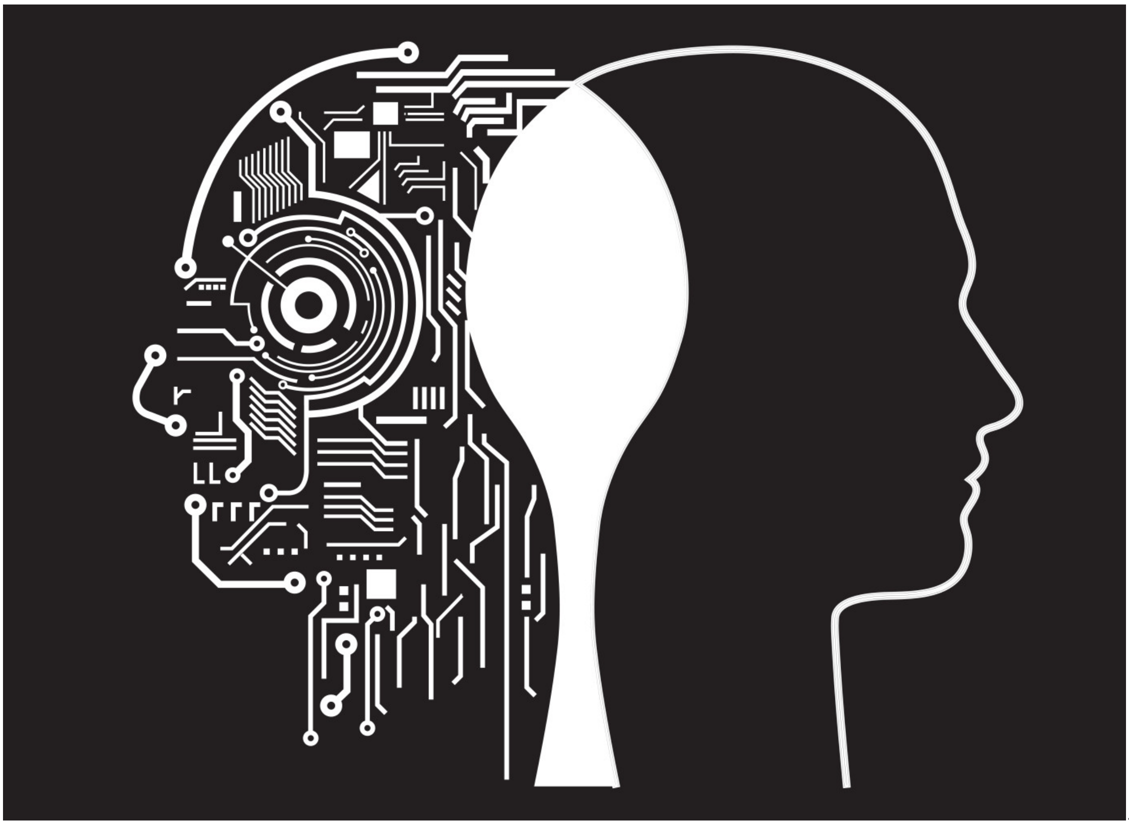

Towards an Automated Knowledge Management System

– An evaluation of questions to ask when validating newly generated knowledge

Master's thesis in Product Development

SALELKAR LAKSHMI PRADIP

Department of Industrial and Material Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2018

Master's thesis 2018

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“ **Simple can be harder than complex** ”

—Steve Jobs

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Abstract

Knowledge recycling has been put into practice in Volvo Trucks Technology by employing the check-sheet concept. But the problem with the check sheet system is unavailability of information at the right time, inaccessibility of the check-sheets themselves, and miscommunication of information by not obsoleting old information, or rather requirements, and hence committing mistakes, resulting in longer product lead times. This research aimed to develop an interrogative question set, so as to say a human decision support system which would serve as an actionable knowledge for the knowledge community existing in Volvo Trucks Technology in real time. The essence of this research is to facilitate right knowledge at the right time to the right people by asking "the right questions" within the community. Backcasting and Design Research Methodology have shaped the way the research has been conducted. The proposed set of questions "know what", "know why", and "know how" were developed from case studies conducted on a gear box employed as an example of a mechanical component, and a set of check sheets used by Volvo Trucks Technology. Qualitative research was conducted in the form of semi-structured and structured triad interviews to analyze the questions using the triangulation method and gap analysis. A benchmark was established in a way the qualitative information has to be analyzed. Findings of the research have been presented in the result section. Top 30 questions manifesting from this research have been proposed to be experimented on the AI system.

Keywords: Knowledge recycling, Backcasting, Design Research, Check sheet, Interrogation, AI

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Lakshmi Salelkar, Gothenburg, October 2018

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1
Introduction

A good decision is based on knowledge and not on numbers –Plato

"A man is crawling intently around the lamppost on a dark night. When a police officer comes along and wants to know what he is doing, he says he is looking for his keys. "You lost them here?" asks the cop. "No" the seeker replies, but this is where the light is" [1].

The purpose of the research undertaken is to investigate a way to transfer knowledge from an experienced individual to an individual with a lower level of knowledge in the same field, by asking the right knowledge extracting questions. The outcomes from this research aims to develop a decision support system for an engineer, varying from recent graduate to experienced employee of an organization such a manager, to make better actions and decisions during the development phase by reducing the uncertainties. Uncertainties can be reduced by making information flow transparent and accessible to all when it is needed.

The intended deliverables from this research will also assist to form the basis for a system of knowledge reuse support which will be practical and useful for both capturing and reusing knowledge for the organization in an automated way. In a nutshell, human judgment needs better support which assists in solving problems effectively and efficiently. Knowing where the root of the problem lies adds to increased performance in order to avoid the situation exemplified by the author Pasquale, Frank [1].

1.1 Background

Changing requirements in various stages in the product development cycle is a common phenomenon due to following stricter laws and regulations. Engineers today must strive ever harder to reduce lead times by employing the best procedures and avoid mistakes that cause costly revisions [2]. It was rightly predicted that the demands and pressures on many engineers in an organization are increasing at an exponential rate [3]. One way to make processes leaner is by making the right knowledge available earlier at the right time. Most engineering companies possess a great deal of experience and expertise; the challenge is to retain this expertise despite staff turnover, develop it, and deploy it where and when it is needed. But how can effective corporate **Knowledge Management** abbreviated as **KM** in design be achieved [2]?

Research shows that expert designers or specialists possess a wide knowledge or core strengths in terms of their essential expertise of analyzing and rationale of solving problems [2]. Research also shows that obtaining information is a major drain on engineer's time, possessing the necessary range of expertise to integrate this information considering all the important issues can be a much tractable problem [4]. Improved knowledge management tools and decision support systems can provide far more assistance to designers by supporting problem analysis and design synthesis as well as fact gathering [2].

Author Pasquale, Frank [1] has aptly pointed out how gaps in knowledge are putative and real, have powerful implication, as do the uses that are made of them in metaphorical context.

1.1.1 Lack of Transparency

Uncertainties are bound to reduce the transparency of any development processes. To understand these more contextually "Design margins" can be used to specify uncertainties in the design process. A margin is composed of a buffer and excess as shown in Figure 1.1. In organizations where a design changes many times before reaching the final product, there are chances of miscommunication of design margins [6] & [7].

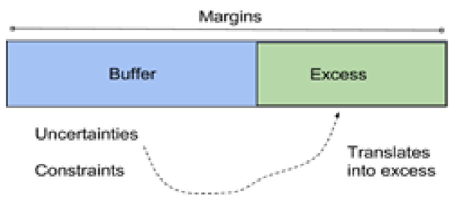


Figure 1.1: Margin

The understanding of design margins and the evolution can make the design process more efficient and reduce design lead time. If companies understand design margins better, they could manage uncertainty or constraint and handle engineering change better which is illustrated in Figure 1.1. As all uncertainties can be translated into excess and more knowledge available over time, the excess can be either optimized or used as a means for modularized products. Knowledge based design margins serves as a key leverage to develop better support system in an organization.

Academically, the concept of design margin is an under-researched design area. Research has also pointed out that there is a lack of support approaches or methods to assist engineers to communicate margins explicitly throughout the product development process. Rather, it is hard to capture knowledge [5]. There is a need to conscientiously ground the topic and bring together different related topics from different engineers and designers who currently lack an explicit communication about margins on key parameters, components or systems, which makes it difficult for them to make accurate decisions about their products [6] & [7]. From the front-end side of design process there is a need for: **Improvements in the existing knowledge capturing processes and understanding of knowledge-based design**

margins at component or product system level.

1.2 Current Situation

A knowledge community termed as **Community of Practice** abbreviated as **COP** is established in Volvo Trucks Technology. Knowledge is normally generated when the community meets and discusses about the mistakes conducted during previous projects. Check sheets have been developed to dissect knowledge into *"know what"*, *"know why"* and *"know how"* [8]. These check sheets facilitate reuse of codified knowledge based on experience to serves as a data supply points for the knowledge community. The next step as pointed out in the research conducted by [8] is automation. Making right information available in real time.

1.3 Research Overview

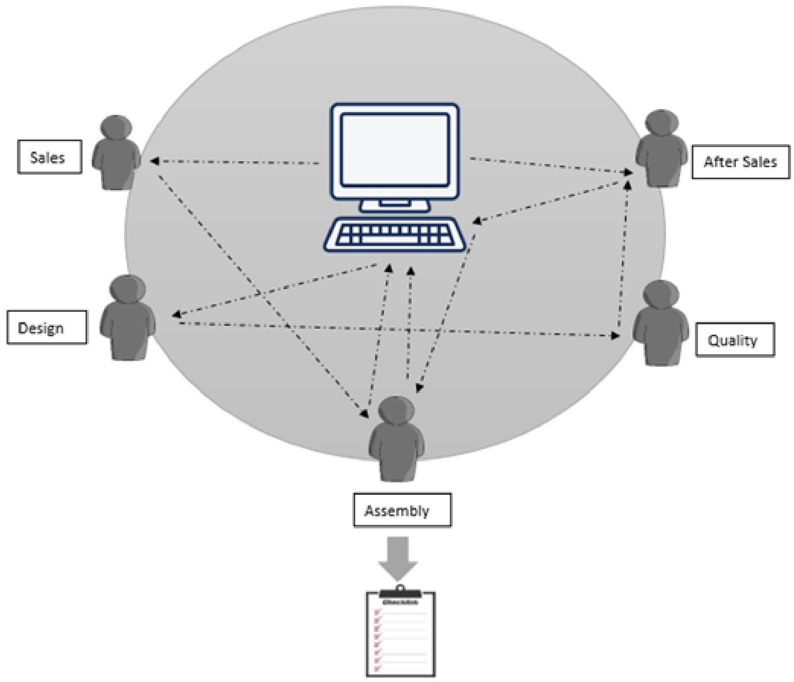


Figure 1.2: Research Overview

As earlier mentioned in Section 1.2, the existing check sheet system prevailing in Volvo Trucks Technology serves as a knowledge reuse source to tap knowledge gained by the organization during various projects. The idea behind the research is to automate the process of capturing the reusable knowledge and hence presenting in a faster and efficient way. Figure 1.2 below presents **COP** which serves as the place to intervene in the existing check sheet system to capture reusable and recurrent rich knowledge in Volvo Trucks Technology. An **Artificial Intelligence** abbreviated as **AI** maybe in the near future be responsible to ask the right questions to the right people in the **COP** and extract right knowledge and present it at right time to the right people in an automated check sheet form. The research highlights the need to improve the existing check sheet system by formulating the right data extracting questions. The research will be focused on formulating the *"know what"*, *"know why"* and *"know how"* questions which will manifest themselves into an intelligent interrogative system, which will be tested on the **COP**.

1.4 Business Drivers

This research mainly focuses on supporting incremental development and exploitation of knowledge, i.e. the efficiency-focused activities of leveraging existing capabilities. The products that are investigated in the companies are many and have short product cycles, factors that increase the opportunity for learning, and are often designed by individuals who hold a great deal of tacit knowledge linked to the product. We want to deliver products faster to the market, but at the same time use the organization's knowledge data base to reduce the product lead times [8].

1.5 Research Focus

To design an actionable knowledge management system using engineers on **COP** as sources to get data for improvement of ever evolving knowledge capturing system in the form of right and generalized questions which extract optimal knowledge.

1.6 Research Questions

The following research questions were formulated:

RQ 1 What are the barriers to automate the knowledge capture process using community of practice in Volvo Trucks Technology which would generate check sheets in real time?

RQ 2 How can these barriers be overcome by applying an interrogative based support system in the community of practice in Volvo Trucks Technology?

RQ 3 What can be learned from applying an interrogative based support system in the community of practice in Volvo Trucks Technology?

1.7 Delimitation of Research

This area of research is broad, so it would be sensible to focus on trivial aspects of the research. The area of applicability of the results generated from this research will be in the automotive industry, preferably truck systems. Previous research-based knowledge applicable to a jet engine manufacturer may be used to supplement and provide better context to the research. The focus in this research will not be in development of the autonomous system or **AI**, but rather to conduct a feasibility study for establishment of a symbiotic interrogative system. Due to vastness of the research and lack of time for analysis purpose only a subsection will be done. The reference check sheet provided for the research will not be presented due to company policies. Not all the semi-structured, informal conversations and structured interviews conducted during the research will be presented. Only those which are used for analysis purpose will be presented in the **Appendix**.

1.8 Research Structure

The subsequent chapters of the research are outlined as follows:

Chapter 2 Frame of Reference presents the relevant literature for establishment of a solid scientific foundation for the research. The sources have been collected over the course of the study of this research topic and have continuously contributed to new ideas and perspectives. Here **RQ 1** gets contextualized.

Chapter 3 Research Methodology presents the strategy and methodology used for conducting this research as well as important considerations for evaluating the quality of the academic results.

Chapter 4 Results presents how the different frameworks, case studies, literature, and experience have been employed to construct a proper way to investigate. Here **RQ 2** gets contextualized. Furthermore, it also presents how the developed framework which is an interrogative question set has been used to develop use cases for three personas. Apart from this top 30 interrogative questions have been presented that can be experimented for the near AI implementation. Here **RQ 2** and **RQ 3** get contextualized.

Chapter 5 Analysis presents analysis of results obtained from the qualitative research. Many concepts used have been motivated by fellow researchers, psychology and common sense. Here **RQ 2** and **RQ 3** get contextualized.

Chapter 6 Discussion

Chapter 7 Conclusion

2

Frame of Reference

***The velocity of knowledge is increasing* – Jim Carroll**

This chapter presents the necessary literature that has been used as a foundation for the research undertaken. The literature has been collected over the research period from various sources and has shaped the research. " The key aspects from the literature adopted in the research or rather has shaped the perspective during the research is highlighted in purple text."

2.1 Knowledge

Oxford dictionary defines knowledge as:

"Facts, information, and skills acquired through experience or education; the theoretical or practical understanding of a subject."

Researchers like Alavi and Leider express their concerns on "understanding knowledge in a varying perspective" as summarized in Figure 2.1 [9].

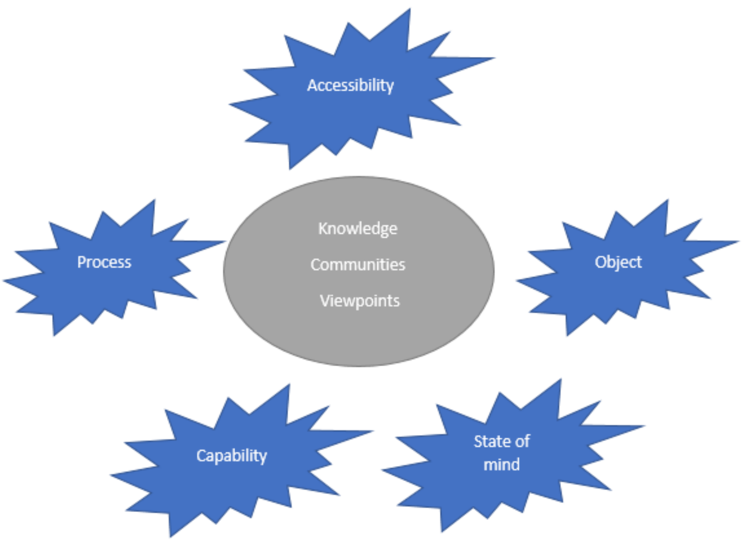


Figure 2.1: Multi-perspective view

A **state of mind** is in general what an individual has experienced, perceived and learned. An **object** in the form of an item that is to be stored and mended. A **process** which is the procedure of simultaneously knowing and acting and hence focused on application or being actionable. A condition of having access to information where **accessibility** is focus and lastly a **capability** which means having the possibility to influence future actions [9] & [10].

“In this research the perspective applied to the definition of knowledge is "union of capability, accessibility, process and object perspectives". In brief for this research it is the personal human capability, both potential and actual, to take action in varied and uncertain situation.”

2.1.1 Knowledge - Aspects

2.1.1.1 DIKW Pyramid

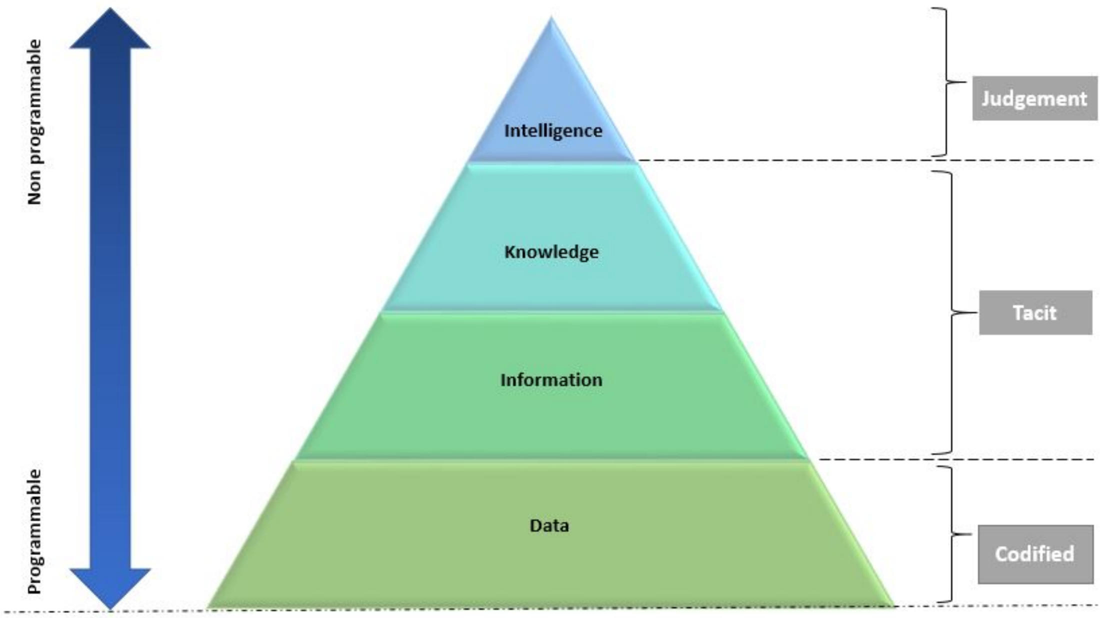


Figure 2.2: DIKW Pyramid

Figure 2.2 presents the non-interchangeability aspect between data, information, knowledge and intelligence. According to Oxford dictionary, **Data** means “Facts and statistics collected together for reference or analysis.” **Information** means “Facts provided or learned about something or someone.” **Knowledge** means “Facts, information, and skills acquired through experience or education; the theoretical or practical understanding of a subject.” **Wisdom** means “The quality of having experience, knowledge, and good judgment; the quality of being wise” [11].

“In this research the component under focus will be Tacit.”

2.1.1.2 Translation to 2D Representation

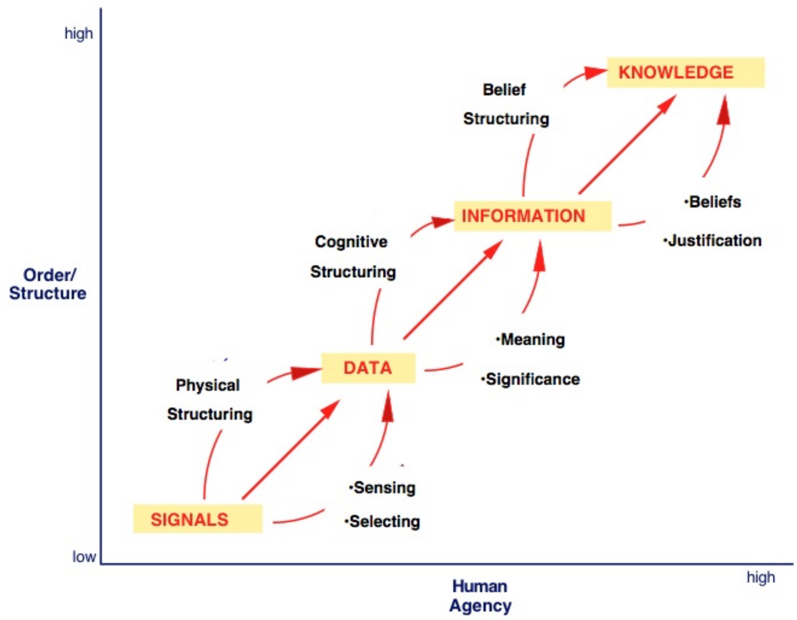


Figure 2.3: DIK continuum [14]

Figure 2.3 presents **DIKW** in a continuum as proposed by [14].

"The idea behind Figure 2.2 & Figure 2.3 and the implications that results from both are are quiet contrary. But as an argument, these can be still considered a rather not discrete concepts but rather arbitrary delimitation of an analog scale."

