to adapt them for the purpose of this study.

3

Method

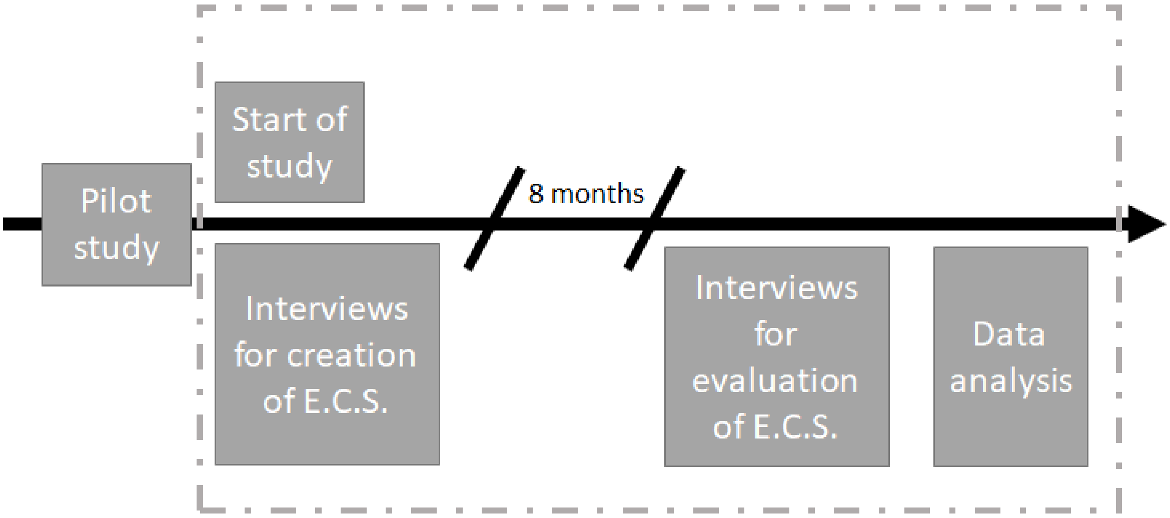
THIS STUDY HAS BEEN carried out as a longitudinal study (Yin, 2017) and consists of two different parts, the design and the analysis of engineering check sheets. The analysis of the engineering check sheets were both qualitative and quantitative. The engineering check sheet design as well as the qualitative data collection for the analysis where done through interviews, with me as the interviewer or co-interviewer for engineering check sheet interviews (the other interviewers were either a knowledge management specialist or an intern, both working for the case company), with the exception for the two engineering check sheets designed as a result of the knowledge management specialist's pilot. For the data collection interviews I took the role as a passive observer. All interviews were audio-recorded and transcribed, and complemented with field notes taken during them. Data were also collected from the engineering check sheets. See figure 3.1 for a schematic timeline for this study and the relation to the pilot study.

3.1 Ethical considerations

Brinkmann and Kvale (2009) recommend considering the following questions when performing qualitative interviews:

- Can the interviewees give an informed consent?
- Can confidentiality be ensured?
- How important is anonymity?
- What are the possible consequences for the participants?
- Who will have access to recordings and transcriptions?
- Are the transcription and used quotes loyal to the interviewees meaning?

Figure 3.1: Timeline for this study.



To ensure the ethical conduct of this study, these questions have been considered. All interviewed engineers were informed of the purpose of the interviews and audio recording and asked if they would consent to participate. Their managers were not informed of their participation in the study. All quotes taken from the transcriptions have been considered in the context to avoid misrepresentation. While the consequences for the participants are considered small due to the nature of the study (what knowledge is needed) steps have been taken to ensure the anonymity of the participants (e.g. masking of names, genders, component names). In according to the consent given by the interviewees, only the people working directly with the engineering check sheets have had access to the audio recordings and transcriptions.

3.2 Designing the engineering check sheet

The main objective with the engineering check sheet was to capture knowledge from designing engineers that explains their reasoning during concept development so it easily and readily could be reused in a later project, by the same or another engineer. The engineering check sheets were already implemented for two components at the case company, and the engineers that were to be interviewed had been introduced to the method through a short course held by an in-house knowledge management specialist.