2.1.1.3 2D Representation

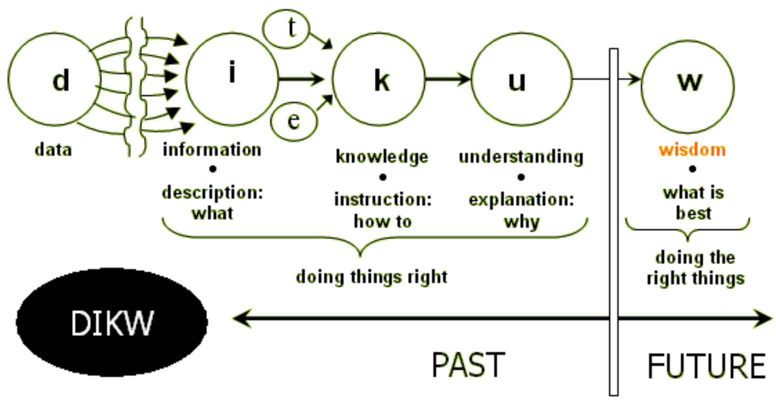


Figure 2.4: DIKW flow diagram [13]

An interesting perspective presented by [13] in Figure 2.4 ties up the *"know what"*, *"know why"* and *"know how"* questions to the **DIKW** concept. The **"e"** symbolizes **Explicit knowledge** and **"t"** symbolizes **Tacit knowledge**. Explicit knowledge is information-based, formal and methodical and can be communicated and shared in books, reports, requirements specifications, scientific methods or computer programs. Tacit knowledge comprises of two parts:

- Experience, rooted in the individual behavior or in the work community.
- Intelligence, deeply rooted in our minds.

"In this research the component under focus will be Expert based - Tacit."

2.1.2 Knowledge - Characteristics

According to [12], there are six characteristics of knowledge:

- **Transferability**: Knowledge can be successfully extracted from one context to another. Extractions when it comes to transferability include:

  1. **Explicit to Explicit** Explicit to explicit knowledge transfer can be represented by information that is written and shared in reports, where new knowledge is synthesized into information from many different sources [17] & [18].

  2. **Tacit to Tacit** Tacit to tacit knowledge transfer can, by efficient means, be made through observing skills, imitate and practice. However, the methodical understanding in this kind of knowledge transfer is often lost [17] & [18].

  3. **Explicit to Tacit** Explicit to tacit knowledge transfer represents the creation and reframing of information into own tacit knowledge. In the long run, new individual innovations become resources, necessary in the daily work [17] & [18].

  4. **Tacit to Explicit** When tacit knowledge is expressed in its core, it can be converted into explicit knowledge. However, the conversion of tacit knowledge into explicit knowledge implies the expressing a model of the inexpressible [17] & [18].

- **Subjectivity**
  Knowledge can be interpreted differently, which may be dependent on people's knowledge base and the applied context.

- **Embeddedness**
  Knowledge can be difficult to access or reformulate.

- **Self-reinforcement**
  Knowledge does not lose value when it is shared, in fact the value of it may grow when it is widely spread.

- **Perishability**
  Knowledge may become obsolete over time.

- **Spontaneity**
  Knowledge can develop impulsively in a process that is difficult to control.

"Research done by [11] supports that **subjectivity** and **transferability** can be considered out of all the characteristics are of greatest concern for knowledge reuse in the research."

2.1.3 Knowledge Management

2.2 The Future of "Knowledge"

In a world of increasingly global competition, agile development of products or services have become more, not less, important [19]. A business is, in its essence, a vast collection of knowledge and information. It is what's behind the creation of benchmark products and services, and it exists as a web of insights and ideas shared by staff [20].

Knowledge is growing exponentially. Increasing your industry knowledge gives you a competitive advantage and assists you in the growth of your business [19]. As the basis of competition has shifted more and more to the creation and assimilation of knowledge, the role of the **KM** systems will be critical [17], [8] & [19].

2.2.1 Expectations for Decision Support System

By 2020 or sooner, it will be all about **"just-in-time knowledge"**. In a world of fast knowledge development, none of us will have the capability to know much of anything at all. **The most important skill we will have will be the ability to go out to get the right knowledge for the right purpose at the right time** [22].

Coming to consensus with views expressed by **Tim Eisenhauer**, below trends were important to highlight and point out when we talk about integrating **KM** and **AI** to improve the decision support system:

- **Social element**
  Taking inspiration from how social media has revolutionized the way the user interacts with the internet. When social media elements, for example chat feature, polls, video sharing, etc. are blended with **KM** tools, the tasks would become easier. Engineers can communicate more intuitively and engage more effectively. Social networking sites like Facebook, Twitter are highly effective tools for marketing and communication, and they are also extremely easy to use [21].

- **User engagement**
  Currently, many engineers are actively looking forward to contribute to their companies by sharing their insights and ideas or reflections. **KM** is rather translating from its control to cultivation environment. There are different terms for what has replaced it, such as peer-based knowledge, community knowledge or the infinite global idea cycle [22] & [21].

- **Union of content creation and KM**
  Content such as blogs and articles are essential tools for marketing. Organizations regularly generate new content to keep pace with increasing demands for information. **KM** tools should allow features like tag, share, and organize content as soon as it is created. This helps to cut down on confusion and makes **KM** a more interactive process [22] & [21].

- **Space segmentation**
  KM in its social community wherein the information assets will be shared, refined, and organized. However, information overload, particularly during periods of rapid growth and success can be disastrous. **KM** should allow for segmentation of information into multiple community spaces. The segmentation or thin slicing of the knowledge will continue to play a major role in the future of social intranet or **AI** and **KM** [21].

- **UI**
  The point of contact between your engineer and your software system is the **user interface**, or **UI**. The **UI** is basically what the engineer sees on the screen when logging in, and it directly affects how he or she navigates and experiences the software system. A well-designed **UI** will allow to leverage the software system properly, while a confusing UI will only frustrate and confuse the team [21].

- **Updates**
  Automatic, consistent updates are becoming increasingly necessary as new challenges and solutions emerge. Most companies have considerable amounts of obsolete knowledge that has to be flagged as old or not in use. Employing the ideas of keeping everything updated will assist in reducing the bottlenecks in the processes. Social intranet software suites are always in flux, improving with each update, and the future holds even more surprising tweaks that will help to improve productivity [21].

- **Customization and Scalability**
  Several social intranet software options can be described as "one size fits all." These are suites that claim to fit the needs of practically every type of organization, but is there really such a thing? Your company is unique, and you need a knowledge management software solution that fits you rather than something generic. Customization is essential to the success of your software implementation. As social intranet and **KM** tools evolve, they will continue

to become more customized, allowing to scale your solution to match your organization's growth [21].

- **Establish Early-Warning Systems**
  Reducing uncertainties and having a transparent overall development process is of the essence. **KM** tools should assist in creation of flagging systems that serve as early-warning systems [19].

"This research will contribute in **Establishment of Early-Warning System** and the interrogative system development will try to look into **Customization and Scalability**. "

"**RQ 1** gets contextualized in this section. The future trends and the existing method of check sheets turn to be futile for a sustainable transition."

2.3 Product Development

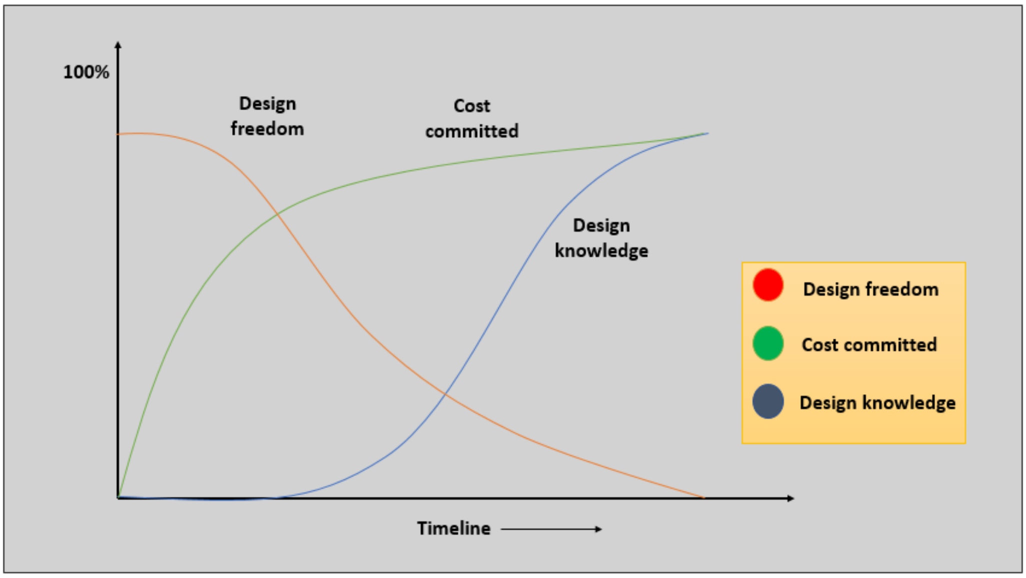


Figure 2.5: Product life-cycle [23]

Product Development is a highly knowledge intensive field [15]. The effectiveness in carrying out all the development activities depends a lot on the availability of information. As presented in Figure 2.5 the main aim in developing a decision support system would be to make right reusable-knowledge available early in the product development cycle. This results in lowering the costs and ensures faster development.

2.4 Expert Knowledge

As presented by [24], expert knowledge is coded as tacit knowledge and can be hardly verbalized by experts. The extraction of tacit knowledge requires methods that are based on stories.

2.4.1 Narrative Method

In the research conducted by [24], in the context to gain experiential knowledge, narrative method of **Triad** was put into action. This was one of the methodological approach to investigate expert knowledge. Other narrative methods include storytelling, techno-expert-workshops and interviews with he experts.

2.4.1.1 Triad Interview

As presented by [24], this is a method developed by Dick Hails aims transfer experiential knowledge. It is characterized by initiation of dialogue upon an agreed topic. It comprises of three people with specific roles:

1. Narrator: who performs the role as the expert for the topic for the validity of knowledge [24].
2. Listener: who performs the role as a novice who wants to learn from the expert [24].
3. Layperson: who serves as a moderator [24].

The expert describes situations where he gained significant experiences. These can be situations where something went really well or solutions and understandings that were achieved during the accomplishment of a complex task. The listener follows the experts handling and tries to understand. The immersion to this handling is alleviated by the role of the moderator who is responsible for the conditions of this dialogue. The moderator ensures that the narrator and the listener are both close to the topic, ambiguities are reassessed and really personalized and tacit knowledge is transferred. The moderator keeps the external perspective whereas the listener can put himself into the expert's position [24].

"The above triad approach has been followed in the research while conducting interviews. Instead of three people the role of the listener and the layperson was conducted by only one person. The relevant triad interviews have been documented in text form and have been presented in the Appendix of this research."

2.4.2 Interrogative Question Formulation

"Temporal aspects"

Mapping of linkages of task characteristics with techniques of solving the task is the essence [25]. Before having a linkage made, in order to understand the role knowledge plays in a particular task domain, it is necessary to know the following:

- **Compartmentalizability** of the task knowledge: Activities can be categorized into high knowledge (specialized and non-repetitive) and low knowledge (standardized and repetitive) [26]. Sub task serves as a compartment. "When human experts talk about what they do, they frequently first locate themselves by naming some sub-task and then indicate what conditions have to be satisfied in order for some behaviour to be appropriate" [25].

- **Uncertainty** of the task information: The task environment strongly shapes the nature of the task in two scenarios:

  1. The reliability of the data it provides [25].

  2. The point in time, relative to the task the data it provides [25].

- **Applicability** of the task knowledge: Applicability factors have been established in order to make search more efficient.

  Applicability factor = 1: Performing the action will result in transition to a state on the solution path.

  0 < Applicability factor < 1: There is some likelihood that performing the action will result in the transition to a state on a solution path [25].

- **Thickness** of the task knowledge: Task knowledge is considered to be thick if the same scenario can evoke wide variety of action depending the persons meta goals. Levels of abstractions are indication of the thickness of the task [25].

"If someone who claims some piece of knowledge K is always relevant in situation S is asked to justify that claim, the knowledge K' that is used as justification is also relevant in situation S, K' has the same function as K, but presumably is more basic and thus relevant situation besides S." "If problems that arise while task is being performed can be solved with knowledge having no direct connection to the task, endless opportunities for creative problem solving open up [25]."

"In the research undertaken, used the above temporal aspects and used them as a guiding thought during the interrogative system development or while conducting triad interviews specifically while "moderating"."

2.4.3 Thin Slices of Knowledge

Thin slice of knowledge in this research is referring to a specific domain specific knowledge and a thick slice refers to rather knowledge at community level. These definitions reflect on the term **"zoom ability"** or level of detail. Giving the user of the interrogative system access to which level of knowledge he or she wishes to address.

"For this research, understanding how to dissect knowledge and hence make a question to capture the relevant aspect of the knowledge chunk was what was critical."

2.4.4 Frame of Reference

Process module: “Where are we in the process of product development?”

An argument stating, “Language can play a significant role in structuring or reconstructing, a domain as fundamental as spatial cognition or human cognition” was put forth by [27]. The idea of incorporating the **Frame of Reference** abbreviated as **FoR** was put into action during the qualitative research conducted into the research during the interviews [27].
In the study conducted by [27], they tried to understand how the process of codification is greatly influenced with respect to the three frames of reference (at an abstract level):

- Relative or egocentric
- Intrinsic or object centric
- Absolute

English speakers use normally two **FoRs** relative and intrinsic. The absolute frame is used for large scale geometric description. The intrinsic **FoR** requires objects to be parsed into their major parts like ‘front’, ‘back’ and ‘side’. This is done to find the named facets of the landmark object used in intrinsic body. English language uses oriented template giving the ‘top’, ‘bottom’, ‘side’ as well as functional criteria. This results in that once the object is parsed, the second step of projecting it into a space from the designated facet of the object is done [27].

“Do you want to pick perspective?” Relative **FoRs** can be lifted from the self and rotated and applied to other people and objects which often results in a perspective view [27].

"The research undertaken, tried to investigate the influence of **Language** and **Perspective** on the **Process Module aspect**."

3

Research Methodology

My methodology is not knowing what I'm doing and making that work for me – **Stone Gossard**

This chapter presents the methodology framework that has been chosen as the basis for the research performed. Why it was chosen and how it has been adopted has been focused.

3.1 Research Design

Design is a rather multifaceted dynamic phenomenon involving multiple stakeholders that work together to converge an idea from conceptual stage to reality.
In today's scenario, apart from the engineering aspect of a product, the overall life cycle of the product has significant impact. The rationale with which designers design a specific product, be it a simple coffee mug or a complex jet engine, now involves new complexities and economic significance. Factors varying from engineering design to transportation, installation, and finally maintenance now also dominate as design constraints which affects the design process.
Design based research should be a systematic but flexible methodology aimed to improve practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories [33] & [32].
Owing to the pragmatic nature of design research, it provides a solution, to a real-world problem, which thus forms a design principle in general, which then can be used by practitioners depending on the context [34] & [35]. Design research has three phases which occur as overlaps, namely:
Experiential (late 1950's): it is focused on transfer of experience from senior personnel like senior design engineers. Here the knowledge transfer was more about explanation of their work and their rationale or observation of design projects undertaken by them [36].
Intellectual (1960's onward for 20 years): it is focused on provision of logical and consistent basis for design. This was the manifestation phase wherein methodologies, principles, etc. breathed life [36].
Experimental (1980's onward): it is focused on gathering data, both in laboratory and practice, to understand further what the terms designer and design actually

mean. The essence of this phase was rather on understanding the impact the new methods and tools had on the design process [36].

3.1.1 Methodology

Backcasting framework and **Design Research Methodology** abbreviated as **DRM** has been adopted for this research in a flexible and opportunistic way. This framework has not been used proactively in a linear fashion but rather its general idea has been shaping the general practice undertaken during the research.

3.1.2 Backcasting

The backcasting methodology is generally useful [37], when:

- The problem to be studied is complex.
- There is a need for major change.
- The problem is a matter of externalities.
- The scope is wide enough and the time horizon long enough to leave considerable room for deliberate choice.
- Dominant trends are part of the problem.

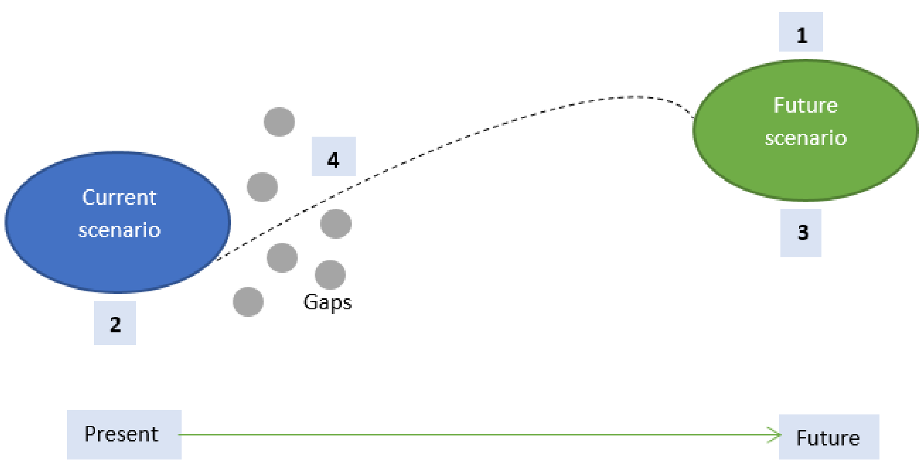


Figure 3.1: Backcasting [38]

This perspective for developing solutions in a challenge driven innovation environment is extremely useful. The first stage shown in Figure 3.1 aims to build an understanding of the conditions that need to be met in the sustainable future. In this stage identifying the guiding question is vital.

Guiding thought: “We want to make explicit the right kind of knowledge extracting questions that the community can be addressed with. Make explicit a method that is appropriate for the community to answer the question. Make explicit the strategies to validate the responses from the community.”

The second stage is retrospection of the current check sheet system in relation to the conditions for sustainability. Here we focus more on gap identification. The third stage is identifying solutions to bridge the gaps. The final stage is identifying the feasible ways to realize future solution [38].

3.1.3 Design Research Methodology

The aim of DRM is to help design research become more effective and efficient.

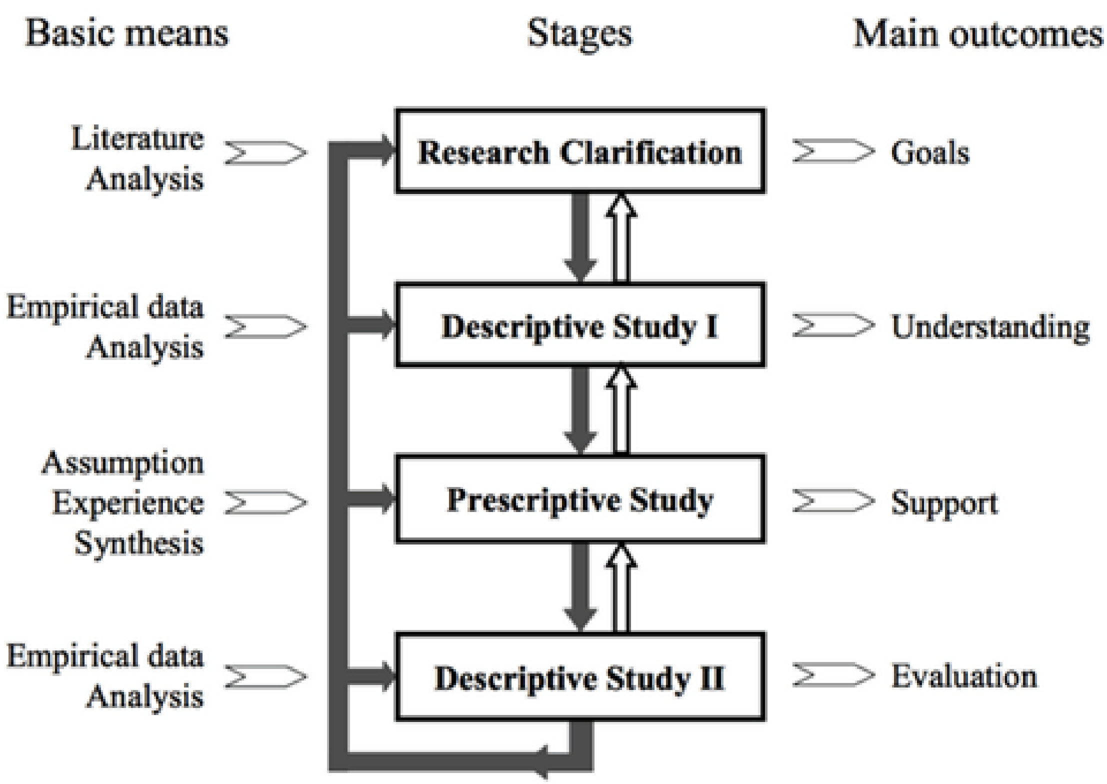


Figure 3.2: Design Research Methodology [36]

In the most generalized form, as presented in Figure 3.2, DRM consists of four stages which are **Research Clarification** termed as **RC**, **Descriptive study I** termed as **DS I**, **Prescriptive Study** termed as **PS** and **Descriptive Study II** termed as **DS II**. As an overview, the first activity of DRM, that is a RC, clarifies the objectives and assumptions that initiate the research project and hence formulate a goal for the subsequent activity. The second activity, DS I, is to find literature or empirical data to understand the object of the study, which is often a problem recurrent in industry related to the process. The third activity, PS, is the activity to create tools, processes, methods or guidelines as proposed solutions to the problem studied. The final activity, DS II, is to test the support and intended outcomes [36]. The undertaken research relies on the Type 2 study which includes RC, DS-I and initial PS.

3.2 Applied Research Methodology

As stated earlier, the undertaken research relies on the Type 2 study including **RC**, **DS-I** and **initial PS**.