3.2.1 The engineering check sheet format

The engineering check sheet were designed in Microsoft Excel, with each row corresponding to issue or activity identified from the data collected from the interviews. The issue is described in the column “Know-What”. In the column “Know-Why” the rationale behind

Table 3.1: The layout of a engineering check sheet. First row consist of the headlines, the second is a short description of the purpose for each column and the third row is taken from an engineering check sheet produced during this study.

Know-What	**Know-Why**	**Know-How**
The activity / Issue	Why it is an issue	What action is taken to solve the issue
Draft angles	The draft angles have an effect on which kind of coarseness can be allowed on the material surface for plastic	The following limitation is known regarding the draft angles effect on coarseness: [Redacted technical data]

why the issue is seen as an issue and in some cases the consequences of not managing it is documented. Recommended actions to handle or mitigate the risks with the issue is documented in the column "Know-How", along with best practices, expert knowledge and, if it could be identified, the rationale behind why the action is recommended.

3.2.2 The design cycle

The data for the engineering check sheets were collected through a series of iterative interviews with one or a small group of engineers responsible for the component in focus for the particular engineering check sheet. The interviews were conducted in three stages: initiation, correction, and confirmation. At least one interview was done in each stage. For some engineering check sheets, several interviews where needed in the correction stage.

A typical engineering check sheet design cycle started with one initiation interview, where the interviewee was made familiar with the scope of the engineering check sheet, through the introduction course and with examples from the existing engineering check sheets. The first interview followed a guide consisting of introduction of the engineering check sheet, asking the engineer to explain their component's functionality, if development of the component is done in-house or by a supplier and if there are any known problems with the component, both currently and historically. This was done both as a way for the interviewer to get a basic understanding of the component as well as to get the interviewee to speak more freely and make the interviewee comfortable. After using these topics for getting the interview started and the interviewee comfortable, the interviewees' answers governed the direction of the interview.

To identify the relevant information the interviews were recorded and transcribed. The transcription were analyzed for answers and comments from the interviewed engineer alluding to best practices, rules of thumb, solutions to known problems and rationales behind design decisions. The data was organized in three categories of the engineering check sheet: "Know-What" (issues), "Know-How" (how to handle specific issues) and "Know-Why" (why it is an issue).

Different activities, decisions, concerns and issues that could arise during the concept development were identified and categorized as "Know-What". Early in the design cycle many of the Know-What's were missing either rationale ("why it was an issue" or Know-Why) and/or actions ("how to handle the issue" or Know-How). The interviewer added his own interpretations, based on logical reasoning and experience from other components, and a question of the validity of the statement. Such statements were marked for elaboration in the follow-up interview. This resulted in a rough draft for the engineering check sheet. The draft was updated after each interview and used as a guide for discussion for the next interview. Based on the draft, the engineer was asked follow-up questions and to correct misunderstandings.

For most of the engineering check sheet, after the third or fourth interview, the interviewer could no longer identify new questions and the engineer did not offer corrections for the knowledge captured. At this stage, one last interview was conducted, consisting of the lead engineer for the component confirming that the information in the engineering check sheet was correct and ownership of the document was transferred to the engineer.

3.3 Qualitative analysis of the engineering check sheet

To assess the quality of the knowledge captured in the engineering check sheets, 8 months after the initial interviews, three follow-up interviews with engineers were conducted. Two of the engineering check sheets chosen were chosen in part due to that the engineers responsible for that specific part had changed since the original interviews were conducted, but all of the chosen engineering check sheets were chosen due to a high level of quality (assessed by the case company's knowledge management expert). These interviews focused on determine if the engineers had used the engineering check sheet and if so how, as well as correctness and the re-usability of the capture knowledge. A secondary goal for the case company were to re-validate the contents of engineering check sheet.

The interviews were conducted by an in-house knowledge management specialist and an in-house process owner for knowledge management at the case company. I participated as a passive observer during the interviews. The interviewees were chosen based on that their component was in the concept phase of development for a current project, the engineering check sheet for their component were deemed to be highly mature by the in-house knowledge management and the engineers for having many years of experienced working as engineers. Two of the engineers interviewed had worked less than a year with the component at hand and had not been part of the engineering check sheet design process. The other two engineers worked in the same team, together on the same component, and had done so for several years as well as been interviewed for the designing of the engineering check sheet (see table 3.2). The interviews were audio-recorded and the observer recorded non-verbal action, such as showing pictures and presentations or physical representations (e.g. showing how big a space between two components with his hands).