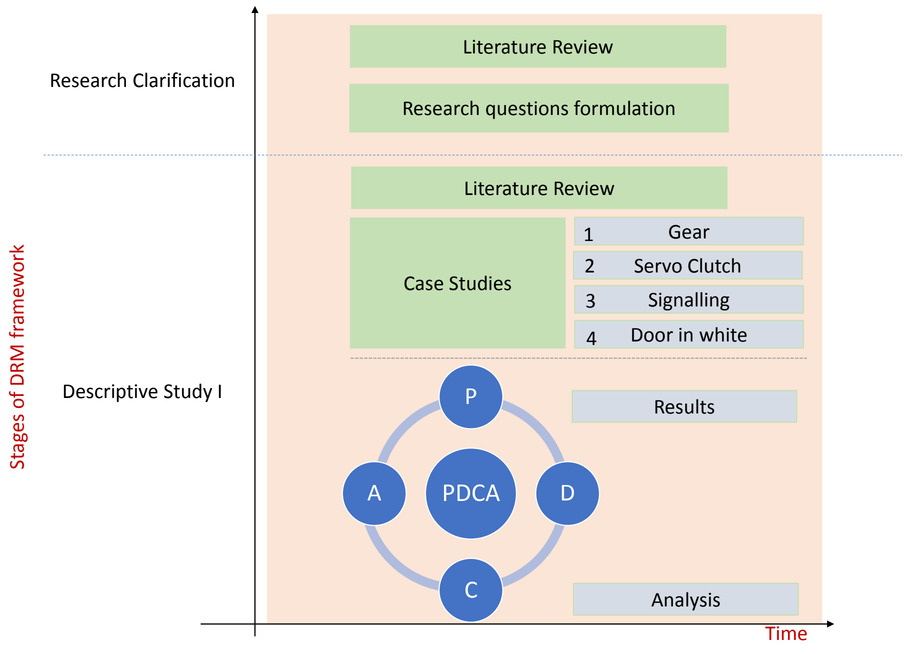


Figure 3.3: Applied Methodology

RC phase was composed of conducting literature review and investigating the need and hence formulating research question for the research. In the second phase of **DM I**, literature review was done to investigate any previous work carried out. Concurrently, case studies were done on four mechanical components. The components were selected based on being pure mechanical system, electro-mechanical system, electronics and finally components with conflicting requirements. These were used to develop modules of information extraction questions. A **Plan-Do-Check-Act** abbreviated as **PDCA** cycle approach was used after formulation of the question. Interviews with Volvo Trucks Technology and Chalmers University of Technology, observations, informal meetings, and surrounding discussions were used in the analysis stage. The anticipation of the future is about applying some model of the world, which connects the past and the present to the future, to a set of data to produce predictions regarding the future state of the world [39]. The research was based rather on a qualitative exploratory-descriptive design and entails conceptual or theoretical research. The analysis stage was done using triangulation method and gap analysis. Figure 3.4 summarizes the overall stage progression of the entire research.

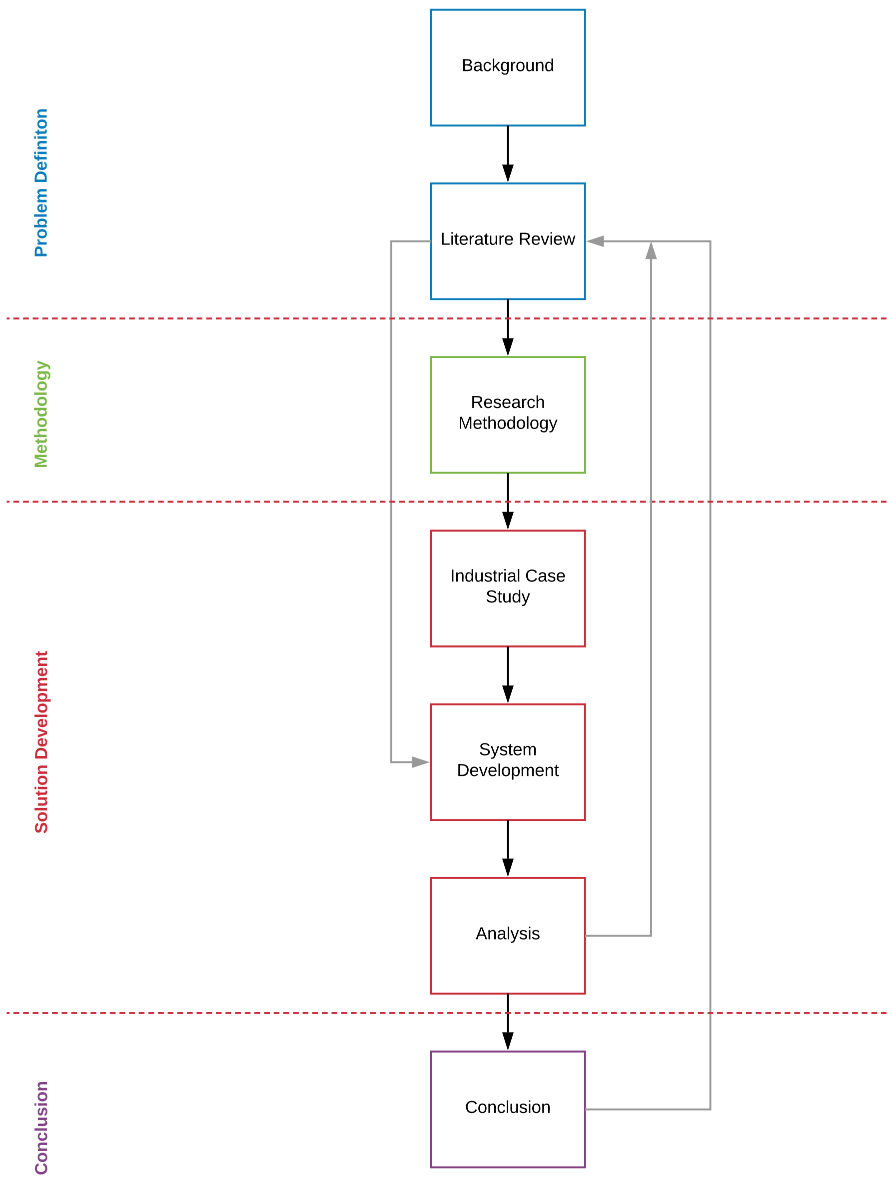


Figure 3.4: Research stage progression

4

Results

Eureka! - I have found it! **– Archimedes**

This chapter presents the rationale adopted during concept development for the interrogative system. Why it was chosen and what it is comprised of has been presented. "The standalone term "system" in this chapter is generally referring to a product system. This definition holds true for all tables (including respective Appendix) associated with the Interrogative system."

4.1 Applied Backcasting

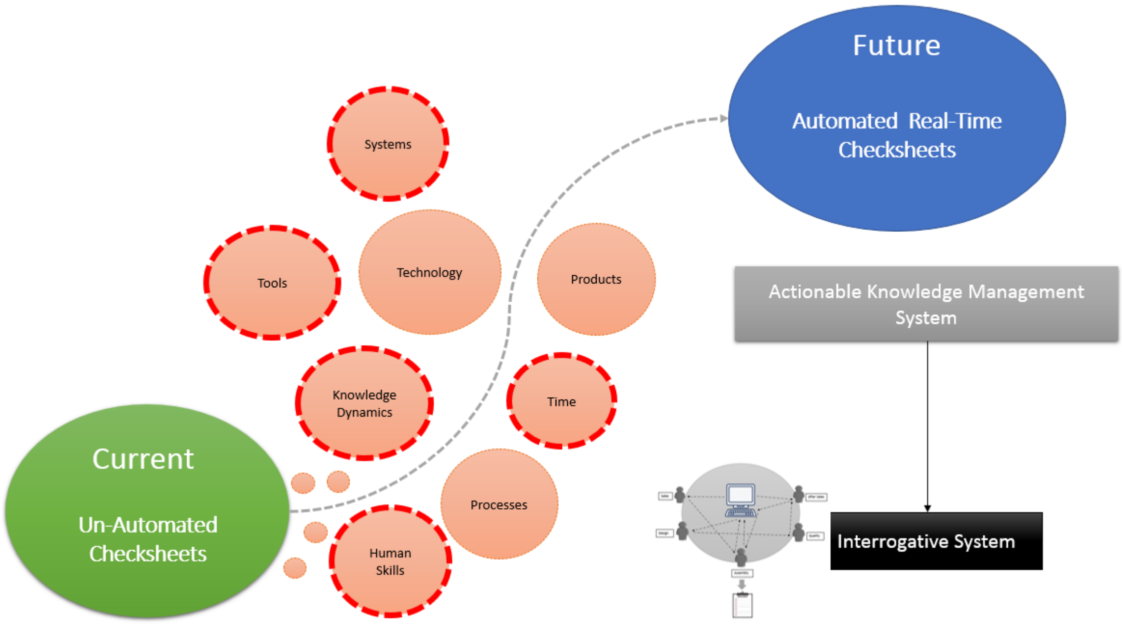


Figure 4.1: Applied Backcasting

In Chapter 3, Section 3.1.2, page 18, the basic concept of backcasting was presented. Figure 4.1 tries to illustrate the loop holes which prevent reaching the ideal automated scenario in the future. While conducting this research, human skill and knowledge dynamics were key loop holes to be investigated. The interrogative system design is intended to be human-centric.

4.2 Case Study

Case studies have been conducted in order to have a reference interrogative system built.

4.2.1 Gear

A gear is chosen as an example of a random mechanical component. The component has been analyzed based on its functionality, and suitable questions have been formulated in order to put forth the context of gear design in generalized form. In-depth analysis has been presented in Appendix A.1. The main purpose of this task was to understand, for a simple mechanical component, what can be some of the knowledge extraction questions. [53] & [54] have shaped the formulation of Appendix A.1.

4.2.2 Check sheet

The following check sheets were provided in order to understand the knowledge capture process at Volvo Trucks Technology. These check sheets have not been presented for documentation purpose due to data privacy issues.

1. Servo clutch
2. Door in white
3. Signalling

The rationale behind choosing the three components was to have mechanical, electromechanical and conflicting trade-off management situations.

4.3 Inspiration

Research presented by [2] inspired or rather shaped the interrogative system to have a block design. This was also chosen in order to facilitate employing databases in the future for a particular chunk of knowledge slices and hence to construct a **Graphical User Interface** abbreviated as **GUI**. Figure 4.2 presents the overall block design of the interrogative system.

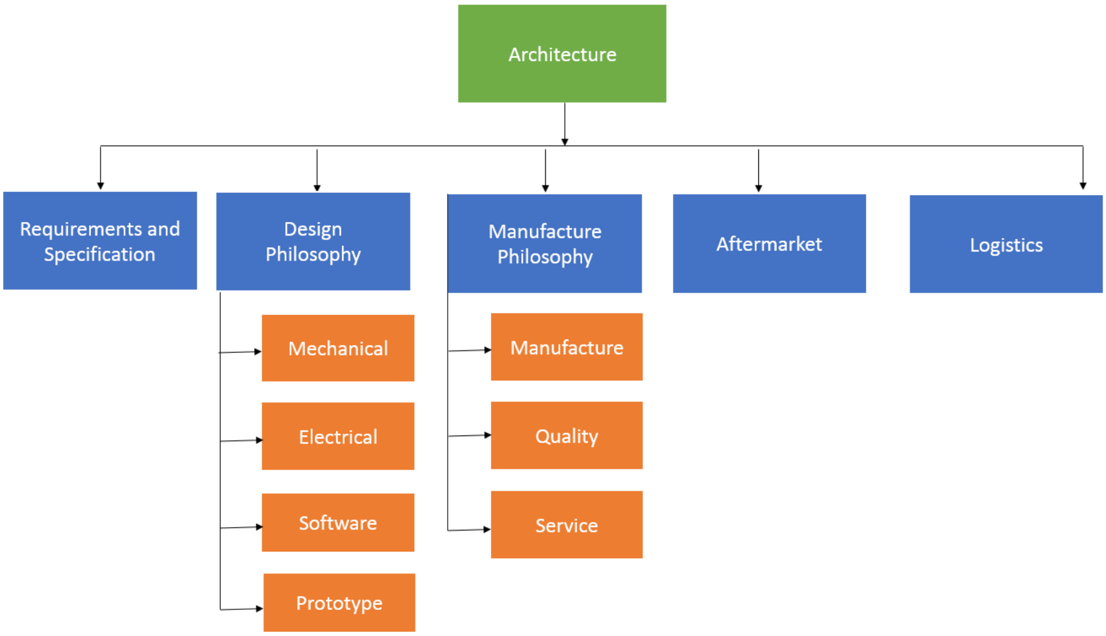


Figure 4.2: Block design

4.4 System Architecture

Why: In science, computing and engineering, a black box, Figure 4.3, is a device, system or object which can be viewed in terms of its inputs and outputs, without any knowledge of its internal workings. Its implementation is opaque or "black." Almost anything might be referred to as a black box: a transistor, an algorithm or even the human brain [40]. In a product developers perspective, additional sets of information can be referred to as feedbacks, design space and parameters that affect the black box. The gear case study in Appendix A.1 also motivated adopting the use of the black box concept.

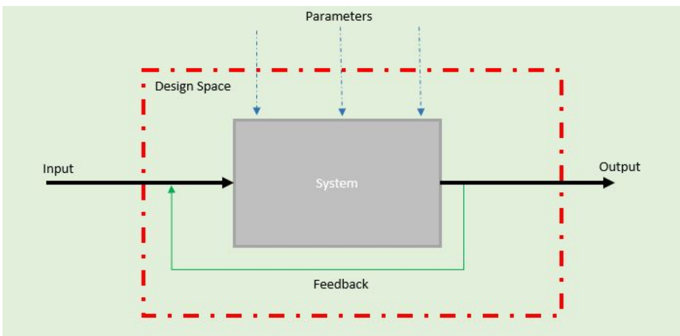


Figure 4.3: Black box [40]

What: Figure 4.4 presents the basic concept behind the check sheet system in Volvo Trucks Technology. This inspired in the Creation of Table 4.1. Fourteen different segments of the System Architecture are presented. This segmentation assists the user to understand the overview of the product under development in terms of its system design perspective. In depth thin slices associated with the fourteen segments have been presented in Appendix B Section B.1 Table B.1. In Appendix B Section B.1.1 Table B.2 seven more slices associated with competence supplements the system architecture in the above Chapter 4 Section 4.4 further.

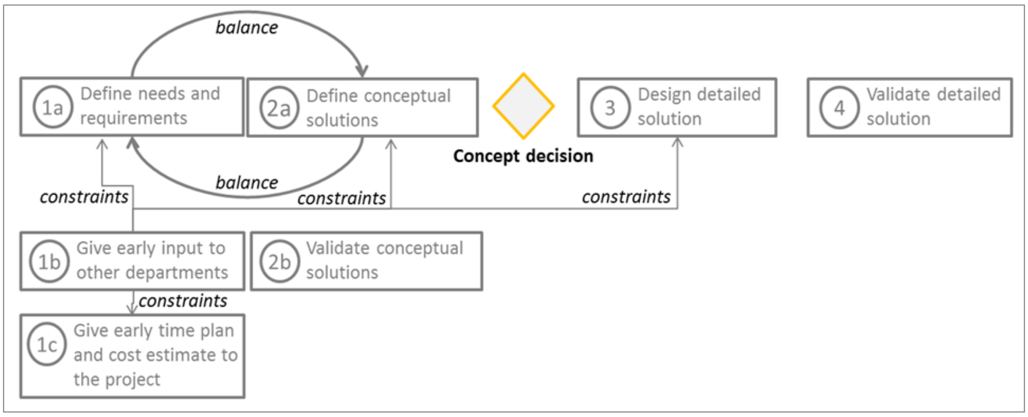


Figure 4.4: Overall idea of check sheets in Volvo Trucks Technology [41]

System Architecture Level 1.1	
1	Name
2	Function
3	Association
4	Functional dependency
5	Boundary
6	Environment
7	Input
8	Output
9	Criticality
10	Dependency
11	Compatibility
12	Variant
13	Market
14	Novel Idea

Table 4.1: System Architecture Level 1.1

4.5 Requirement Specification

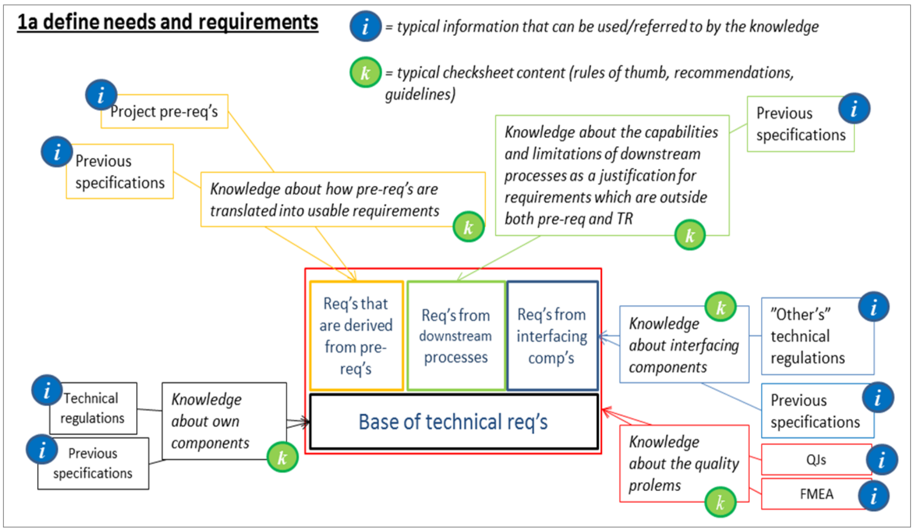


Figure 4.5: Overall idea of check sheets in Volvo Trucks Technology [41]

Why: The requirement specification represents an unambiguous agreement on what the team will attempt to agree on in order to satisfy the customer needs, company policies or laws and regulation [15]. The frame work used for construction of this section is based on Figure 4.5 as adopted by Volvo Trucks Technology.

Requirement Specification Level 1.1
1 Core standard(s)
2 Stakeholder(s)
3 Organizational requirement(s)
4 Derived requirement(s)
5 Base technical requirement(s)
6 Downstream processe(s)
7 Interface(s)
8 General best practice(s)

Table 4.2: Requirement Specification Level 1.1

What: Table 4.2 presents eight different segments of the Requirement Specification. This segmentation assists the user to understand the overview of the product under development in terms of its system design perspective. In depth thin slices associated with the eight segments have been presented in Appendix B Section B.2 Table B.3.

4.6 Design

4.6.1 Design Philosophy

Why: This layer tries to capture the the rationale or the thinking process which designers use to solve problems.

What: In depth thin slices associated have been presented in Appendix B Section B.3 Table B.4.

4.6.2 Design Mechanical

Why: The inspiration to structure the design segment was drawn by the article published by [42].

Design Mechanical Level 1.1	
1	Tools
2	Experience
3	System
4	Material
5	Process
6	Safety
7	Aesthetics
8	Function
9	Sustainability
10	Spark

Table 4.3: Design Mechanical Level 1.1

What: Table 4.3 presents ten different segments of the Design Mechanical level. In depth thin slices associated have been presented in Appendix B Section B.3.1 Table B.5.

4.6.3 Design Software

The inspiration to structure the design segment was drawn by the article published by [42]. This section follows the same guidelines that have been used to construct Design Mechanical Level with some minor changes. In depth thin slices associated have been presented in Appendix B Section B.3.2 Table B.6.

4.6.4 Design Electrical

The inspiration to structure the design segment was drawn by the article published by [42]. This section follows the same guidelines that have been used to construct Design Mechanical Level with some minor changes. In depth thin slices associated have been presented in Appendix B Section B.3.3 Table B.7.

4.6.5 Prototype

Why: Prototyping is a process of developing approximations of products. Prototypes are commonly used for learning, communication, integration and establishment of milestones in the product development process [15]. Having this segment would be a supplement for the other design segment, as this serves to be a very knowledge intensive area.

What: In depth thin slices associated have been presented in Appendix B Section B.3.4 Table B.8.

4.7 Manufacturing Philosophy

Why: This layer tries to capture the the rationale or the thinking process which designers embody to understand the manufacturing process in general.

What: In depth thin slices associated have been presented in Appendix B Section B.4 Table B.9.

4.7.1 Manufacturing and Assembly

Why: The inspiration to structure the design segment was drawn by the article published by [42].

What: Table 4.4 presents thirteen different segments of the Manufacturing and Assembly level. In depth thin slices associated with the twelve segments have been presented in Appendix B Section B.4.1 Table B.10.

	Manufacture and Assembly Level 1.1
1	Tools
2	Fabrication
3	Equipment
4	Ergonomics
5	Information downstreaming
6	Assembly
7	Secondary Processes
8	Defects
9	Product Specific
10	Safety
11	Spark
12	Information Up streaming

Table 4.4: Manufacture and Assembly Level 1.1

4.7.2 Quality and Control

Why: Quality control is a process through which a business seeks to ensure that product quality is maintained or improved with either reduced or zero errors. This is done by training personnel, creating benchmarks for product quality, and testing products to check for statistically significant variations [43].

What: Table 4.5 presents three different segments of the Quality and Control level. In depth thin slices associated with the three segments have been presented in Appendix B Section B.4.2 Table B.11.

	Quality and Control Level 1.1
1	Product
2	Process
3	Validation

Table 4.5: Quality and Control Level 1.1

4.7.3 Service

Why: Service is something that we have to do, operationally, if we wish to achieve the item's inherent reliability [44].

What: Thin slices associated have been presented in Appendix B Section B.4.3 Table B.12.

4.7.4 After Market

Why: Secondary market that supplies accessories, spare parts, second-hand equipment, and other goods and services used in repair and maintenance. Some aftermarkets, such as those for automobile add-ons, parts, tires, wheels, etc. are very large. Also called replacement market or secondary market.

What: Thin slices associated have been presented in Appendix B Section B.5 Table B.13.