There is always a risk that the interviewees post-rationalize their actions or distort

Table 3.2: The interviewees time working with their respective component and eventual participation in the design for the engineering check sheet

Engineering check sheet	Number of interviewees	Time working with the component	Participation in engineering check sheet design
ECS 1	2	Several years	Yes
ECS 2	1	Less than a year	No
ECS 4	1	Less than a year	No

the truth to meet expectations they believe the interviewers have (Holme, Solvang, & Nilsson, 1997). To mitigate this risk the interviewees were informed both in the invitation to the interview and at the start of the interview that the purpose was to evaluate the re-usability of the knowledge captured in the engineering check sheet and the engineering check sheet as a tool. This was also done to mitigate the risk that the engineers would misinterpret the purpose of the interviews as a control for if they had used the engineering check sheets.

The interviews were formalized around four subjects of interest:

- Usage: If and how the engineers have used the engineering check sheets
- Correctness: If the content of the engineering check sheet is correct and describe their process correctly,
- Attitude: The engineers overall attitude towards the engineering check sheet as a tool
- Completeness: If there is any crucial information missing from the engineering check sheet

After the interviews, the engineering check sheets were updated with the new information given by the engineers. The difference between pre-interview and post-interview engineering check sheet were documented.

3.4 Quantitative analysis of the contents of the engineering check sheets

Six of the engineering check sheets was determined to be 'operational' by an in-house knowledge management specialist together with engineers with the role of "knowledge owner" (a title given to senior engineers with several years experience working with relevant product development).

The content of the engineering check sheets were analysed by highlighting the part of the text that were relevant to the research question and code them to a more abstract concept, taking the context of the text into consideration. For example, "Draft angles" were coded as "Geometrical problem for production". This abstraction allowed the analysis to move the focus from specific knowledge to categories of knowledge. To reduce the number of concepts, the concepts were consolidated into overarching themes when it were possible to do so without misrepresenting the purpose of the captured knowledge."Geometrical problem for production" were consolidated with the category "Poka-yoke" (among others) to create the theme "Secure manufacturability".

3.5 Motivation for the chosen methods

Qualitative interviews were chosen since it allows for an outsider (the interviewer) to gain knowledge from the inside. In a qualitative interview the aim is to have the interviewee influence the direction of the dialogue (Holme et al., 1997). An alternative method, which could yield data which is closer to how the engineers really work, would be to shadowing them as they work (Blake & Stalberg, 2009)(McDonald, Professor Barbara Simpson, Gill, Barbour, & Dean, 2014). This method was dismissed due to taking too long time and that it could be hard for the researcher to discern the knowledge used, due to the sheer amount of data.

The method for quantifying the content of the engineering check sheets weer chosen so that it would be possible to statistical generalisations (Holme et al., 1997).

3.6 Additional interviews

To complement the information from the interviews with engineers at the case company, three additional, semi-structured interviews were conducted with the purpose to gain insights into how simple, everyday checklists (i.e. grocery lists) are used. Three interviews, with focus on grocery lists, were performed with three people: one living alone, one sharing her apartment with two other people, and one person living with their spouse and young child.

Grocery list were chosen due to their lack of formality. As the engineering check sheets follow a specific structure and a grocery list does not, this offer the opportunity to enrich the checklist model and observe similarities and differences between formally structured checklists and non-formal checklist.

3.7 Data collection from aviation

In addition to interviews in regard to non-formalized, non-enforced checklists, three recordings from aviation were studied to gain insights into how formalized and enforced checklists can affect procedures. One sound recording of radio communication between traffic control and the pilot on a plane with malfunctions (VASAviation, 2018), one video and sound recording of the cockpit during a flight (Fernandø Brunner, 2012), and one case study of a crash (Air Safety Institute, 2020), with sound recordings of radio communication between pilot and traffic control as well as analysis of what went wrong.