4.7.5 Logistics

Why: Logistics refers to what happens within one company, including the purchase and delivery of raw materials, packaging, shipment, and transportation of goods to distributors via established channels. The major role played by logistics from the customer side is timely delivery and from the internal company efficiently coordinating resources to allow for timely delivery of raw materials that can be purchased, transported, and stored until used.

Logistics Level 1.1	
1	Warehouse
2	Transport
3	Management Structure

Table 4.6: Logistics Level 1.1

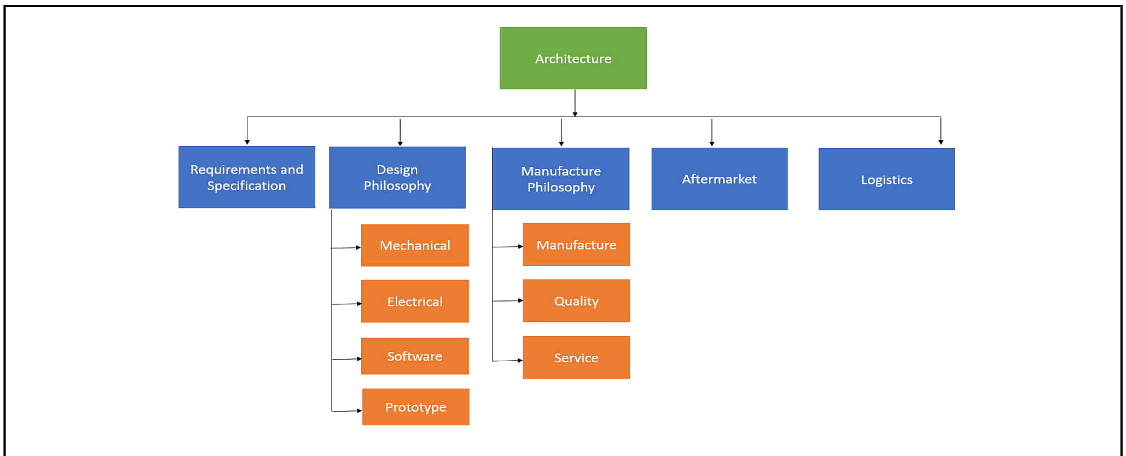
What: Table 4.6 presents four different segments of the Logistics. Thin slices associated with the three segments have been presented in Appendix B Section B.6 Table B.14. The study conducted by [47] has been employed in the creation of thin slices.

4.8 Use Case

This section presents how the developed interrogative system is put into practice. However, only two sections of the developed interrogative system will be discussed in depth for its use. A generalized use case for three personas will be presented and a suggestion of top 30 questions for the near future AI is made.

4.8.1 Interrogative System

The previously presented rationale and necessary premises have culminated in the interrogative system adopting the structure presented in the overview in Figure 4.6. In Appendix C Section C.2 Interview C.2.1.2 application of System Architecture on the design engineer from Volvo Trucks Technology has been documented in detail.



Overview of Interogative System	
1	System Architecture
1.1	Competence
2	Requirement Specifications
3	Design Philosophy
3.1	Design Mechanical
3.2	Design Electrical
3.3	Design Software
4	Prototype
5	Manufacturing Philosophy
5.1	Manufacture and Assembly
5.2	Quality and Control
5.3	Service
6	Aftermarket
7	Logistics

Figure 4.6: Interrogative Overview

Taking feedback from the interview the questions as presented were frozen and presented visually in Figure 4.7. Appendix B Section B.1 Table B.1 presents the same as Figure 4.7.

What question(s) do I ask to understand my product's architecture with a system perspective?

System Architecture		
	Level 1.1	Level 1.2
1	**Name:**	What is the system?
2	**Function:**	What purpose does the system serve?
3	**Association:**	What other system(s) is it associated with?
4	**Functional Dependency:**	What other system(s) is it dependent on for its functioning?
5	**Boundary:**	Can the system boundaries be defined? What are the system boundaries? Does the design comply to the boundary definition? If not, what is done? What other aspects of the system's features can be considered for the boundary definition? (If it exist)
6	**Environment:**	What is the environment of operation in which the system operates? Which are the environmental parameter(s) the is system sensitive to? (If it exist) How does the environment affect the system design?
7	**Input:**	What is/are the input(s) to the system? Is/Are any margin(s) associated with the input(s) of the system? (If it exist) What is /are the margin(s) associated to the input(s) of the system? (If it exist)
8	**Output:**	What is/are the output(s) from the system? Is/Are any margin(s) associated with the output(s) from the system? (If it exist) What is /are the margin(s) associated to the output(s) from the system? (If it exist)
9	**Criticality:**	Does the system have any critical part(s)? Which is/are the critical part(s) of the system? (If it exist) How is risk associated with the critical part(s) identified and handled? (If it exist) Which is/are the critical performance related parameter(s) of the system which govern the overall design? (If it exist)
10	**Dependency:**	Are there any coupling parameter(s) from other systems affecting the current system? And what are they? (If it exist) What is /are the margin(s) associated to the coupling parameter(s) to the system? Is the knowledge about the existence of dependency referred to al team members? How is it done?
11	**Compatibility:**	Is the system compatible with other system(s) or subsystem(s)? Is the system architecture feasible? Is/Are there any architecture reference(s)?
12	**Variant:**	Is/Are there any variant(s) of the Architecture? What are the categories of the variant existing for the system? (If there are any variants) Which parameter(s) depend on the variant(s) selection for the system? (If there are any variants) What is the top deciding factor(s) for decision of selection of the system? (If there are any variants)
13	**Market:**	Is/Are there any ongoing market trend(s)? What are they? Do the ongoing market trend(s) affect variant selection? Do the ongoing market trend(s) affect architecture?
14	**Novel Idea:**	Is the design concept for the system new? Is there any post project concept(s) that can be considered when the design concept is novel? What type of post project(s) data in terms of parameter(s) would be important for the new design concept? What is/are the risk(s) associated with the lack of competence(s) in case of new design concept? What other alternative(s) can be opted to cope up with the lack of competence(s)? What are the major risk(s) associated with the new system design? How can the risk(s) associated with the new system design be dealt with ? What can be done to prevent such major risk(s)?

Figure 4.7: System Architecture

In Appendix C Section C.1 Interview C.1.2 presents application of Requirement Specification on the Design Engineer from Volvo Trucks Technology.
Taking feedback from the interview the questions as presented were frozen and presented visually in Figure 4.8. Appendix B Section B.2 Table B.3. presents the same as Figure 4.8.

How do I understand the rationale for the existence of the requirement?		
Requirement Specification		
	Level 1.1	Level 1.2
1	Core standard(s):	What are the requirements that the system needs to satisfy in order to comply to company's core standards?
2	Stakeholder(s):	Who are the stakeholders and what are the requirements that come from stakeholders who are involved with the system?
3	Organisational requirement(s):	What are the requirements from business division that affect the system? How are they made available? What are the requirements from the marketing division that affect the system? How are they made available? What are the requirements from sales that affect the system? How are they made available? What are the requirements from suppliers that affect the system? How are they made available? What are the requirements from research and development that affect the system? How are they made available? What are the requirements from testing that affect the system? How are they made available? What are the requirements from design - mechanical that affect the system? How are they made available? What are the requirements from design - electrical that affect the system? How are they made available? What are the requirements from design - software that affect the system? How are they made available? What are the requirements from manufacture that affect the system? How are they made available? What are the requirements from quality that affect the system? How are they made available? What are the requirements from service that affect the system? How are they made available? What are the requirements from the after market that affect the system? How are they made available?
4	Derived requirement(s) :	What are the derived requirements from previous project(s) that affect the system? How are they made available? How is it ensured that, the compliance is met for a carry over project(s)? What are the important requirements from previous specifications that might affect the system? Are there any important requirements from trade-offs? What is done to handle them? What are the requirements associated with installations of the system? How are they handled ? Are there any Installation interfaces that affect the system? Are they critical interfaces? Why are such interfaces termed critical ? Are there any product variant compliance check for the requirements? What are the economic requirements that govern the project undertaken?
5	Base of technical requirement(s):	What are the requirements from legal law and regulations? Are there any legal (National) law and regulations? How do they affect the system design? What is done to satisfy them? How is it validated? Are there any legal (International) law and regulations? How do they affect the system design? What is done to satisfy them? How is it validated? Are there any safety regulations? How do they affect the system design? What is done to satisfy them? How is it validated? Are there any product regulations? How do they affect the system design? What is done to satisfy them? How is it validated? Are there any environmental regulations? How do they affect the system design? What is done to satisfy them? How is it validated? What are the system requirements for the product to function? What are the product requirements? What are the pre requisites? What parameters can be possible pre requisites be that affect the system? How are pre requisites identified ? Why are they important? How is the knowledge of pre requisites captured and transferred? Which pre requisites dominate ? How are pre requisites addressed? What can these pre requisites be used to define? How sensitive is the system to the pre requisites?
6	Downstream processe(s):	What are the requirements from the downstream processes that affect the system? How is the knowledge of downstream processe dependent data captured and transferred? How are parameters due to downstream processe dependent data addressed? How sensitive is the system to the parameters due to downstream processe dependent data?
7	Interface(s):	What are the requirements from interfaces and how are they managed?
8	General best practice(s):	How do you treat requirements that are incomplete or incomprehensible? How do you prioritize requirements? What techniques do you follow? How do you search and find requirements? What are possible sources? Is it efficitent? How do you treat changing requirements? Which tools do you use for keeping track of the changing requirements? What are some of the techniques for specifying requirements? Which works for you? And in which case?

Figure 4.8: Requirement Specification

4.8.2 Actionability Premise

The near future AI is expected to be associated with two databases, of which one database comprising of hypotheses, and the other consisting of tentative knowledge extracted from the COP. With respect to this research, efforts were put forth to link this above-mentioned AI operation to interrogative questions.
Taking inspiration from heuristic technique, in order to establish a mapping of interrogative questions, or in a sense to establish a flow which the near future AI system needs to adopt, it is essential to first have an overall sense of directionality.
The premise of the mapping boils down to the term **"Actionability"**. The proposition (hypothesis) on which the actionability is satisfied is characterized by how well the *"know what"*, *"know why"* and *"know how"* questions are sufficed by the tentative knowledge from the COP.

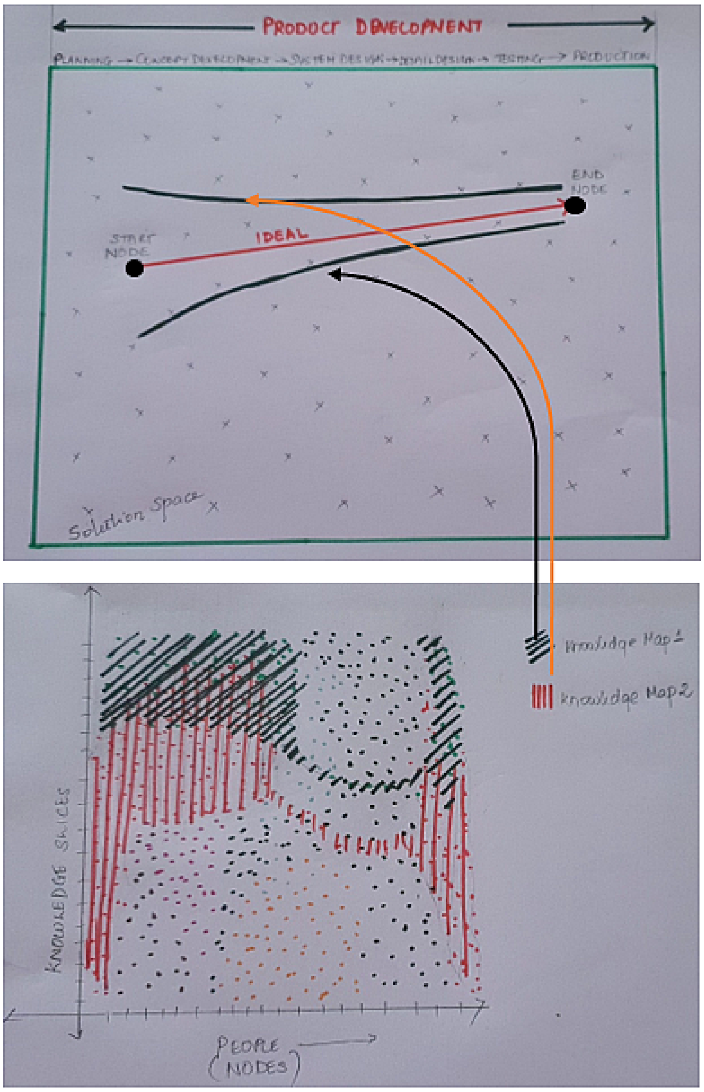


Figure 4.9: Heuristic framework Top and Bottom [15]

Thought experimentation is illustrated by Figure 4.9. **For the Top**: The process of product development [15] is mapped. The solution space is comprised of nodes of people. For a particular product, within that products particular COP there lies a start node and an end node. **For the Bottom**: The path form reaching the end node is dependent on the understanding of what slice of knowledge can be sufficient to satisfy the premise of actionability. This mapping is something which in the near future will be done by the AI but for this research moderation done by a human can mimic the above scenario.

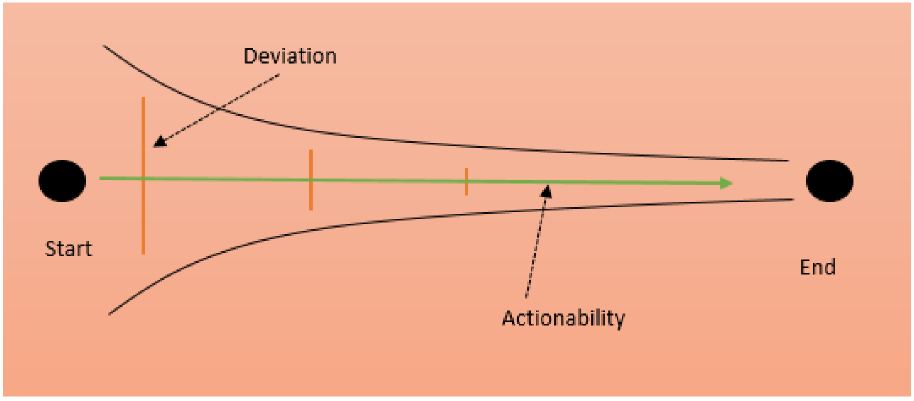


Figure 4.10: Actionability Premise

Figure 4.10 is the simplistic output of the thought experimentation.

4.8.3 Instances of Use Cases

In this section, taking inspiration from above Section 4.8.2 efforts are put forth to present three use cases which the near future AI can adopt for the interviewing of experts from:

1. Techno-commercial professional
2. Design professional
3. Manufacturing professional

The suggestions are made based on the feedback by interviewing Design Engineer from Volvo Trucks Technology. The mapping is based on human moderation.

4.8.3.1 Techno-commercial Professional

The end user in this case is a Tech-commercial Professional who is to be interviewed for the purpose of tacit knowledge extraction. The professional can be a Project Manager, Business Developer or Sales Engineer.

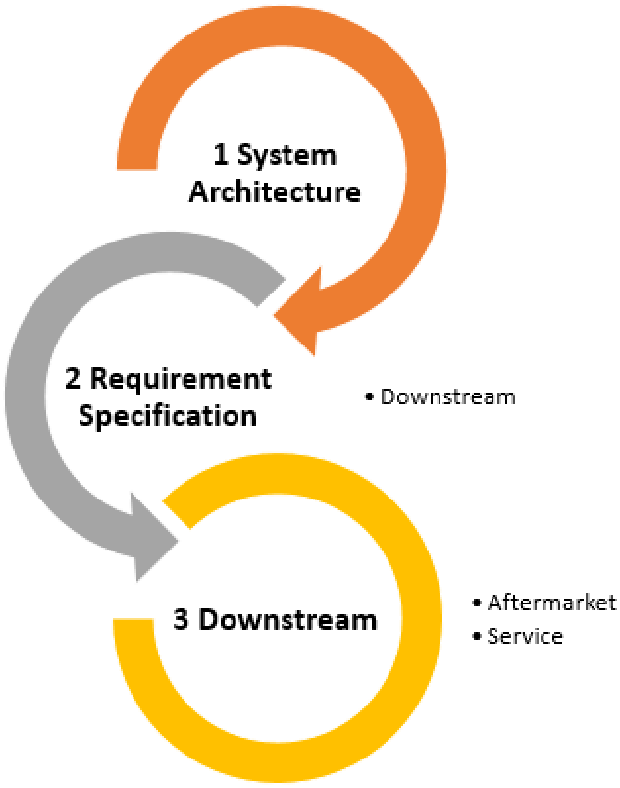


Figure 4.11: Techno-commercial Summarized

Figure 4.11 presents an overall process of interview to be adopted by the knowledge expert who is conducting the interview or the AI. The system architecture followed by requirement specification followed by downstream. A mapping has been presented in Figure 4.12. Priority numbers of 1, 2 and 3 have been provided in order to have a smooth iteration. Priority 1 starts with system architecture wherein some of the levels which need proper moderation leads to Priority 2 requirement specification. Priority 3 is dual in nature. wherein the data extracted from requirement specification can add more validity to the data gathered from priority 1. The main skill to extract data depends on how the actionability premise is satisfied.

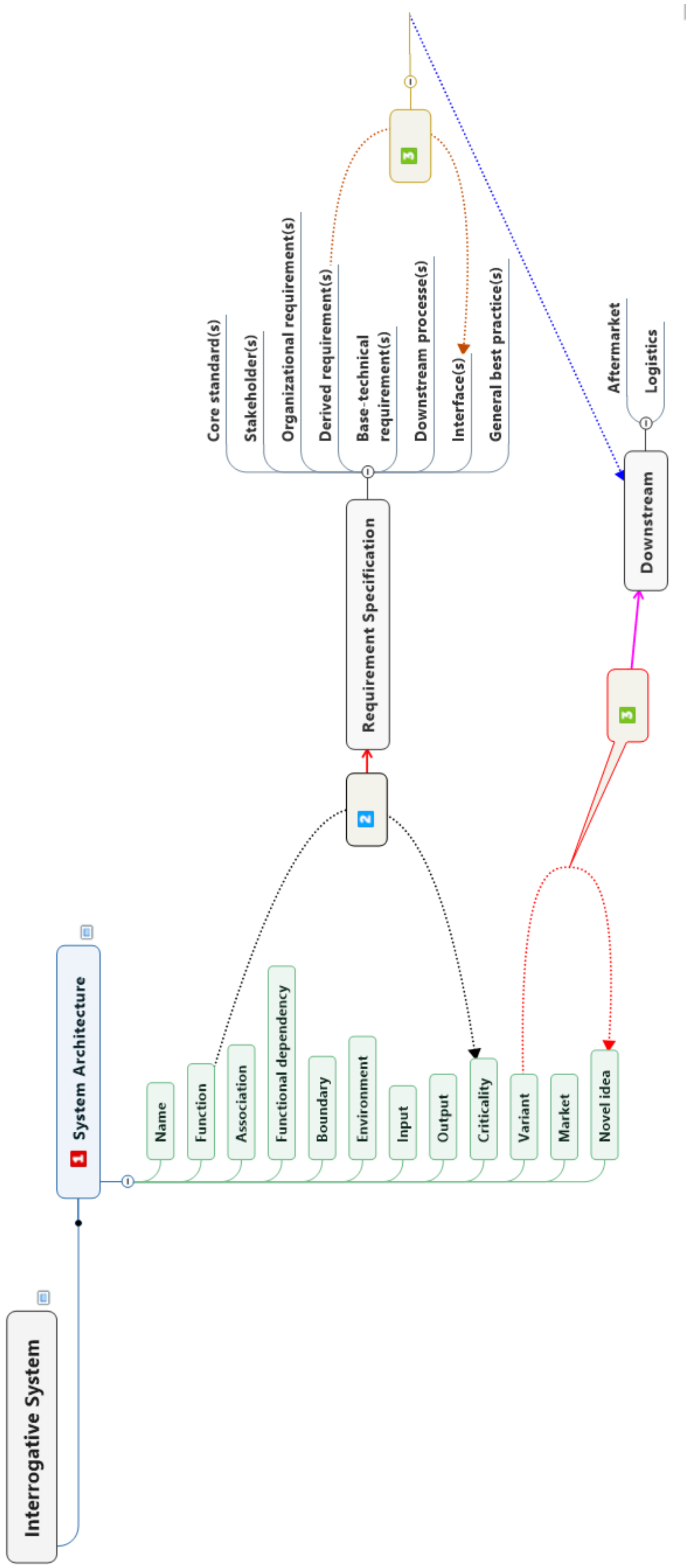


Figure 4.12: Techno-commercial Mapping

4.8.3.2 Design Professional

The end user in this case is a Design Professional who is to be interviewed for the purpose of tacit knowledge extraction. The professional can be a CAD Designer, Field Application Engineer or Application Developer.

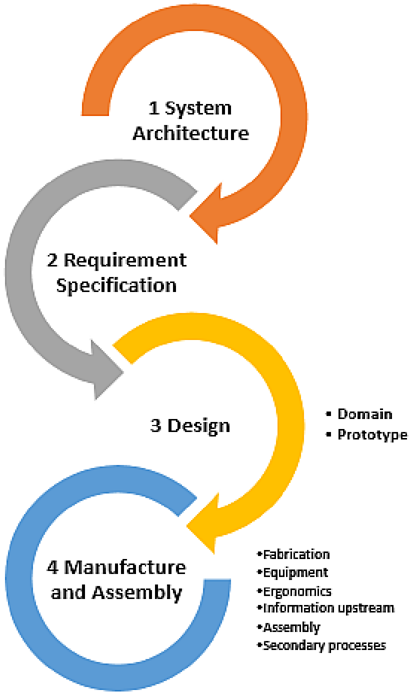


Figure 4.13: Design Summarized

Figure 4.13 presents an overall process of interview to be adopted by the knowledge expert who is conducting the interview. The system architecture followed by requirement specification followed by design of the experts domain of interest finally followed by manufacture and assembly. A mapping has been presented in Figure 4.14. Priority numbers of 1, 2, 3 and 4 have been provided in order to have a smooth iteration. Priority 1 starts with system architecture wherein some of the levels which need proper moderation leads to Priority 2 requirement specification. Priority 3 is provided to design. Priority 4 is given to manufacture and assembly to ensure that design for manufacture guidelines is followed. The main skill to extract data depends on how the actionability premise is satisfied.

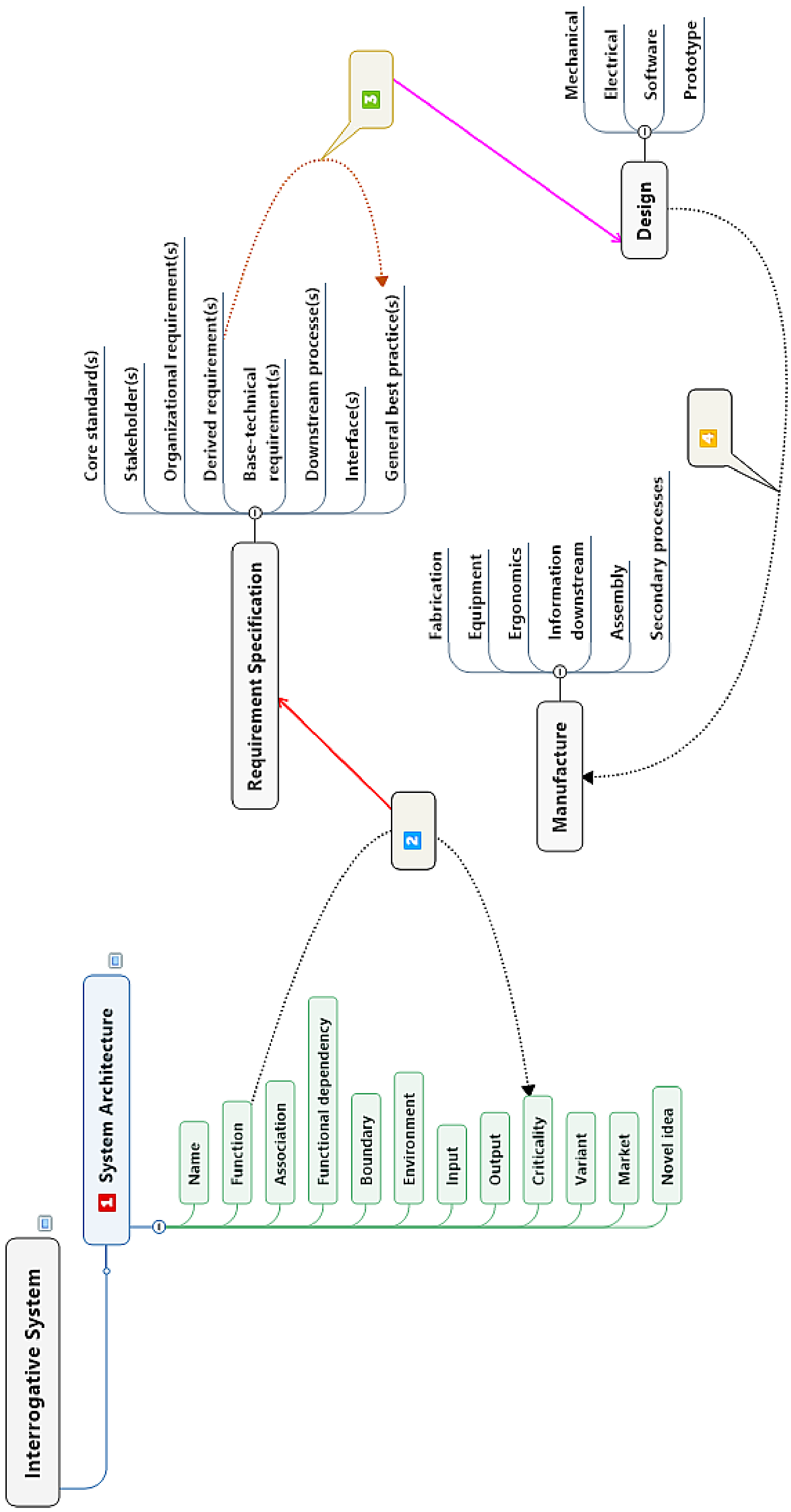


Figure 4.14: Design Mapping

4.8.3.3 Manufacturing Professional

The end user in this case is a Manufacturing Professional who is to be interviewed for the purpose of tacit knowledge extraction. The professional can be a Process Engineer or Production Engineer.

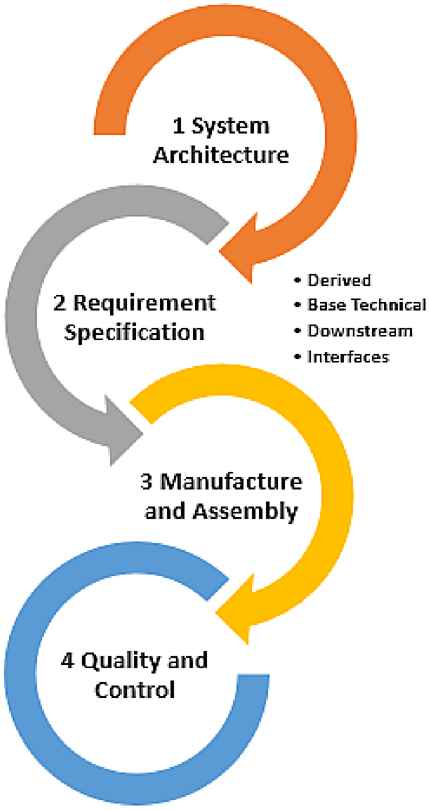


Figure 4.15: Manufacturing Summarized

Figure 4.15 presents an overall process of interview to be adopted by the knowledge expert who is conducting the interview. The system architecture followed by requirement specification followed by design of the experts domain of interest finally followed by manufacture and assembly. A mapping has been presented in Figure 4.16. Priority numbers of 1, 2, 3, 4 and 5 have been provided in order to have a smooth iteration. Priority 1 starts with system architecture wherein some of the levels which need proper moderation leads to Priority 2 requirement specification. Priority 3 is given to manufacture and assembly. Priority 5 is given to quality and control. The main skill to extract data depends on how the actionability premise is satisfied.

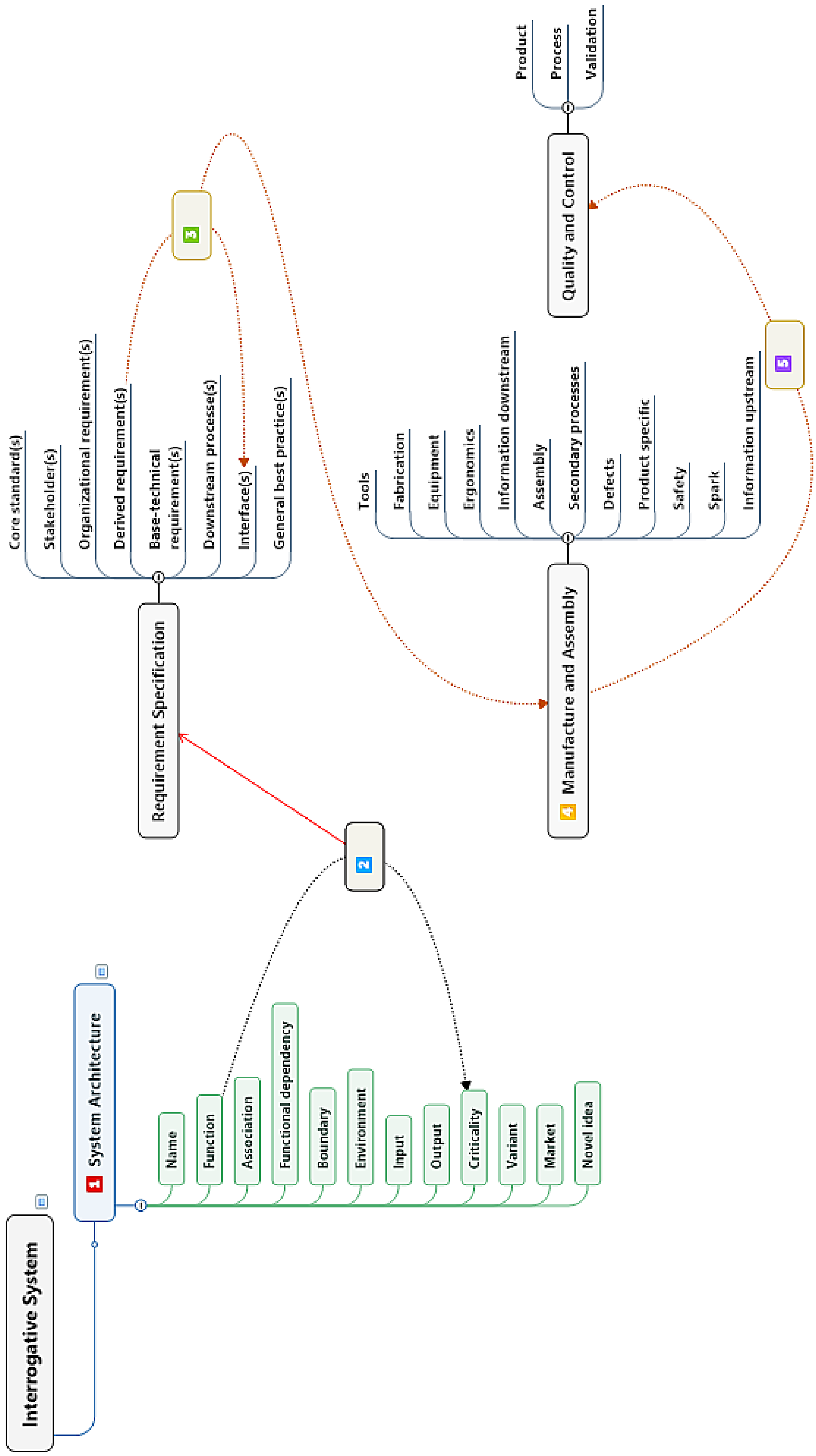


Figure 4.16: Manufacturing Mapping

4.8.3.4 Top 30

Figure 4.17 presents a proposal of the top 30 questions the near future AI system can use. The proposal is based on how well the questions extracted tacit knowledge when the interview was conducted with the Design Engineer from Volvo Trucks Technology. The questions proposed are however subject to bias. These questions are tested on an expert with expertise in Mechanical Engineering. The feedback from other domains like Software Engineers, Electrical Engineers, or other specialists when interrogated by these questions will be critical to refine the semantics acceptable to their domain. The questions proposed will be delimited to only the Mechanical domain. The three personas presented in Section 4.8.2 can be tested with the following questions.

	Proposed questions to the near future AI?
0	What is the system?
1	What **Purpose** does the system serve?
2	Which **Stage of Development** are we in?
3	Is there any **Post Project Concept(s)** that can be considered?
4	How do you treat requirements that are incomplete or incomprehensible?
5	What are some of the **Derived Requirements** from previous projects that affect the system?
6	How are the **Derived Requirements** identified and sufficed?
7	What are some of the **Base Technical Requirements**?
8	How are the **Base Technical Requirements** identified and sufficed?
9	What are the requirements from **Interfaces** and how are they managed?
10	Which **Tools** supplement design process and how?
11	What are the **Risks** associated with the system?
12	What can be the possible **Challenges** to opt for the system's architecture?
13	What is the rationale to select specific **Material** for design?
14	Is the design compatible with other **Integrating** processes?
15	Does the design ensure **Safety** against all failure mode(s)? How is it done? How is it documented? How is it made available?
16	How does **Aesthetics** affect Design?
17	How does **Integration** affect Design?
18	What are **Top 5 Best** practices established for Design?
19	How is the **Learning** from **Prototype** translated?
20	What is the **Criteria** for **Fabrication** process selection for the system?
21	How is the **Equipment Capability** ensured to handle the fabrication for the system?
22	What is done to ensure that the system design is feasible with respect to **Ergonomics**?
23	What ways can be implemented for making **Assembly** fast and efficient? What are the challenges? What are the benefits?
24	What are the **Secondary Processes** associated with the system?
25	How is **Product Conformity** ensured while **Manufacturing**?
26	Does the product meet all aspects of the **Specification**?
27	How is the **Learning** from **Quality** translated?
28	How is product **Maintenance** ensured from the customer side?
29	What aspects of the **Products Life Cycle** processes affect the **After Market**?
30	What aspects of **Re-engineering** or **Spare Management** affect the **After Market** sales?

Figure 4.17: Proposed questions to the near future AI?

5

Analysis

When you can't let it go, validate it! **– Jodi Aman**

This chapter presents strategies that has been used to conduct Analysis of the research performed. Why it was chosen and how it has been adopted has been focused.

5.1 Qualitative Research

Qualitative research claims to describe lifeworld's perspective "from the inside out", implying from the point of view of the people who participate. It makes use of the unusual or the deviant and unexpected as a source of insight and a mirror whose reflection makes the unknown perceptible in the known, and the known perceptible in the unknown, thereby opening further possibilities for self-recognition [48].

The very openness to the world of experience, its internal design and the principles of its construction are, for qualitative research, not only an end in themselves giving a panorama of "cultural snapshots" of small life-worlds, but also the main starting point for the construction of a grounded theoretical basis [48].

5.1.1 Triangulation

Triangulation involves combination of a minimum of two data sources, investigators, methodological approaches, theoretical perspectives or analytical methods within the same study. The data can be drawn from different sources at different times, in different places or from different people [48], [49] & [50].

While conducting this primary research two different types of interviews, conversational interviews and structured-question interviews, have been adopted. Structured-question interviews using **Triad** method as presented in Chapter 2 Section 2.4.1 at the page 14 have been adopted for Case 1 & Case 2.

Efforts were put forth in Case 1 & Case 2 for obtaining information which provides data sets that may or may not complement one another [48]. These assist in proving or disproving a hypothesis.

As pointed out by [49], "by using multiple methods, the researcher strives to decrease the "deficiencies and biases that stem from any single method" creating "the potential for counterbalancing the flaws or the weaknesses" of one method with the strengths of another.”

"Methodologic Triangulation has been adopted in this research."

5.1.1.1 Hypothesis

The following research hypothesis was proposed: H_1: "A particular interrogative question when presented in the COP by a knowledge expert yields valuable actionable knowledge."

5.1.2 Benchmark

The research presented by [51], presents the following observations:

1. **Commonality of Approach**: Similarity in strategy adopted by experts while problem solving by application of problem decomposition [51].
2. **Differences in Specialization**: Knowledge can be captured at an individual expert level or at a community level. For this capture to occur, segregation of experts with domain specific knowledge is vital [51].
3. **Nature of Expertise**: Sometimes the skills of an expert are not grounded in theory but are grounded in practical experience [51].
4. **Separability of Task**: Sub-problems often have inter-dependencies between one another and experts cannot work on one in isolation [51].

The above observations have been used in establishment of benchmarks in Case 1 & Case 2.

Case 1 Requirement Specification

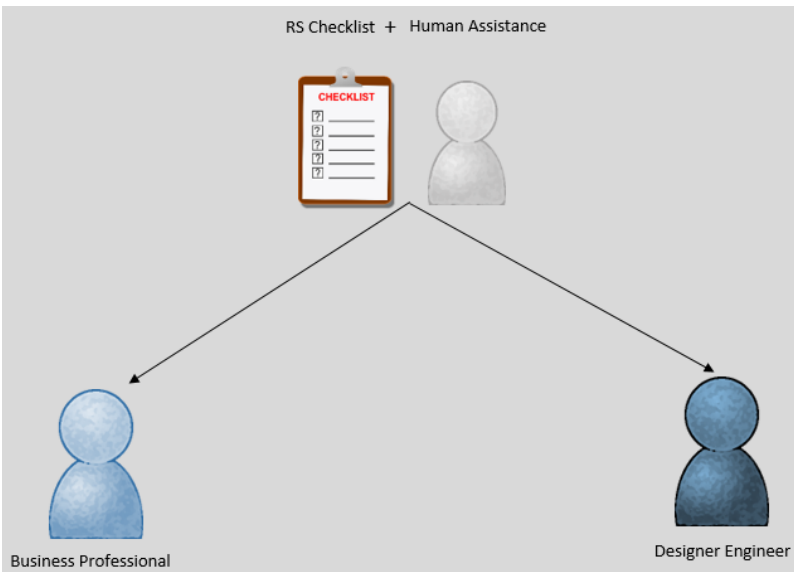


Figure 5.1: Case 1 Overview

Overview of interviews have been presented in Appendix C.1.1 & Appendix C.1.2. Due to time constraints only few questions from the requirement specification list were presented. A human knowledge expert intervened in the interview. A context or a story was added every time a question was presented. It was also observed how many times the following phrase *"What do you mean by that?"* was presented by the interviewee. The session was designed to answer generalized best practices first and later was narrowed down to the field of specialization. Figure 5.1 presents the overview of Case 1.

In general, the interview with the business professional who is also a professor at Chalmers University of Technology focuses on understanding how the requirement specification affects the aerospace business where the focus is more on safety.

The interview with the design engineer from Volvo Trucks Technology who has vast expertise with mirror design focuses on understanding how the requirement specification affects the overall product design and its manufacture in a designer's perspective with respect to the truck sector.

- **Benchmark**

  Efforts are laid to test the performance of the interrogative questions presented in Case 1. No valid literature could be used to translate qualitative data to a unique quantitative benchmark. The research put forth by [51] and unstructured conversation with fellow researchers has been used to link qualitative data to a quantitative benchmark. The benchmark established termed as S_1 and will test the hypothesis H_1.

  Qualitative

  Commonality in Approach: Interview with the business professional and interview with the design engineer from Volvo Trucks Technology both highlighted how laws and regulations freeze a design parameter. Safety was critical aspect of design for both. Both argued that the existing processes fail to make an old requirement obsolete. This results in a knowledge based uncertainty.

  Differences in Specialization : The knowledge resulting from the business professional is more relevant at a community level while that from the design engineer from Volvo Trucks Technology is more relevant at an individual level.

  Quantitative

  Word count: Average 122 words per questions for interview with business professional which consisted of 13 questions and for interview with the design engineer from Volvo Trucks Technology 97 words per question which consisted of 26 questions.

  Human intervention: 4 times

Relevance: Generalized knowledge when it comes to Interview with the business professional, while highly actionable knowledge when it comes to interview with the design engineer from Volvo Trucks Technology.

S_1: "The knowledge resulting from the design engineer from Volvo Trucks Technology was more actionable owing to the fact that it was more domain specific."

Case 2 Experimentation

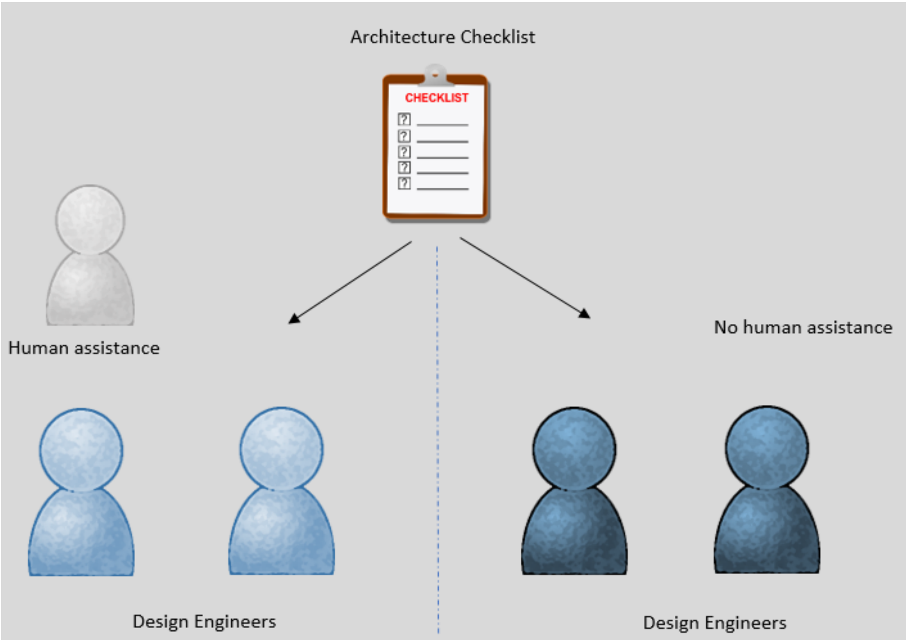


Figure 5.2: Case 2 Overview

The interviews conducted have been presented in Appendix C.2.1.1 & Appendix C.2.1.2 termed as Group A. Group A had a human knowledge expert who intervened in the interview session. Appendix C.2.2.1 & Appendix C.2.2.2 termed as Group B. Group B consisted of a human knowledge expert mimicking a bot with no intervention. Due to time constraints only few questions from the requirement specification list were presented. It was also observed how many times the following phrase *"What do you mean by that?"* was tracked. The session was designed to answer generalized best practices first and later was narrowed down. Figure 5.2 presents the overview of Case 2.
Group A consisted of design engineer from Volvo Trucks Technology and design engineer from SAFER. A product of their field of expertise was selected, a mirror system in case of designer from Volvo Trucks Technology and a neck restraint system in case of design engineer from SAFER.
Group B consisted of software design engineer and IT engineer from Chalmers University of Technology. A product of their field of expertise was selected, lab assignment for advanced functional programming for the software designer and IT support services for the IT engineer. Both the participants were masters students from Chalmers University of Technology.

- **Benchmark**
  The benchmarks established here will try to test the hypothesis against the two groups with a knowledge expert performing two different functions. The benchmark established termed as S_2 and will test the hypothesis H_1.

  Qualitative

  Commonality in Approach: Group A performed better then Group B. Both the groups had domain specific expertise but when a context is not provided, the answer to an interrogative question is invalid and thus not actionable.