4

Findings

THE RESULTS SHOWS THAT THERE are at least 15 reoccurring categories of knowledge in the knowledge captured in the analysed engineering check sheets. Through the qualitative evaluation of the engineering check sheets the interviewed engineers give credit to the applicability of the knowledge captured.

4.1 Nature of the captured knowledge

The captured knowledge can be organized as either *referential*, *instructive* or *informative*.

4.1.1 Referential knowledge

Referential knowledge is mostly represented by the theme 'References to documents', giving direct links to where in the system a certain document is stored. Given the vast amounts of different data systems and servers used at the case company, this helps the engineers, novice as experienced, to find the information they are looking for. As an interviewed engineer put it, it is not the lack of information that is the main concern but rather to find the relevant information. References to documents could be seen as thin slicing of how to find the correct information.

4.1.2 Instructive knowledge

While the experienced engineer knows, often tacitly rather than explicitly, which cues to look for, the novice engineer most often does not. The captured knowledge that is instructive helps the novice engineer identify these important cues, replacing the experience needed to identify thin slices of information and knowledge. In addition, the captured knowledge and information do also suggest what action to take.

The themes that are generally instructive are 'Specific problem areas', 'Interfacing component', 'What to speak with the supplier about', 'Maximizing durability', 'Improve quality impression' and 'Understanding the component'.

4.1.3 Informative knowledge

The informative knowledge describes different solutions and their pros and cons. This information is generally not of a pure 'thin slice'-nature, but rather a way to specify the available solutions. Some of the captured knowledge presents the engineer with what thin slices to use. Even if the informative knowledge not always helps the engineer to thin slice the information available, it is still important to capture it. It offers already explored solutions with the experience of what works and what will not.

The themes that are mostly informative are 'Secure manufacturability', 'Material choice', 'Best practice/Thumb rules', 'Case company's internal safety demands' and 'Breaking down high level requirements'.

Furthermore, there are some themes that contain captured knowledge of both informative and instructive nature: 'How to cut cost', 'Who to talk to [internal]' and 'Differences between technical solutions'.

4.1.4 Reoccurring categories of knowledge

There were 15 different categories of information identified in the six engineering check sheets (called ECS 1-6) that were analysed (see table 4.1). At least one of these categories is found in each row of the engineering check sheets, bar the few rows lacking "Know-How".

Analysis of the categories

Each category tend towards one of the different question columns of the engineering check sheet ("Know-what", "Know-how" and "Know-why") with one or two exceptions per category.

The two most common categories identified where "Best practice/Rule of thumb" and "Specific problem areas" frequently show up pairwise, where the later often identifies an especially difficult problem (as a "Know-what") and the former offers a heuristic way to find a solution (in the form of a "Know-how").

"References to documents", "Who to talk to [internally]" and "What to speak with the supplier about" often shows up as the "Know-How" to "Know-what" of the "Understanding the component", "Interfacing components" and "Difference between technical solutions" categories.

The categories "Material choice", "How to cut costs", "Maximizing durability" and "Improve quality impression" seldom shows up alone, but more often together pairwise or in trios as "Know-how".

The remaining categories ("Breaking down high level requirement", "Case company's internal safety demands" and "Secure manufacturability") all answers "Know-what" but do not show any specific pattern when it comes to other categories.