  Differences in Specialization: The knowledge resulting from group A is more relevant at an individual level.

  Quantitative

  Word count: Group A on an average had almost double the word count per question of Group B.

  Human intervention: For every question presented Group B needed more human intervention the Group A.

Relevance: The data from Group B was less relevant than that of Group A.

S_2: "The knowledge resulting from Group A was more actionable owing to the fact that it was more domain specific and in depth."

5.1.3 Gap Identification

A single data extraction point was selected from Volvo Trucks Technology. The data extraction point selected was based on her specialized experience as a design engineer in mirror team. In depth one to one interviews were conducted at Volvo Trucks Technology. Owing to the time constraint only a few interviews were documented and the remaining sound recording files were handed in. The overview of the gap identification interview has been presented in Appendix C.3. The data collected via the interview was then checked with the data available over the design forum which the community uses. There was some data that had not been collected by the interrogative questions.

Supplier Integration

System designers have all the knowledge sufficient for integration and it is the supplier that has knowledge at the deeper level. Design at its early stage has a lot of supplier integration for example, in the start of a project, at least two suppliers will be selected. Here, the system designer's key focus is to manage the supplier and negotiate. This can be achieved via effective communicative and collaborative skills. Volvo Trucks lays emphasis on performance and quality while Renault is more focused on fuel and cost efficiency. This means that partnership with the supplier is key to keep up with the requirements specifications according to the parent company. The knowledge community relies on B2B or P2P relations for its knowledge database. This also depends on the data transparencies of the supplier companies. For example, a frequent problem occurring was "**EMC disturbances**". Through collaborative communication, this check point was sent to suppliers to nullify the recurrent problem but there are times wherein a set of check points cannot be established such as **Aerodynamics**. This is rather a general term. The check points established for general concepts employed with 75% quantitative and 25% via subjective evaluation techniques.

Mode of communication

To get the part what a designer has designed for, written documents are used, and they are about 20 to 30 pages long. In each section the supplier must commit to the requirements. This is then stored in digital form and sent to all associated with the project.

6
Discussion

This research work done would be extremely useful in the near future wherein amplification of human capability through development of smart decision or guidance support system can not only result in lead time reduction in an organization during product development but also pave the way for human and machine interaction [52]. The symbiosis between a human and a machine is the ideal condition but for this research only one aspect is under focus: Interrogative question set formulation and testing its feasibility. Developing strategies to analyze the fundamental concepts. As per research, this zone of knowledge management systems is still a hot zone among various researchers. A lot of previous effort has been diverted to integrate smart systems to complement and augment human capability. No research was done in development of the reference data points to act as knowledge translation from one person to another.
This research is only established to DS I, and PS aspects have been touched upon to develop a data compartmentalization. The Analysis strategies adopted in this research is biased owing to the limitation of time and availability of people. But, a strategy is put forth into which analysis criteria have been specified and applied.
The discussion presents reflections on results that manifest from the the results and analysis of the interrogative system presented in the research. These results can be used as a guideline to further develop an automated version of check sheet systems. Further, this section tries to link the research with the research question formulated earlier in Chapter 1.

Reflections

Results

In Chapter 4, pages 23 – 31, the rationale to construct an interrogative database was presented. Research methodology that assisted or rather shaped the perspective the most was Backcasting, as presented in Chapter 3 section 3.1.2, page 18. As presented, the interrogative question bank was split into different categories, or segments. The most promising advantage of categorization was that it assisted while conducting the triad form of interview. As expressed by the design engineer at Volvo Truck Technology, "It was very easy for me after a busy day to get into the core discussion when questions were presented." Every category has a mix of the *"know what"*, *"know why"* and *"know how"* integrated in a level format. The levels have been kept simple to a maximum of level 2. The inspiration from thin and also thick slicing of knowledge was mixed while conducting interview sessions. Informal unstructured interviews assisted a lot in question development.

Use case

In Chapter 4.8, pages 32 – 43, efforts were put forth to how the developed interrogative system can put into practice by using three generalized personas. Potential mapping was presented for professional belonging to **Techno-commercial**, **Design** and **Manufacturing** domain. This mapping was motivated after having conducted a series of interview with the design engineer from Volvo Trucks Technology during the gap identification presented in Chapter 5, Section 5.1.2, page 49. The flow was proposed based on the amount of moderation required to be done. On page 43, a handful of questions were selected and presented as the highly condensed top 30 which could be used by the near future AI.

Analysis

In Chapter 5, pages 45 – 50, efforts were put forth to develop a strategy for analysis and then test the performance of the interrogative question set. Analysis was done in two ways: **Triangulation** in combination with triad interview method, and **Gap analysis**.

Triangulation

In Chapter 5, page 46, a **hypothesis** H_1 was constructed. Two benchmarks S_1 and S_2 were established to test the **hypothesis** H_1. Here only two subsections of the interrogative system was under test. For **Case 1** as presented in Section 5.1.2, page 46, requirement specification was under test. The main reflection from this **Case 1** was to understand how domain knowledge at an individual level and general knowledge at a community level when presented by a set of same interrogative questions generate information. Only the domain knowledge can be termed as actionable. For **Case 2** as presented in Section 5.1.2, page 48, an experimentation was conducted to investigate how human assistance affects the information extraction process. It was inferred that without human moderation, the knowledge collected was not actionable.

Gap Identification

The gaps identified in Section 5.1.2, page 49, was something that was captured in Case 1 with the expert with community knowledge. This is the section where general knowledge at a community level becomes actionable.

Research Questions

In subsection 1.6, page 4, research questions were presented:

RQ 1

The barriers that inhibit developing an interrogative based support system in the community of practice in Volvo Trucks Technology that generate the existing check sheets in real time are:

1. **Verbiage** generation: A lot of irrelevant information which does not serve as reusable knowledge manifests.
2. **No control flow**: There needs to be some way where in moderation which is done by a human needs to be mimicked by the interrogative system.
3. **Actionability loss**: It is essential for the control flow to have a criterion that defines what actionability means in order to reduce verbiage generation and complement the control flow.

RQ 2

These barriers can be overcome by:

1. To avoid verbiage generation, **Mapping** what questions are relevant to which domain is essential.
2. The strategy of **Heuristics** can be implemented to have a control flow governed by a rule-based system.
3. Efforts need to be put forth to clearly map what actionable means. This can be done by ensuring a proper rule-based system developed in the form of **Hypotheses**.

RQ 3

The major learning from application of the interrogative system boils down to:

1. Definition of what actionability means: For the near AI system, trying to establish dimensions by which actionability gets accountable.

Implications arising from findings

The interrogative question set can be easily incorporated in Volvo Trucks knowledge community practice. The compartmentalization or the level definition has been done in a simplistic way in a block format so that it is easy to formulate mathematical models. This has to be still worked around the semantics of the community.

Implications for public or organizational policies

The knowledge community in any organization should have dedicated time slots during specific days of the week.

Limitations of the study arising from limitations of methodology

DRM shaped the research, and the way it was conducted. Backcasting assisted in visualizing the problem. Neither has been implemented in a thorough manner, but they have been shaping the research.
Since no prior research has been made in this field of verifying an interrogative question bank, discussions were held with other researchers such as Claudia Eckart, resulting in employment of the Triangulation technique.
A Hypothesis was made, and two different case study scenarios were conducted to test it. Accurate results require a lot of data, i.e. many different perspectives of many different people with different answers, but due to unavailability of experts in the domain, fellow students and professors in Chalmers were used as data points.
This is qualitative data. No prior research was found on how one could assess it to test the hypothesis. The results from one workshop has been used as a sort of benchmark. This is not an attempt to establish a standard, but rather trying to convert qualitative data into quantitative data to test the hypothesis.
If in the future any research is done in this field, after a certain amount of time this data would be different, for different projects. Whatever methodology is developed must account for these differences with a buffer.

Implication for further research

The questions developed so far now need to be tailored for the knowledge community existing in Volvo Trucks Technology. This development requires community involvement.
Looking into human soft skill, the personality of the people plays an important role. An introvert needs to be presented with a more detailed and more precise, thinner slice of knowledge. For an extrovert, a thicker slice can be used.
It needs to be a community who understands who the participants are, keeping the human factor intact and understanding each other, and working together in a very constructive way. Even if in the future there is automation involved, some form of human involvement will be required.
In a future study, a workshop could be conducted in which domain experts are assembled together. A part of the interrogative system would be experimented on them at the same time, and observations should be conducted to understand how they respond. The further implications from this study could be used to construct generalized guidelines to further develop this interrogative system.

7
Conclusion

In an overall sense, in attempts to converge towards development of an actionable knowledge management system, taking inspiration from a lot of literature review and interaction with researchers, a set of interrogative questions was developed.
These interrogative questions developed were put forth into different compartments or levels by using reference pre-existing check sheets system. Efforts were also put forth to develop use cases, selecting three personas from: techno-commercial, design and manufacturing engineers.
Based on the amount of moderation observed while conducting interviews, efforts were also put forth to propose possible questions from the interrogative question set, which the near future AI system can use. The top 30 questions which provided the most actionable knowledge when a mechanical engineer from Volvo Trucks Technology was interviewed were selected and presented. This selection has potential for improvement, because of being based on limited sample space.
Once this was done, efforts were put forth to develop preliminary evaluation criteria for evaluating these interrogative questions. Triangulation method and Gap Analysis method were employed for a subsection of the interrogative system to check the credibility of the tacit knowledge. A story telling method was adopted to tap the experiential tacit knowledge. The results presented in this research are presented in a generalized way, owing to the fact that knowledge itself is dynamic and people have variable perceptions.

A reflection from this research is that when a question is asked by a human knowledge expert, the interview tends to include some level of moderation to keep the knowledge actionable and relevant. Without such moderation, the knowledge gathered loses relevancy and is no longer actionable. This hypothesis was tested in Chapter Analysis.
Therefore, any future AI intended to replace interaction with a human knowledge expert, while maintaining relevancy and actionability of knowledge, must be able to provide some form of moderation. This kind of moderation appears to be non-trivial, as the moderator must have some understanding of what the interviewee is talking about. Natural language processing may be applied to the input, and the result fed into some form of machine learning algorithm. The output of this could then be used to decide when to moderate, and how.

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A

Case Study

A.1 Spur gear

1. **What is the component?**
   Spur gear

2. **Which criteria determines the selection of a particular type of component?**
   The service conditions, mechanical arrangement, and the input requirements are some of the criteria that govern the selection of a particular type of gear.

3. **What is the function of the component?**
   A Gear system is designed to transmit a certain amount of power for specified speed conditions of the wheels.
   Gear: Function: To Transmit Power

4. **What is the environment in which the component is intended to perform?**
   Metallurgical industry or transmission industry or construction machinery etc.
5. **What material is it fabricated from?**
   Fabrication is customer specific based on their material requirement.

6. **What are some of the parameters associated with the operational environment in which the component it working?**
   (a) Temperature
   (b) Torque
   (c) Vibration
   (d) Design space

7. **What are some of the fixed known parameters or inputs from which the component design can start?**
   (a) Gear ratio
   (b) Speed
   (c) Power

8. **What are some of the changing parameters in the environment whose range is known for which a small margins required?**
   (a) Temperature profile

   (b) Torque profile
   (c) Speed profile

9. **What are some the changing parameters in the environment whose range is unknown for which large margins required?**
   (a) Vibration profile

10. **What other components does the gear unit interact with?**
    (a) Clutch system in case of automobile gear
    (b) Transmission system in case of automobile gear

11. **What are dependent parameters of the component?**
    (a) Module
    (b) Pressure angle
    (c) Number of teeth

12. **How does margins of the dependent parameter affect each other?**
    (a) Change in radius of one gear changes the other to make sure the same torque is transferred.
    (b) Change in teeth profile on one gear changes the teeth profile on other gear to ensure meshing.

13. **What constraints dominate the design?**
    Objective dependent example design for strength, design for light weight etc.

14. **Which parameters can be used to evaluate the performance of the component?**
    (a) Load handling
    (b) Power output

B

Question Bank

B.1 System Architecture

System Architecture		
1	Name	What is the system?
2	Function	What purpose does the system serve?
3	Association	What other system(s) is it associated with?
4	Functional Dependency	What other system(s) is it dependent on for its functioning?
5	Boundary	Can the system boundaries be defined?
		What are the system boundaries?
		Does the design comply to the boundary definition? (If it exists)
		What other aspects of the system's features can be considered for the boundary definition? (If it exists)
6	Environment	What is the environment of operation in which the system operates?
		Which are the environmental parameter(s) the system is sensitive to? (If they exist)
		How does the environment affect the product design?
7	Input	What is/are the input(s) to the system?

		Is/are any margin(s) associated with the input(s) of the system? (If they exist)
		What is/are the margin(s) associated with the input(s) of the system? (If they exist)
8	Output	What is/are the output(s) from the system?
		Is/are any margin(s) associated with the output(s) from the system? (If they exist)
		What is/are the margin(s) associated with the output(s) from the system? (If they exist)
9	Criticality	Does the system have any critical part(s)?
		Which is/are the critical part(s) of the system? (If they exist)
		How is risk associated with the critical part(s) identified and handled? (If they exist)
		Which is/are the critical performance related parameter(s) of the system which govern the overall design? (If they exist)
10	Dependency	Are there any coupling parameter(s) from other systems affecting the current system? And what are they?
		What is/are the margin(s) associated to the coupling parameter(s) to the system?
		Is the knowledge about the existence of dependency referred to all team members? How is it done?
11	Compatibility	Is the system compatible with other system(s) or subsystem(s)?
		Is the system architecture feasible?
		Is/are there any architecture reference(s) from previous project(s)?

12	Variant	Is/are there any variant(s) of the Architecture? What are the categories of the variant(s) existing for the system? (If there are any variant(s)) Which parameter(s) depend on the variant(s) selection for the system? (If there are any variant(s)) What is the top deciding factor(s) for decision of selection of the system? (If there are any variant(s))
13	Market	Is/are there any ongoing market trend(s)? What are they? Do the ongoing market trend(s) affect variant selection? Do the ongoing market trend(s) affect architecture?
14	Novel Idea	Is the design concept for the system new? Is/are there any post project concept(s) that can be considered when the design concept is novel? What type of post project(s) data in terms of parameter(s) would be important for the new design concept? What is/are the risk(s) associated with the lack of competence(s) in case of new design concept? What other alternative(s) can be opted to cope with the lack of competence(s)? What are the major risk(s) associated with the new system design?

	How can the risk(s) associated with the new system design be dealt with? What can be done to prevent such major risk(s)?

Table B.1: System Architecture

B.1.1 Competence

Competence		
1	Do you have the core competence(s)?	Business feasibility Engineering feasibility Design feasibility Manufacturing feasibility Quality feasibility Product handling feasibility Logistics feasibility
2	Best Practice(s)	What are some of the guideline(s) followed?
3	Relevancy	Is the presented question(s) at the level of your expertise? Is the presented solution(s) what you want?
4	Validation	How do you verify the solution(s) you get by the expert(s) answering your question(s)?
5	Time domain	Where are we in the process currently?
6	Zoom ability	What level of detail do you need the solution(s) to have?
7	Frame of reference	What perspective is required to address the issue(s)?

Table B.2: Competence

B.2 Requirement Specification

Requirement Specification		
1	Company's core standard(s):	What are the requirements that the system needs to satisfy in order to comply to company's core standards?
2	Stakeholder(s):	Who are the stakeholders and what are the requirements that come from stakeholders involved with the system?
3	Organizational requirement(s):	What are the requirements from business division that affect the system? How are they made available?
		What are the requirements from the marketing division that affect the system? How are they made available?
		What are the requirements from sales that affect the system? How are they made available?
		What are the requirements from suppliers that affect the system? How are they made available?
		What are the requirements from research and development that affect the system? How are they made available?
		What are the requirements from testing that affect the system? How are they made available?
		What are the requirements from design - mechanical that affect the system? How are they made available?

	What are the requirements from design - electrical that affect the system? How are they made available?
	What are the requirements from design - software that affect the system? How are they made available?
	What are the requirements from manufacture that affect the system? How are they made available?
	What are the requirements from quality that affect the system? How are they made available?
	What are the requirements from service that affect the system? How are they made available?
	What are the requirements from the after market that affect the system? How are they made available?
4 Derived requirement(s):	What are the derived requirements from previous project(s) that affect the system? How are they made available?
	How is it ensured that, the compliance is met for a carry over project(s)?
	What are the requirements from previous specifications that might affect the system?
	Are there any requirements from trade-offs? What is done to handle them?
	What are the requirements associated with installations of the system? How are they handled ?
	Are there any Installation interfaces that affect the system?

		Are they critical interfaces? Why are such interfaces termed critical? Are there any product variant compliance check for the requirements? What are the economic requirements that govern the project undertaken?
5	Base of technical requirements:	What are the requirements from legal law and regulations? Are there any legal (National) law and regulations? How do they affect the system design? What is done to satisfy them? How is it validated? Are there any legal (International) law and regulations? How do they affect the system design? What is done to satisfy them? How is it validated? Are there any safety regulations? How do they affect the system design? What is done to satisfy them? How is it validated? Are there any product regulations? How do they affect the system design? What is done to satisfy them? How is it validated? Are there any environmental regulations? How do they affect the system design? What is done to satisfy them? How is it validated? What are the system requirements for the product to function? What are the product requirements? What are the pre requisites?

		What parameters can be possible pre requisites that affect the system? How are pre requisites identified ? Why are they important? How is the knowledge of pre requisites captured and transferred? Which pre requisites dominate? How are pre requisites addressed? What can these pre requisites be used to define? How sensitive is the system to the pre requisites?
6	Downstream processes:	What are the requirements from the downstream processes that affect the system? How is the knowledge of downstream process dependent data captured and transferred? How are parameters due to downstream process dependent data addressed? How sensitive is the system to the parameters due to downstream process dependent data?
7	Interfaces:	What are the requirements from interfaces and how are they managed?
8	General best practices:	How do you treat requirements that are incomplete? How do you prioritize requirements? What techniques do you follow?

	How do you search and find requirements? What are possible sources? Is it efficient? How do you treat changing requirements? Which tools do you use for keeping track of the changing requirements? What are some of the techniques for specifying requirements? Which works for you? And in which case?

Table B.3: Requirement specification

B.3 Design Philosophy

Design Philosophy
1 What design rationale is followed when project(s) are undertaken?
2 What are the top best design practice(s) followed?
3 How are these design practice(s) implemented?
4 How can these practice(s) be improved and how can the change(s) be handled?

Table B.4: Design Philosophy

B.3.1 Design Mechanical

Design Mechanical	
1 Tools:	Is the project a new design / adaptive design / development design?

	Is there any knowledge from the previous projects which can be used to reduce the lead time of the current system design? Are any planning tools required? Which are they? How are they employed? Is there a CAD model required for the project? What is its location and its format? Do you require information to parameterize the CAD model? What critical information is required for parameterized CAD model generation? Where is the information about parameterization available? Who is responsible for the parameterization information? How is the information validated or tested before implementation? Is the CAD model feasible with requirement specification? Is the CAD model acceptable to the customer? What rationale do you adopt to finalise the CAD model before downstreaming it? Is any testing required to validate the CAD model? Are there any issues from the downstream activities affecting the CAD model? If so, What are they? How are they addressed?

2	Experience:	What is the design rationale behind the system architecture? What can be the possible challenges to opt for the architecture? Is the shape feasible with a manufacturing and assembly perspective? Is the shape feasible to service for product maintainability for the customer? Is the form feasible with a manufacturing and assembly perspective? Is the form feasible to service for product maintainability for the customer? Does the shape affect placement of other components? How can the issue(s) with placement be solved? If they exist?
3	System:	What is the allotted design space? What are the aspects considered while adhering to the design space? Are there any margins associated with the space selection? What are inputs related with design aspects? Are there any margins associated with them? If yes, specify? How is the information made available? What are performance related design aspects?

		Are there any margins associated with them? If yes, specify? How is the information made available?
		What are the output related design aspects?
		Are there any margins associated with them? If yes, specify? How is the information made available?
		What are the design working condition?
		Are there any margins associated with them? If yes, specify? How is the information made available?
		What is the environment of operation?
		Are there any environment related issues that constrain a designer to opt for certain parameters?
		What are the risks associated with the system?
		How can risks be handled? Is the information made available?
		Can the design be standardised?
4	Material:	What is the rationale to select specific material for design?
		Any constraints in choosing the right material?
		Are there any design dilemmas associated with material selection? If yes, specify?
		Are there diverse materials in the system design? And why?

		How is it possible to reduce the diversity of materials in a system if it exists?
5	Process:	What are some of the best practices followed? Is the design compatible with the manufacturing and assembly processes? Is it the design easy to assemble? Is it the design easy to service? Is it the design easy to be handled by logistics?
6	Safety:	What are the mode(s) of failure? How have they been identified? Where are they documented? Does the design ensure safety against all failure mode(s)? How is it done? How is it documented? How is it made available?
7	Aesthetics:	Which parameter(s) related to visibility affect the system design? Which parameter(s) related to user ability affect the system design? Which parameter(s) related to branding affect the system design?
8	Function:	Does the system deliver the result(s) for which it was designed? What are the ways to test the system? Which parameter(s) play a critical role in system testing? How are they documented? How are they made available?

9	Sustainability:	What are some of the trigger points that encourages designers to consider the impact their creations will have on the environment and people? How does these trigger point affect the design?
10	Spark:	How can you improve the existing design processes? Where is it documented? How is the information made available? What else can be done?

Table B.5: Design Mechanical

B.3.2 Design Software

Design Software		
1	Tools:	Is the project a new design / adaptive design / development design? Is there any knowledge from the previous projects which can be used to reduce the lead time of the current system design? How can this be done? Is any planning tools required? Which are they? How are they employed? What rationale do you adopt to finalise the system before down streaming it? Is any testing required to validate the system code? How is it done? How is the information made available?