Table 4.1: The themes present in the engineering check sheets

Theme	**Description**	**Example**
References to documents	Link to external documents containing further information	*Legal requirement, see [Regulatory number]*
Who to talk to [internal]	Who to talk to at the case company and about what	*Done together with Purchasing*
Specific problem areas	Areas which is known to cause problems, for example chafing or durability on a certain piece of the component	*Piston gets stuck*
Interfacing components	Neighboring components that the engineer needs to know about and which has actions linked to them	*Ensure to have tolerances requirements from other functions as early as possible*
Understanding the component	The main issues governing the component is pointed out in the engineering check sheet	*Understand the main function of [Component/Software/ECU]*
Breaking down high level requirements	How requirements on the complete product affect the component	*Investigate how design branding affect component*
Differences between technical solutions	Pros and cons with different solutions	*Integrated or separated [Component]? Integrated is cheaper and easier to assemble, separated can solve issues with clashes*
What to speak with the supplier about	What needs to be discussed with the supplier to avoid problems	*Make sure to get feedback from supplier on A-released design as early as possible to ensure manufacturability*
Best practice/Thumb rules	If there is something that ought to be done in a certain way	*Place clips no further apart than 150 mm*
Material choice	What materials to choose and pros and cons of them	*[Material A] is harder and lighter than [Material B], but do not have as good sound isolation properties*
How to cut costs	Where costs typically occur and where a decision from the engineer can cut the cost	*Reduce variants of [Component] by adding cut-outs*
Case company's internal safety demands	How to meet the expected safety level	*Make sure [Component] do not create sharp edges at impact*
Maximizing durability	Where durability problems might occur and how to avoid them	*Ensure that if protective tubes are used they are sealed to prevent particles to accumulate between tube and hose*
Improve quality impression	What to do to improve the quality impression	*Plan testing with Feature leader early*
Secure manufacturability	How to avoid causing problems in the manufacturing lines	*[Component] might need to be attached before painting. If so, secure drainage holes in the component based on orientation during painting*

Table 4.2: Occurrence of the themes in engineering check sheets.

	Total number of occurrences	% of the total theme occurrence
References to documents	24	6.9% 9
Who to talk to [internal]	34	9.7%
Specific problem areas	52	15%
Interfacing components	26	7.4%
Understanding the component	4	1.1%
Breaking down high level requirement	2	0.57%
Differences between technical solutions	38	11%
What to speak with the supplier about	16	4.6%
Best practice/Thumb rules	57	16%
Material choice	16	4.6%
How to cut costs	27	7.7%
Case company's internal safety demands	2	0.57%
Maximizing durability	33	9.5%
Improve quality impression	3	0.86%
Secure manufacturability	15	4.3%

4.2 Unfinished engineering check sheets

In addition to the six engineering check sheets that were classed as "operational" by various people (knowledge owners, knowledge managers or lead engineers) at the case company, there were also two that were not finished (called ECS 7 and ECS 8). The main difference between the operational engineering check sheets and the unfinished is the number of remaining unfinished rows, containing unanswered questions identified in the engineering check sheet as well as the occurrence of several "Know-What" without a corresponding "Know-How". Similar to the operational engineering check sheets, all rows contained at least one of the 15 identified themes.

4.3 Qualitative results

The three engineering check sheets chosen for the knowledge re-use interviews were ECS 1, ECS 2 and ECS 4. The engineers who participated in the interviews for ECS 2 and ECS 4 had very similar experience of the engineering check sheet. Neither had worked with the component at the time the engineering check sheet were designed, but they had gone through the engineering check sheet with their predecessors as part of the handover process. Interviewees for ECS 1 were same engineers that had been involved in its design.

One of the engineering check sheets, ECS 1, hadn't been used at all since ownership of it had been transferred to the engineer. The ECS 2 and ECS 4 engineers had read their respective engineering check sheet during their introduction to their new responsibilities, and in the case of ECS 2 updated it with some new knowledge and used it to make sure no step in the process is missed and having spoken to all stakeholders.

The interviewed engineers all confirmed that the knowledge captured in the engineering check sheets to a high degree reflect on their work process. The discrepancies from their work process were for the most part not that it was wrong but rather that it was not applicable in the current project.

The general consensus for each of the three engineering check sheets chosen for the knowledge re-use interviews was that the contents were correct, save for some knowledge that had been outdated by new experience from field testing (especially in ECS 1). The engineers stated that they had not used the engineering check sheets as part of their work process but that they had, independent of the engineering check sheets, taken the proposed actions and based their decisions on the same logic that is present in their engineering check sheet. The ECS 2 engineer cited colleagues and the predecessor as the main source of information and knowledge rather than the engineering check sheet.

All engineers expressed that there is a problem with knowing what information to use and how to find it, one said: “If I put it this way, there isn't lack of information. It's rather a question of finding the right information, or the information that is important right now”. They were all positive to that the engineering check sheet could offer support, and the ECS 2 engineer expressed that it would be very helpful for engineers that had changed which component they work with recently.