		Any down stream processes affecting the system code? Which are they? How do they affect? What is done to avoid it?
		Any upstream processes affecting the system code? Which are they? How do they affect? What is done to avoid it?
2	Experience:	What is the rationale behind the design architecture?
		What can be the possible challenges to opt for the architecture?
3	System:	What is the allotted design space?
		What are the aspects considered while adhering to the design space?
		Are there any margins associated with the space selection?
		What are inputs related with design aspects?
		Are there any margins associated with them? If yes, specify? How is the information made available?
		What are performance related design aspects?
		Are there any margins associated with them? If yes, specify? How is the information made available?
		What are the output related design aspects?
		Are there any margins associated with them? If yes, specify? How is the information made available?

		What are the design working condition?
		Are there any margins associated with them? If yes, specify? How is the information made available?
		What is the environment of operation?
		Are there any environment related issues that constrain a designer to opt for certain parameters?
		What are the risks associated with the system?
		How can risks be handled? Is the information made available?
		Can the design be standardised?
4	Library:	What is the rationale to select specific libraries for design?
		Any constraints in choosing the right library?
		Are there any design dilemmas associated with library selection?
		Are there diverse libraries in the system design? And why?
		How is it possible to reduce the diversity of libraries in a system if it exists?
5	Process:	Is the design compatible with other integrating processes?
		What are some of the best practice(s) followed?
6	Safety:	What are the mode(s) of failure? How have they been identified? Where are they documented?

		Does the design ensure safety against all failure mode(s)? How is it done? How is it documented? How is it made available?
7	Aesthetics:	Which parameter(s) related to user ability affect the system design?
8	Function:	Does the system deliver the results for which it was designed? In case of no, what is done to ratify it?
		What deviations are possible which affect system performance? How is the information made available?
9	Integration	When is integration required?
		Is it continuous or at a single point?
		How does integration affect the design?
10	Volatility	Which tools do you like to use for keeping track of requirements?
		How do you treat changing requirements? Are they good or bad? Why?
		How do you search and find requirements? What are possible sources?
		How do you prioritize requirements? Do you know different techniques?
11	Spark:	How can you improve the existing design processes? Where is it documented? How is the information made available?
		What else can be done?

Table B.6: Design Software

B.3.3 Design Electrical

Design Electrical		
1	Tools:	Is the project a new design / adaptive design / development design? Is there any knowledge from the previous projects which can be used to reduce the lead time of the current system design? How can this be done? Are any planning tools required? Which are they? How are they employed? What rationale do you adopt to finalise the system before down streaming it? Is any testing required to validate the circuit design ? How is it done? How is the information made available? Any down stream processes affecting the circuit design? Which are they? How do they affect? What is done to avoid it? Any upstream processes affecting the circuit design? Which are they? How do they affect? What is done to avoid it?
2	Experience:	What is the rationale behind the design architecture? What can be the possible challenges to opt for the architecture?
3	System:	What is the design space? What are the design space related aspects?

	Are there any margins associated to them? What are input related design aspects? Are there any margins associated to them? What are performance related design aspects? Are there any margins associated to them? What are the output related design aspects? Are there any margins associated to them? What are the design working condition? Are there any margins associated with them? What is the environment of operation? Are there any environment related issues that constraint a designer to opt for a certain parameter? What are the risks? What is the the design current? What is the rating of the protection for the current? What is the cable current carrying capacity? What is the size of the cable?

		Is there voltage drop? How is the voltage drop addressed? What are the different modes of failure? Is it compatible with the system/systems?
4	Material	What is the rationale to select specific material for design? Any constraints in choosing the right material? How is it possible to reduce the diversity of materials?
5	Process:	Is the design compatible with the manufacturing processes? Is the design easy to assemble? Is the design easy to service? What are some of the best practices followed?
6	Safety:	What are the modes of failure? How have they been identified? Where are they documented? Does the design ensure safety against all failure modes? How is it done? How is it documented? How is it made available?
7	Aesthetics:	Which parameters related to visibility affect the system? Which parameters related to user ability affect the system? Which parameters related to branding affect the system?

8	Function:	Does the system deliver the results for which it was designed? In case of no, what is done to ratify it?
9	Integration	When is integration required?
		How does integration affect the design?
10	Process	Which tools do you like to use for keeping track of requirements?
		How do you treat changing requirements? Are they good or bad? Why?
		How do you search and find requirements? What are possible sources?
		How do you prioritize requirements? Do you know different techniques?
11	Spark:	How can you improve the existing design processes? Where is it documented? How is the information made available?
		What else can be done?

Table B.7: Design Electrical

B.3.4 Prototype

	Prototype
1	Why do you need to build a prototype?
2	Is the budget for prototyping feasible?
3	Are any planning tools required? Which are they? How are they employed?
4	What is the fidelity of a prototype?

5	What rationale do you use to select the particular fidelity?
6	What best practices are followed while prototyping to test?
7	What best practices are followed while prototyping to decode?
8	Do you have benchmarks to accurately measure the prototypes against?
9	What rationale is followed to benchmark?
10	What is the learning from the prototype? How is it documented? How is the information handled?

Table B.8: Prototype

B.4 Manufacturing Philosophy

Manufacturing Philosophy	
1	What are some of the guidelines followed during manufacturing?
2	What are some of the best practices in manufacturing adopted? How are they evaluated?
3	What are some of the best practices concerning with challenging technologies? How are they evaluated?
4	What are some of the standardized assembly practices followed? How are they evaluated?

Table B.9: Manufacturing philosophy

B.4.1 Manufacturing and Assembly

Manufacture and Assembly		
1	Tools:	Are any planning tools required? Which are they? How are they employed?

2	Fabrication:	What is the criteria for fabrication process selection for the system? What are some of the fabrication processes involved in manufacturing of the system? Are there any trade-offs that limit the selection of a particular process? What are they? How is it handled? What rationale is used while opting to select certain fabrication techniques when dealing with trade off? Are there any parameters that affect the system while employing the fabrication techniques? What are they? How are they handled? How are such parameters identified? How is the information handled? How severe can the parameters be if not addressed with? How can they be identified in the later stages of manufacturing if not addressed? Are there any processes which might later affect the functionality of the system? Which are they? How are they handled? What are some of the quality related issues associated with fabrication processes of the system? What other processes can be considered? And what are the risks associated? What influence does material have in fabrication processes?

3	Equipment:	How is the equipment capability ensured to handle the fabrication for the system? What are some of the best practices followed for handling equipment? Are there any parameters that affect the system while employing the assembly techniques? What are they? How are they handled? How are such parameters identified? How is the information handled? How severe can the parameters be if not addressed with? What influence does material have in equipment selection?
4	Ergonomics:	Is the system design in accordance with the existing ergonomics of the assembly line? What is done to ensure that the system design is feasible with respect to ergonomics?
5	Information Down streaming:	Is there any information down streamed? What is it? Is the information available to all team members? How clear are assembly drawings and outlines which are down streamed? Are they easy to understand?
6	Assembly:	What ways can be implemented for making assembly fast and efficient? What are the challenges? What are the benefits?

		What are some of the strategies that are employed to reduce the assembly cycle times or increase the throughput of an assembly line? Does the system affect the strategy in terms of manufacturing and assembly? If yes in what way? Does the proposed design of the system affect the ongoing assembly practices? How? How is the information handled? What are the system specific requirements that determines assembly selection? What are the issues associated with manufacturing practices? How can damage to other systems be minimized by assembly? Is it easy to assemble?
7	Secondary Processes:	What are the secondary processes associated with the system? What is the criteria for secondary process selection for the system? What are the quality related issues associated with these? How are they addressed? How is the information handled? Are there any important parameters that affect the upstream process? Which are they? How are they identified? How is the information handled?
8	Defects:	Are there any defects caused by manufacturing processes when the system is in production? What are they?

		Is it possible to avoid these defects when the system is in production?
		How can these defects be addressed when the system is in production? How is the information handled?
		How is the quality of the product ensured?
9	Product Specific:	Which Manufacturing tolerances dominate for the product? How are they identified?
		How can they be within the acceptable limits? How is the acceptable limit established?
10	Safety:	Is the system safe to manufacture?
11	Spark:	How can you improve the existing design processes? Where is it documented? How is the information made available?
		What else can be done?
12	Information Upstreaming:	Is there any information up streamed? What is it ?
		Is the information available to all?

Table B.10: Manufacturing and Assembly

B.4.2 Quality and Control

Quality and Control		
1	Product:	Is the product durable based on the functionality?
		What aspects of durability do you consider and why?

		Is the product operational in the set environment? How is the product operational set environment check done? Is the product operational in the extreme environment? How is the product operational set environment check done? How do you estimate the range of the extremity of the environment? Does the product comply to all quality standards established? What is the variance of the parameters of the product? Do parts fit accurately and neatly? Are measurements within the tolerances specified? Are the registration marks correct and do they line up? Does the product meet all aspects of the specification?
2	Process:	What happens to products that fail at any stage of their manufacture? What is the pass rate of manufacturing processes? What is the yield rate of from the production line? How are the parameters distributed? What are the limits? How are they established?

	Is the product manufactured correctly, meets appearance criteria and inspect for proper function? What are some of the bottle necks identified in the process? How are they identified?
3 Validation:	What do you consider for validation? What are you looking for while validating? How do you analyze the results? Why are you looking for these? What does it indicate? What do you know about it? What do you do to avoid negative scenarios? What to do if there is indication of high margin?

Table B.11: Quality and Control

B.4.3 Service

Service
1 How is product maintenance ensured from the customer side? 2 What can be done to prevent potential failure from the customer side? 3 Are there any repetitive problems identified from the customer side? 4 How are these problems solved? 5 How is the information handled?

6	How does servicability of a product affect warranty period?
7	What are some of the best practices for the servicability?
8	How is the data from the field (customer side) made available?

Table B.12: Service

B.5 Aftermarket

Aftermarket	
1	What aspects of the product's life cycle processes affect the after market?
2	What aspects of re-engineering or spare management affect the after market sales?
3	What is a good indicator of after market effectiveness?
4	What are the dominant effects from the overall value chain on after market performance?
5	How can product servitization be improved?
6	How can cost-effective aftermarket services be incorporated?
7	What are some of the best practices followed for improving the processes in after market?
8	What are the benefits of employing after market concepts like part standardization or modularization on production or on product design?

Table B.13: Aftermarket

B.6 Logistics

Logistics		
1	Warehouse	Where is/are the facilities and sources located? How is it staffed? What is the actual need for each commodity at the facility and how does this need vary over time? What is the facility's storage capacity? What are the storage conditions, and are they suitable for the items being stored? How is the inventory controlled, and is it secure?
2	Transport	What types of transportation are available? What size batches of commodities are cost-effective to transport? How long does it take to get from one facility to the next? How often can shipments be made? Are the answers to these questions different during different seasons of the year?
3	Management structure	Who decides what (and when and how many) commodities move through a link from one facility to the next? How does he/she decide? How much should be ordered?

	When should it be ordered? What governs the decision of reorder? Any bottle beck activities that affect the reorder?

Table B.14: Logistics

C

Appendix Interviews

C.1 Case 1

C.1.1 Business Professional

Interview

Details

Expertise: System Design Engineer

Location: Chalmers University of Technology

Date: 7 May 2018

Duration: 1 hour

Objective: Testing requirements questions.

Time: 17:00-18:00 pm

L: 0. Which frame of reference do you want to use for the interview?
O: System Design engineer.

L: 1. *What do you do with requirements that are incomplete or incomprehensible?*
O: The top-level requirements are setting contracts. So, you have contract-based requirements. You do quite careful establishment of the requirements that you have to do, then, if it is not possible to extract the level of detail or accuracy, you normally agree with the customer on how to update the requirements, contractually.

L: 2. *How do you prioritize requirements? Do you know different techniques? Which one do you normally use?*
O: Now, I am a lecturer or professor, I don't use specific techniques but, what I think is important in that, is you involve the stakeholder of the requirements. You don't set the requirement prioritising yourself. Because, the one who will pay or charge the benefit from the requirement prioritisation should be the one who should express the prioritisation requirement. That could be customer in case of external or in case of internal, in a way the company wants to be perceived, say example, if they want to raise environmental profile then they should adopt to the profile in concurrence with the market strategy. It may be internal efficiency or cost target which can be given as priority by the company and put high requirement sufficiency level. Now, this product should be minimum use of new technology as we want to minimise the risk and cost and maximise the reuse of the product. So that means there three different stakeholders that could have a say.

L: 3. *How do you search and find requirements? What are possible sources?*
O: Requirement database, meetings, documents like for example interface control document.

L: 4. *How do you treat changing requirements?*
O: The formal way is by keeping the requirement database or requirement definition updated. Now there maybe be negotiation at any level maybe from the senior down to the engineering level. What's important is when you agree on an update or requirement you should "signal" it verbally or in a written form in order to make the old requirement version obsolete in some way and to say its new requirement on this topic. Common problem faced now a days, is a new design has been designed to meet the old requirement. This is the effectivity view of the

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Figure C.1: Interview Business Professional , Page 1 of 4

problem. Ideally you should document or update the agreed requirement change data in written form.

L: 5. *Which tools do you like to use for keeping track of requirements?*
O: Highlight the requirement which is changed is the essence. That's just notification, that's one way to address or show that, if there is any requirement change. So, it could be dependent on the IT environment or the way you work, or it can be flagged in sense expressed in a meeting. In a system level that means requirement management system, notification to the ones concerned that yes, this requirement has been updated. It is more important to be able to signal that the older requirement is suddenly not valid anymore. This is intuitive but difficult in large organisation.

L: 6. *What are the requirements from interfaces and how are they managed?*
O: In engine or jet engine business again, there are different companies doing different components of the part of engines. There is the integrator who keeps control of the that. This is done in a very formal way. They have something called as an interface control document. This interface control document has an agreed set of interfaces that is simply manage if there is a proposed change in that, then they need to announce that or its negotiation between other neighbour, maybe another company or maybe another system integrator. So, let's say that the component manufacturer wants to change the interface position, it can propose that, but, it's not in its sole power to do that unless they have approval of the integrator. The integrator needs, of course, to take responsibility for the consequences of their interface change in jet engine business. It is very controlled and a formal process to do so and that is depending on which phase you in of the products design. There are different freeze periods, so that means later in the process it is more difficult to redefine or change. During certain period this parameter is frozen, so you cannot play along with it then you need to work with the change management procedure and work with changing it and it is more expensive and time consuming.

L: 7. *What are the requirements from the downstream processes that affect the system? And How is the knowledge of downstream processes dependent data captured and transferred?*
O: Requirements in terms of manufacturing requirements. These can also be expressed as constraints. One of the challenges is that it is not always known where a component or a product will be manufactured, that means it may manufactured ideally but the resource of the workshop or the site or the supplier producing that part is not yet selected and that is a problem then you need to make generic and then final tune. Ideally some businesses are more used to this. A company such as Ikea for instance they may they are given a budget. Your product must not cost over this budget. This is a sever constraint, or it should not be made of such material we can't handle in the workshop or intend to use.

L: 8. *How much sensitive is the system to the parameters due to downstream processes?*
O: There are many of course, at higher levels: program level sales volume or production level. The is difference in producing 1 or 100 or millions of products, so there is a big difference. If you are producing millions of products, then you might want to build a new company. If I pick another topic is, when you have a component or product and that will have performance functionality. Here it come down quickly to tolerances or accessibility or quality controlling parameters, they are definitely influenced.

Figure C.2: Interview Business Professional , Page 2 of 4

L: 9. *What are the requirements from legal law and regulation? And how do they influence product design?*
O: In jet engine business, it is very much so that everything that we produce, it must be certified, this means that a greater focus is put on certification requirement. It must be certified by the flight authorities, there are few of them like the FDA. These are basically at a higher-level but of course requirements but the integrator or the OEM is the one responsible for the certification but then they need to define the requirements in a way that they are compliant with the certification. For example, Airbus is the manufacturer of the air craft. The OEM for engine like Rolls Royce is required to certify by engine authority together with Airbus for a certain air craft. Everything comes down to safety in the end. The requirement at the top most level ensures that "no single failure may result in a catastrophic failure." Everything that may go wrong cannot be compromised in the safety of the system. For example, if you have a blade off identified, it has to be eliminated since that is a fatal error and thus can make the plane crash. It is thus critical to have some redundant system to take over when failure occurs.

L: 10. *What are the pre-requisites? What parameters can be possible pre requisites be that affect the system?*
O: First thing that comes to my mind is that you need to know the technologies. They need to be matured enough, tested and validated in a relevant context before they are even considered. You don't get a new untested technology although it looks promising without having done significant amount of testing and verification. When this has been done, then it may be considered. This is very much because of the safety critical businesses, if you take some other business may be less sever on the safety criticality issue. It still would be high cost and high risk for immature technology integration as in a case of failure for example in automotive business. Many of the OEM's must recall all the failed cars if there is some component failure or defect. In case of aerospace it is one step further, we cannot have an outcome of failure at all.

L: 11. *Are there any Derived requirements?*
O: Yes.

L: 12. *What are the derived requirements from previous projects that affect the system? How is it ensured that, the compliance is met for a carryover project or projects?*
O: Yes. There is normally something called as base line. There are many different ways to do that, first one is the documentation of best practices and instructions. You kind off update the instructions or guidelines based on practices. You also have a product with the definition of the previous product as a reference that is used to compare anything with the previous product. There are also softer ways of doing that by trying to keep experience people that has taken part in the previous project to take part in the new.

Lot of effort is put into the knowledge transfer exercise. This is something done in addition to documentation. During the new project, effort is made to bring people from last projects to have a knowledge sharing exercise. The new team has started to issue the requirement document or new program plan and old team to review or critically access the proposals and come with contributions. In a sense you use the pool of experienced people as a reference group.

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Figure C.3: Interview Business Professional , Page 3 of 4

The other way can be there are some people in an organisation or senior fellows or senior engineers. They have the role of actually facilitating while ensuring transfer of knowledge between different projects. They have seen literally all the projects coming in. In GKN case, its institutionalised that people are responsible for example type of component. They may not be the designers in the projects, but they are responsible to go as reviewers or mentors or specialist just to ensure knowledge transfer.

L: 12. *What are the requirements associated with installations and how are they handled?*
O: Installation requirements are not common in aerospace business like the automotive or tuck business. The focus is more about safety or certification.

L: 13. *What is your views about organisational requirements in general?*
O: It's really the business idea of the company. Normally if you want to be a high-tech company you probably consider prioritization before put high and of course cost is always an issue. The cost may be a severe objective. It is not always treated as a requirement its treated-on project level program objective.

There is tension between the business program how to gets funded we do business case on that how to do and what must be the cost but then the design teams they have to kind of fine ways to comply with whatever they have to do with the project budget.

Money is always the hot topic, there may be different strategic biases, let's say its important to get certain technologies in the market. There might then be a scenario that this component may have not been cost efficient. GE has famous example, its additive manufactured where they have done fuel nozzle. They don't talk about how much that costs and that's probably for a reason as they have spent a lot to make it certified. You cannot say it's a cost-efficient way of doing it. But then again there maybe they have reused some of the knowledge for forth coming projects. The debate however is how much of the previous knowledge can be translated into future projects.

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Figure C.4: Interview Business Professional , Page 4 of 4

C.1.2 Design Engineer

Interview

Details

Expertise: Design engineer for mirror section.

Location: Volvo Trucks Technology

Date: 17 May 2018

Duration:30 mins

Objective: Testing requirement specification questions.

Time: 11:00-11:30 pm

L: 0. Which frame of reference do you want to use for the interview?
F: Mirror design engineer.

L: 1. *What do you do with requirements which are incomplete or maybe incomprehensible?*
F: In practice, here, I would go to the ones who sets the requirements. There is normally always someone who's responsible for setting the requirements. It's not me. But in some cases, I have experience that, no one knows who owns the requirements. And in those cases, I've been asking my community, I have been searching form all different sources, and then I can also ask my suppliers, for example, what they think. When all of this is concluded, in some cases, we have disregarded it, and said that this is probably something old that we do not consider anymore.

L: 2. *How do you prioritize requirements? Any of the techniques, maybe, which you follow?*
F: No, since I already know which features are. Normally you ask for all features, which ones care about my design? And they come to me and say, I want to review your design, because I care. Some features are not, and some are very, and these ones are the ones that I talk to first, and then dependent on what kind of input they have, I prioritize. Some of the things you know that these will be minor things that I can change in the end, and these will be major things that need to be set in the early phase of the concept. Because when you decide if it's a 2mm gap or a 3mm gap, or if it should be grainy texture, and so on, these are for later. I need to have it in mind, that it's for later. And then when they ask about features like visibility, this is the major concept thing; you need to set the visibility first, for me to have the correct position. And then, maybe durability for example.

L: 3. *How do you treat changing requirements?*
F: You would have to see what the impact would be on the design. And then it would be a discussion whether it's relevant or not. If it's relevant, then we would have to re-design it, and then the project would have to design for this.

L: 4. *Which tools would you use to keep track of the requirements?*
F: We have a technical regulation, it's called, it's a list of requirements that you have, attached to all parts, saying that this part fulfils these requirements. And we always have one to start from, and then you maybe take away some of the requirements if you're designing for a specific target.

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Figure C.5: Interview Design Engineer , Page 1 of 5

L: 5. *So, now let's go to downstream processes. What are the top five requirements that come from downstream, if there are not five or maybe one you can tell, whatever comes to your mind?*
F: *What do you mean by downstream?*
L: 6. *Manufacturing, quality of service, sometimes after-sales, after-market?*
F: Manufacturing is of course the order of things, that they should be. The complete unit in itself cannot wait too much because they need a fixture of something to lift it, the lifting tool, and the order that they should do things, how to assemble it, so they could have requirements for example for a third-hand solution which we call it, which means that they could hang it up, and then take and attach it.
So, these are typical requirements from their side. A difficult requirement from their side is that you should have a cover for example, or panel, and you should be able to assemble it in a good way, both that it's not too difficult to push it in place, and that you hear a click, that ok, it's in place now.
So that it's not vague, is it there or is it not there. At the same aftermarket may say that we need to detach it, so it must be possible to be detached, and be re-attached.
That's from manufacturing perspective. And then, after-market is the same way, they want to detach everything in an easy way, and they want to have a design that makes it possible to change only the glass, instead of a complete mirror.
If the glass breaks, you don't want to change the entire mirror. And that you must think about when you design, so that it's easy to change it. Then there could be other.