The work process around the engineering check sheet was a source of concern for all engineers interviewed. They found the lack of organization and process in regard to how the engineering check sheet should be used, where they should be stored and when they should be updated questionable. Two of them expressed fear for the engineering check sheet to become a tool for control to be used in hindsight rather than preventive, or as one of the engineers put it: “yet another checklist that you go through before concept gate”.

The ECS 2 and ECS 4 engineers, who had just been working with their respective component for a relatively short while, expresses that the engineering check sheet is useful when starting on a new component and that the engineering check sheet has a function as a handover document and for continuity.

Section: Checklists

4.4 Checklists

The usage of checklists as a support tool in aviation and for grocery shopping has been analysed in order to create a basic framework for checklist which can be used to evaluate other checklists.

4.4.1 Interviews regarding usage of grocery lists

In the small sample of interviews performed for this study, all interviewees stated that they used grocery lists to remember everything, decrease time spent thinking in store, decrease time needed to spend in store, and to save energy. One of the interviewees said: “It is easier to make decisions when planning rather than in the store, especially since I try to eat healthy and they try to manipulate me to buy candy and snacks just before the cashiers”. All three people interviewed regularly used grocery lists when buying food, stating their usage as: “very often”, “almost always” and “always unless only fruit”. The last one self reported that unless she only was going to buy “a fruit or similar” she always used a list which she did not deviate from. The “very often” interviewee were less disciplined, saying that the shopping list was the minimum and often bought more than the items stated on the list, while the “almost always” provided a middle ground, sometimes buying one or two additional items but most of the time stuck to the list. When going shopping in none-grocery stores (e.g. clothing stores) two of the interviewees stated that they did not feel a need for a shopping list, quoting that they could keep all items they were going for in their mind. The third interviewee (the “always unless only fruit”) claimed to use shopping lists even for none-grocery shopping, as a way of reducing energy spent and especially to protect against over buying.

4.4.2 Usage of checklists in aviation

In aviation the usage of checklists are seen as a necessary tool to be able to safely manage the aircraft. The use of checklists are therefore enforced and even while performing standard procedures, that the flight crew have performed countless of times without any problems. Deviating from the usage of checklists in either standard and non-standard situations are seen as strong candidate for error introduction and in cases of accidents, a definitely root cause (not necessary the only) to the accident. Proper usage of checklists support the flight crew in extraordinary situations, for example during system malfunction, as well as makes sure that best practices are adhered to.

4.4.3 Framework for checklists

By looking at a checklist in a simple form, e.g. a grocery list, the following characteristics for a good checklist can be demonstrated:

- Understandable and relevant - each item is understandable from the context of the list
- Verifiable - each item describe its own acceptance criteria
- Accessible - the checklist is on hand when needed (i.e. in the store)
- Broken down and atomic items - each item describes one delivery

Furthermore, an efficient checklist have these additional attributes:

- Ordered - the order of the items on the list matches the order in the store (i.e. the order in which the should be executed)
- Complete - the checklist contains everything needed within its scope
- Correct - the items in the list matches what is available in the store

The most of the characteristics identified in this study can be related to the general qualities defined by Li et al. (2018) as per the following:

- Understandable and relevant - Comprehensiveness & Relevance
- Accessible - Accessibility & Timeliness
- Broken down and atomic items - Comprehensiveness
- Ordered - Accuracy
- Complete - Accuracy & Comprehensiveness
- Correct - Validity

The characteristic “Verifiable” does not have any explicit counterpart in Li et al. (2018). This is probably due to the characteristics being self-evident and implicitly expected, as it can be argued that if there is no way of verifying that the instructed action has been performed (and performed correctly), no value has been added.

For the purpose of this study, two actors for checklists are introduced, the principal (or planner) and the agent (the executioner). The principal creates the checklist to give support to the agent during the execution. In some cases, these are the same person but when used in professional situations, such as healthcare or aviation the principal is someone in position of responsibility who wants to make sure that the correct actions are taken to protect value, e.g. themselves from liability, customers from harm, the company from bad PR or to create value by increasing efficiency or quality.

For a grocery list, the principal and executioner are quite often the same person and the value the checklist creates is efficiency (less time spent in the store) and quality (ensure all needed product bought). Some sellers offer their customers a product catalogue, which can be viewed as an inverted grocery list, or an order sheet. Instead of a list of everything that should be bought, it is now a list of everything that can be bought. The customer then goes through the list and chooses the items that correspond to their needs. The seller acts as the principal and makes sure that the product catalogue items are atomic, understandable, relevant, ordered and correct. The customer, acting as an executioner, checks every item as needed or not needed. The action here is to evaluate need, compared to the grocery list where the need is identified during creation of the list.

From the perspective of the principal, the purpose of the checklist is to add some kind of value, most often increased efficiency or quality. For repeated procedures, checklists (as any other instruction) can be used to standardize the procedure. In aviation, there are checklists for every task the flight crew need to perform to ensure a safe flight in normal conditions, but there are also specific and specialized checklist for emergencies, where the checklist becomes a tool for troubleshooting and problem solving, providing a systematic approach to handle the situation (Hales & Pronovost, 2006).

The use of checklists can create conflict between the principal and the executor. In aviation, the use of checklists is considered best practice and the usage is not questioned by novices or more experienced pilots. The same does not hold true for healthcare, where Gawande (2010) found resistance from experienced physicians to use checklists for a standard medical procedure with the purpose to reduce infection rates. Where the checklists were implemented infection rates would go down to virtually zero, showing that the experienced physicians for one reason or other missed crucial parts of the procedure without the checklist.

5

Discussion

The engineering check sheets are, by the definition used in this study, a form of checklist. According to the interviewed design engineers, the content of the engineering check sheets are correct, but not applicable to all projects or phases of projects. Since this study only considered a single, albeit considerably large with automotive standards, project, it is not made clear what is or is not applicable in different projects, nor what affects this.

To a large extent, the content in the engineering check sheets is about how to find information, how to avoid known problems, and how to fulfill generic project requirements.

The design engineers are given a lot of freedom when it comes to the usage of the engineering check lists, since there is no follow-up (outside of this study) of usage. This is quite similar to how grocery lists are used, but far from the strict usage of aviation checklists. The contents, however, show almost no semblance to a grocery list. Some parts of the engineering check sheets have similarities to the content one might find in an aviation checklist, but where the aviation checklist gives a specific solution the engineering check sheet proposes how to find the necessary information needed to create a solution.

5.1 Usage of the information in the engineering check sheets

There is a need to highlight the difference of using the engineering check sheets, as a "physical artifact", and independent usage of the information stored in the sheet. In the first case, this includes the design engineer reading the engineering check sheet and then take actions based of the information presented there. The second case have the design engineer acting in accordance to the information within the engineering check sheet, but uses other sources (e.g. experience, own or colleagues').

During the second wave of interviews, the interviewed design engineers reported almost no usage of the engineering check sheets outside the creation done as part of this study. However, they also reported that they had, independent of the engineering check sheet, taken the suggested actions and followed the same logic that is documented in the engineering check sheets. This further helps establish that the content of the engineering check sheets is correct.

5.2 Engineering check sheets as a tool

Theoretically, the engineering check sheets can fulfill several different roles to support knowledge management and improve the design process. The main roles identified are:

- Facilitation of knowledge
- Minimize impact of biases
- Minimize impact of lack of experience
- Support decision making by suggesting thin-slices
- Support knowledge conversion (explicit to explicit)
- Support knowledge conversion (tacit to explicit)

For the inexperienced engineer the engineering check sheet could facilitate the necessary knowledge to avoid costly mistakes and help her build up the experience to know which information (e.g. thin slices) that are important to make an informed decision. The thought of the check sheet acting as a facilitator that, similar to how Vygotsky (1978) describe the role of a human facilitator in context to his zone of proximal development, helps the inexperienced engineer solve problems that she could not solve without the check sheet does not seem far fetched, considering the content of the engineering check sheets. However, since all participants in this study were experienced engineers, there is no hard evidence for such conclusions, and as such there is no definitive answer to how helpful the check sheets are when it comes to facilitate knowledge or minimize impact from biases or lack of experience.

The structure of the engineering check sheet is based around supporting the engineer working with them externalize knowledge. This is done by have the engineer answer the question “What is an issue for this component” (“Know-What”). By being aware of what the issue is, the engineer can then focus on answering the more complex questions of “‘Why is it an issue?” (“Know-Why”) and “How do we solve it?” (“Know-How”). To be able to answer the “Know-How”, the engineer either need make her tacit knowledge explicit by externalisation or create a rationale for the solution based on a combination of pieces of explicit knowledge. Due to the limited time and the researches lack of experience within the field of design engineering, it is impossible to evaluate if knowledge conversion has taken place due to the usage of the engineering check sheets. As a footnote, it could be stated that since the knowledge in the engineering check sheets is written down, the knowledge is explicit.

5.3 The 7 characteristics of a good checklist

Of the 7 characteristics of a good checklist this study have identified, “Understandable and relevant”, “Verifiable”, “Accessible”, “Broken down and atomic items” and “Correct” has either been reported as fulfilled by the interviewed design engineers or identified as fulfilled by analysis. The fulfillment of “Ordered” has not been investigated, and it is possible that all actions proposed in individual engineering check sheets can be performed in any other, but it is also possible that there is a specific order the actions need to be taken. Adding an additional question, a “Know-When”, could possibly help highlight such dependencies.

This leaves the characteristic “Complete”. In aviation, as well as for grocery lists, “Complete” is an important characteristics, and without it, there is a considerable risk that the task (e.g. safe flight of the airplane, buy the correct amount of the correct items) is not carried out, possibly leading to an accident or the lack of needed items. Each check of a grocery list or an aviation checklist is a specific action, e.g. collect this item, make sure this meter shows an okay value. In comparison, each check in the engineering check sheets is of the construct “take this action to collect this information” and it is then expected that the design engineer can use her experience to make the necessary design decision. The problems the different checklists tries to solve are different in nature. Each unique grocery list is used once (and then discarded) to solve the problem with remembering to buy all needed items. Aviation checklists gives the solution “given this situation what order of actions is needed to minimize the risk”. In contrast, the engineering check sheets give the necessary actions to find the most important information that might otherwise be forgotten. For an engineering check sheet to be “Complete”, there would be a need for actions for all possible outcomes of the information collection, which would quite quickly make the engineering check sheet very cumbersome to use, as well as violate the “relevant” part of the characteristic “Understandable and relevant”. Therefore the decision to not try to make the engineering check sheets “Complete” were taken.

6

Conclusions

THREE CONCLUSIONS HAVE BEEN MADE BASED ON THE RESULT OF THIS STUDY. The first conclusion elaborates on the need of the engineering check sheets, the second conclusion is in regard of the method of creating the engineering check sheets, and the last conclusion is in regard of the difference to other checklists.

6.1 The need

The result of this study shows that the engineering check sheets is not a necessary tool for experienced design engineers, as they already have the needed experience to know which actions they need to take. It would on the other hand probably be impossible to create the engineering check sheets without experienced engineers. The effect of engineering check sheets in the hands of novice engineers has not been investigated as part of this study, and it is a candidate for further studies.

6.2 The method

Based on interviews conducted with the involved design engineers, using interviews to extract the information that should be put into the engineering check sheets is feasible and reasonable efficient method. Since it is the only method investigated in this study, there might be other methods (e.g. shadowing) that could yield more information, but compared to interviews they are more time consuming.

6.3 Difference to other checklists

The engineering check sheets are similar to both grocery lists and aviation checklists in that its purpose is to increase the probability of desirable outcome. However, the nature of the desirable outcome in both grocery lists and aviation checklists are well known and well defined, while the outcome of the design engineers work is not. This uncertainty of the outcome of the design process is due to the need to balance a large set of high level requirements, some of which is impossible to optimize at the same time (e.g. quality and part cost). The problem for the design engineer is more about being able to find the correct information for how to optimize the solution in regard to the given requirements, rather than applying a specific solution. In terms of procedure, a grocery list supports the procedure of buying the correct items, an aviation checklist supports the flight crew in the procedure of performing a safe flight, and the engineering check sheet supports the design engineer in the procedure of knowledge gathering and requirement engineering.

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