Variants maybe? Or maybe the colour? Because in countries like India, you need the sun shielding. And then some countries want, in the mirrors specifically, to have text, that it says, "Objects in the mirror may be larger", and we don't have it here.
And they want it in, maybe Arabic. And then we have, in the case of aftermarket for example, they say "I want to be able to detach everything in two minutes".
These are things to design for. Then, not in my case, but other cases, another feature leader says, "But then people will steal the things!"

You cannot just pull like this and then take the entire lamp or whatever, because people would steal lamps from each other. So, it must be a bit hard, and so on.
And then market, of course. For mirrors, market is a big thing, because some markets want, as I said, language. And then we must solve language for that specific market.
And then other markets, they have problems with moisture, for example, which is not a problem.

L: 7. *Fog lamps?*
F: Fog lamps we don't really have that problem. We don't really consider that problem in the same way.

L: 8. *Let's talk about some base technical requirements. And we go into legal laws and regulations. What is done to satisfy them? These requirements, the legal ones. There might be like, international, national, safety requirements, or maybe environmental requirements. You can just tell me in brief?*

F: There are several, I should say. First of all, the mirror, the field of view. That's the main topic, so that's what we start with.

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Figure C.6: Interview Design Engineer , Page 2 of 5

Then we have environmental ones, which could be that we cannot use certain materials, and that we already have when we go out to our suppliers, saying "This is our blacklist", or "These materials cannot be included". Is it possible that you design with respect to sustainability or the environment?
You select the manufacturing processes to be more environmentally friendly, or anything like that? Maybe joining processes are about some other material or something like that? Is it done?
If we would have that, normally we do not interfere in what the suppliers want to do, but if they give us the selection between this process and this process, then environmental would be one factor.
But when it comes to designing for environmental, it's important for us to design it in a way that they can disassemble it and sort it, to throw the plastics in one bag and the metallic in one bag, so that you do not do an integrated design which is impossible to take apart.
That's the sustainability part. Lifecycle aspect of your product. So, the lifecycle is a part of it.

L: 9. *What are some of the prerequisites, if they exist?*
F: For a product, there are always prerequisites, where we start from. Then we have a base, and they want to add. You always have, like, "We have this solution today, but we want a new solution to also do this and this and this".
So, then you add this, or you find a completely new solution.

L: 10. *Is it possible to identify these prerequisites? Before even starting the project?*
F: Yes and no. Some of the things I can pick up from the markets, we know that the legal requirements are moving towards something, maybe. And then you understand that, this is probably something that the market wants. And the same way goes for hearing different trends, you can feel that, oh they would probably want to do this. So yes. And, small things, that on the road, I can see that they paint our mirrors in different colours.

We paint some parts, but not all, and they paint every single mirror completely. Then I can see that already and we can have it in mind when we design or select the materials, that this should be possible to paint.
We will not do it but let the customer do it. And this is not even mentioned from the product, but we know it, we see it.

L:11. *How is this knowledge captured and transferred? Now you know it, how do you transfer it?*
F: In the community. And then it's about being observant more.

L:12. *How much is it that the system is sensitive because of these prerequisites, is it too much or is it minor? I mean suppose, if you design a mirror and I paint it, is it sensitive?*
F: No. If I had it in mind, I could make it more adaptable to it, and less. I can really destroy that possibility by selecting a material that is not possible to paint. These things happened. Not to the mirrors, but to some other parts where we maybe didn't know that the customer wanted to do it. They do something, always, which we don't know, and then we design in a way where it's not possible anymore.

For sure, that happens. That would not be my responsibility to understand this, because this is the brand Volvo, because I only work with product development, I don't sell trucks.
That's another problem of business.

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Figure C.7: Interview Design Engineer , Page 3 of 5

L:13. *Have you faced any issue where you have designed something where in you cannot paint something and the customer paints it, and then he's literally angry and then he claims for warranty? How do you guys handle this situation?*
F: Those ones, they would reject, because we never said that you would be able to paint it, but it would be something that is brought to us from downstream to say that, and then they would add it as a requirement for the next time, that you need to, that the customers would... and in some cases there are actual projects where they say that many customers would like to do it, we need to fix this.

L:14. *And this knowledge has been given to you by the service team? Or market?*
F: By market. I don't really know how it comes to them, but it comes to me.

L:15. *Now let's go into derived requirements. Are there any derived requirements from the previous project that affects your system design?*
F: Yes, normally we all start by that and then add requirements.

L:16. *How do you guys ensure that the compliance is met over the carry-over projects?*
F: We do testing. But that would be vehicle testing in the end. As a complete system.

L:17. *Any of the requirements from the trade-offs? And what is done to handle?*
F: I mean you pretty much said that when you begin, everything is conflicting, and the best way is to meditate. In the best cases, you have a person, a feature leader, who fights for their thing.

So, you have many people fighting for it, and then you have to find a compromise. Everyone knows that you have to have a ready mirror by this date, so we need to find the best solution. The worst case is when no one is really fighting for that thing, and only I know that it's good. Then it's much, much harder.

L:18. *It's more like prioritizing or flagging, which is more critical?*
F: Yes, because I'm like the mediator, to a combined, best solution. Should not heat up too much? Problem solving is what I work with, problem solving in terms of conflicting requirements.

L: 19. *What are your views about requirements that come from these installation interfaces? When you install the mirror into the chassis? Are there any requirements that come?*
F: Yes, those are the ones I mentioned before, that it cannot be too heavy, it has to be attached in a certain way. Most critical thing is maybe that they say that, "Only this screw is allowed". Then we have to design around that, because they have one standard screw which they use for hundreds of them. And then I need to design around that screw.

L:20. *Are you aware of any economic requirements that govern the product design? Cost?*
F: Yes. And then you get a target or a frame. And that's needed, if you don't have --Then you can design a mirror of gold. You really need that to keep it contained. Contain it in the box? Yes, otherwise it would be impossible. That would be one of the system boundaries also, right? Yes. The cost.

L:21. *And there are a lot of organizational requirements, department by department, but, in short, which is the most governing department? That affects you as a developer and the design?*

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Figure C.8: Interview Design Engineer , Page 4 of 5

F: Two parts, but one is really set. One department is the Body in White, but then you set the interface, and then it's set. Otherwise it's electrical.

L: 22. *Who are the stakeholders?*
F: All the feature leaders, and the customers are, but not in practice. The brand represents the customers. Aftermarket.

L: 23. *When you organize these community of practice meetings, have you considered to have all the stakeholders in the meetings sometimes, if it's that critical? Call even the customer?*
F: No. Never the customer.

L: 24. *Suppliers maybe?*
F: Yes, often we go, the entire community. We visit a supplier, and the supplier shows everything about what they have. So, the suppliers yes, we don't ever invite them, but we invite ourselves.
And yes, we have stakeholders, but only the representative from the stakeholder community. In those community meetings, there is someone from aftermarket, and someone from manufacturing. But it's not the same persons that I work with.

L: 25. *And which is the requirement that the system needs to satisfy to comply to the company's standard? Quality, is it?*
F: These are the ones. The quality and the environmental thing. Now it is that the environment has been included? No, our core values have always been quality, safety, environment. Always. But environment now is more than fifteen years ago.

L: 26. *So, environment is now the topmost priority and then you go for quality?*
F: No. Safety, quality and then environment. Safety and quality, for example, they go hand in hand in many cases.

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Figure C.9: Interview Design Engineer , Page 5 of 5

C.2 Case 2

C.2.1 Group A

C.2.1.1 Automotive Design Engineer from SAFER

Interview

Details:

Expertise: Automobile engineer specialised in vehicle safety

Location: Chalmers University of Technology

Date: 12 April 2018

Duration: 1 hour

Objective: Testing system architecture questions

Time: 10:00-11:00 pm

L: 0. Which frame of reference do you want to use for the interview?
T: Automotive design engineer.

L: 1. What is the system?

T: Neck restraint system called **WHIPS (Whiplash Protection System**)

L: 2. What purpose does the system serve?
T: To start off with, the human body remains in a relative rest position with respect to the car. When a car is subject to a rear impact crash scenario, the body which is in contact with the seat accelerates forward at the same rate as the car. The head however, not being in contact with anything during this sudden acceleration, continues to remain in the same position due to inertia. As a result, while the body is thrust forward, the head and neck snaps backwards. In the next few instances, the rate of acceleration acting on the car decreases to that of equilibrium with the striking car. However, in this time, the head would have just achieved the previous acceleration values and would snap ahead of the body which is now moving at a slower speed. This mechanism is called whiplash.

However, if the seat can move freely in a longitudinal direction at the point of impact, it would now allow the entire seat, area of body in contact and the neck to move at a relatively same acceleration with respect to each other. Thus, preventing and reducing the inertial effects on the neck by distributing it all over the body. This same movement can also be achieved by increasing the seatback angle briefly.

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Figure C.10: Interview Group A , Page 1 of 5

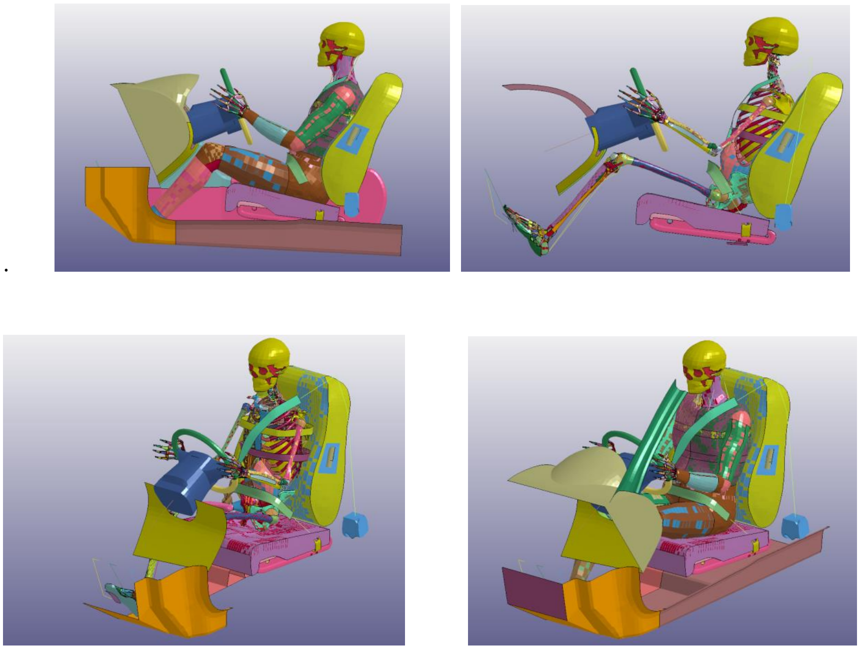

Figure 1. Crash areas [Image source: Johan Iraeus. Dept. of Vehicle and Traffic Safety. Chalmers University of Technology. From course Impact Biomechanics (TME196)]

The biggest problem is, the distance "D" as shown in the **Figure 1**, between the back and the seat back increases significantly. So, the neck spans forwards and then when your body fall back it snaps backwards. So, if the seat moves, it moves back with your sour during this time, this initial backward and forward movements is how the human body and the seat behave to absorb the impact. Which is kind off making your body inertially at rest with respect to the entire crash scenario. So that way you need a system to prevent this sudden movement of neck to eliminate the injury or in extreme cases death. The true essence is the whole system depends on how your body moves in case of a crash.

L: 3. What other system/ systems is it associated with?
T: The seat, seal belt system, air bags system and the overall internal cabin space of car and the chassis of the car.

L: 4. What other system/ systems is it dependent on for its functioning?
T: Human biomechanics, sensors like accelerometers etc.

L: 5. Can system boundary/boundaries be defined?
T: Yes.

Figure C.11: Interview Group A , Page 2 of 5

L: 6. What are the system boundaries?
T: Well the geometry and placement of the seat itself. For example, if you can define how much the seat moves in such a way that it can account for all acceleration within a certain range that you define that does not affect the person seating behind. Your seat is moving backwards in case of rear impact. If you define it quantitatively say 10 cm, then you have a total of 30 cm allowance to the back seat. The person seating on back has about 20 cm even when the seat is fully slid back. Same with the angle of seat, you don't want to go too far back which can make you slide off the seat.

L: 7. Does the design comply to the boundary definition? If not, what is done?
T: Yes.

L: 8. What more aspects of the system's feature can be considered for the boundary definition? (If they exist)
T: The seat, seat belt, air bags around the steering wheel and curtain airbags. In case of the curtain air bags, they play a critical role. In the case when you are hit at a slight angle in rear collision scenario. Most air bags are developed for front and side impact. During the rear collision what happens is that, if you move, the odds are you will hit the glass. But with a slight angle, you hit the b pillar (which is solid metal) and not the glass.

L: 9. What is the environment of operation in which the system operates?
T: Ideally it should work in any environment of operation.

L: 10. Which are the environmental parameter/parameters the system sensitive to? (If they exist)
T: The only environmental parameter that I can think of could be more like the angle of impact. For example, if you are driving in an intersection and someone hits you from the rear at an angle then, the car is thrown in a spin or the car experiences fishtails, in this case environment is factor, if its icy you will spin out more compared to a dry surface. These makes the system less effective.

It is in the end somehow going to affect the way the system is going to interact with the human body and hence can be considered an environmental parameter that makes the system sensitive.

L: 11. How does the environment affect the product design?
T: Not applicable as far as I know.

L: 12. What is/are the input/ inputs to the system?
T: Geometrical dimensions of the system for example.

L: 13. Are any margin/margins associated to the input/inputs of the system?
T: Yes

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Figure C.12: Interview Group A , Page 3 of 5

L: 14. What is /are margin/ margins associated to the input/inputs of the system?
T: With respect to the design of the system, it can be dominated by many freeze parameters from the other systems for example, a 10cm seat motion design constraint, the reason for this is, inside the car cabin you have only a certain amount of space that you can move freely, you don't want to affect the other passenger seat space allotted.

With respect to the geometrical system design, it is designed for a certain body type, not for all body type. An average person's dimensions are considered. 50th male is not representative of the physiologies of various regions. Also, male/female physiologies differ, and hence cannot be considered to be enough.

L: 15. What is/are the output/outputs from the system? And what are they?
T: Sensors actuate the system, addressing the body movement in the case of a crash which can be frontal, rear or crash at an angle.

L: 16. Are any margin/margins associated to the output/outputs from the system?
T: Yes.

L: 17. What is /are margin/margins associated to the output/outputs from the system?
T: Range rate is considered while considering the trigger of the system. The activation of system at the right time.

L: 18. Does the system has/have any critical part/parts?
T: Yes.

L: 19. Which is/are the critical part/parts of the system?
T: The sensor can be considered as critical part. Errors associated with sensor functioning can happen, for example, you don't want to trigger the restraint system when it is not a safety critical system. It can be quite annoying or may lead to a crash if the system is deployed.

L: 20. How is risk associated with the critical part / parts identified and handled?
T: Either it does not work or results in bad performance.

L: 21. Which is/are the critical performance related parameter/parameters of the system which govern the design?
T: As a matter of fact, performance never gets affected, the system can only function in one specific way it is intended for, no matter what the severity of crash is. In a scenario of a crash, every level of acceleration above a set level would work as a trigger to the system. If u define as "1 *g*" constant acceleration as crash, any crash that happens as "*1g* or above" would trigger the system. Another aspect is the medium of signalling. If you use a radar information for example, to trigger the system, the systems on board the car should calculate that there will be a crash happening and trigger only if a crash is certain. The striking car if it stops 50 cm from your car then the system should be smart enough not to trigger and consider it near crash scenario.

Performance is the way the system calculates. For example, you have a radar on board the car which measures the distance between the car and the striking car. The radar sends a beam of

Figure C.13: Interview Group A , Page 4 of 5

sound and then it calculates the time "t" it will take to hit and bounces back. this gives the distance you estimate. The distance at time "t_1" and then at "t_2" is used to find the distance the approaching object has moved from point 1 to point 2. You have the rage rate over rate, so the range rate is the rate at which the range is closing. This gives you the time to collision. You can use the system in the absence of radar and in that case, it will rely primarily on accelerometer and it will be more accurate compared to the radar. Accelerometer value other values such as the radar values also act as supplementary or verification system. This are the same accelerometers that trigger the air bag. In short you are preparing for impact before impact happens. It is a preparatory system

L: 22. Is the design concept for the system new?
T: Yes

L:23. Is the system architecture feasible?
T: Yes, on an average family car not an extremely compact cars like smart car.

L:24. Is there any variant of the Architecture?
T: Not exactly. But in the future, there will be variants.

L:25. What is the top deciding factor for decision of selection of the system?
T: Keeping certain age group in mind 21 to 40 years for instance. The initial development is for the common user but for users above 40 years of age the variant design will be based on improvement of the existing system.

L:26. Are there any post project concepts that can be considered when the design concept is novel?
T: Human body's reaction to various crash scenarios.

L:27. How can the risks associated with the new system design be dealt? What can be done to prevent such major risks?
T: Product should be standardised from legislative perspective and requirement fulfilment perspective. For example, 15 years ago, only the front two seats had seat belts and there were no rear seat belts. Having the rear seat belt was a premium option. So ever since legislation passed new laws it became out of scope for OEM and customers not to opt for the new technology.

L:28. Are there any ongoing market trend/trends? What is it?
T: All Volvo cars are pre-equipped with this safety technology called as WHIPS (Whiplash Protection System). This increase the cost a bit but then highlights how important safety in the car. For example, in Asian countries like India, people don't pay much attention to safety.

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Figure C.14: Interview Group A , Page 5 of 5

C.2.1.2 Design Engineer from Volvo Trucks Technology

Interview

Details

Expertise: Design engineer for mirror section.

Location: Volvo Trucks Technology

Date: 17 May 2018

Duration:30 mins

Objective: Testing system architecture questions.

Time: 14:00-15:00 pm

L: 0. Which frame of reference do you want to use for the interview?
F: Design engineer for mirror section.

L: 1. What is the system?
F: It's a mirror system, here we deal with several mirrors for a truck in general.

L: 2. What purpose does the system serve?
S: The mirror system is responsible in showing the area from the front and the rear of the truck to the driver.

L: 3. What other system/ systems is it associated with?
F: Attachment-wise, it's attached to the body in white of the truck. And then, it has interfaces to some of the exterior parts, such as the panels and so on, and then its function interface to visibility. So here we are concerned with direct and indirect visibility.

L: 4. What other system/ systems is it dependent on for its functioning?
F: If you see the mirror attachments and so on, that would be an internal component. Inside the system would be the mirror glass, for example. As with the external, it would be dependent on that the attachment points are in the right position and that it has an electrical interface for heating and adjusting.

L: 5. Can system boundary/boundaries be defined?
F: Yes.

L: 6. What are the system boundaries?
F: There are set boundaries when it comes to geometrical dimensions, for example, how far away it can come from the trucks, which cannot be as wide as possible, and it cannot be low or high as possible, it needs to follow the truck to be able to show the field of view required. There are legal requirements for the field of view which are setting the requirements on where the glass needs to be placed to show the correct field of view for the driver. So, we have a driver

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Figure C.15: Interview Group A , Page 1 of 5

position, which gives the field of view on the ground. Then we have the height of the truck that sets the size of this field of view.

L: 7. Does the design comply to the boundary definition? If not, what is done?
F: Not applicable.

L: 8. What more aspects of the system's feature can be considered for the boundary definition? (If they exist)
F: There are constraints in terms of vibration, for example, I don't know if that's a typical constraint. Because, if there are too much vibrations, you will not see anything from the mirror.

L: 9. What is the environment of operation in which the system operates?
F: Any environment.

L: 10. Which are the environmental parameter/parameters the system sensitive to? (If they exist)
F: Yes, it's sensitive to hot and cold environment, in terms of moisture for example, if there's moisture on the screen, or on the glass. And then of course, cold in the same way, if there's frost on the glass. We have things to solve that. And there could also be harsh wind, or snow coming in, and dust and things that are disturbing the image. Or the view.

L: 11. How does the environment affect the product design?
F: First of all, you need to design in a way that for example snow or dust doesn't collect in certain areas that disturbs the image so to say. So, in that case you would be dependent on the rest because all the dirt would come from the rest of the truck or from the drag of the wind taking all the dirt for example and ending up in it.

L: 12. What is/are the input/ inputs to the system?
F: First one would be the eye point, from where the driver is seeing, because that more or less sets what the mirrors can show, and it's the location, the height of the driver towards the ground, and it's a legal requirement, of what area it should... this sets the position of the mirror glass, and then you create the solution around it.

L: 13. Are any margin/margins associated to the input/inputs of the system?
F: Yes.

L: 14. What is /are margin/ margins associated to the input/inputs of the system?
F: Yes, it's both that people are different, but the legal requirement is set. They set what an average person is, so this will not be correct for everyone, but close enough according to the legal requirement. And then also, a truck can be... we design for only one specification or what you say, but the truck can have different tires, it can have different chassis, it can have different frames and everything, that makes this go up and down, and the higher the mirror, the more

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Figure C.16: Interview Group A , Page 2 of 5

you see, because the glass can show more or the field when it's higher, and the lower, the lower. So, then we go for the absolute lowest, because that is the worst situation.

L: 15. What is/are the output/outputs from the system? And what are they?
F: Direct and indirect vison.

L: 16. Are any margin/margins associated to the output/outputs from the system?
F: Not applicable

L: 17. What is /are margin/margins associated to the output/outputs from the system?
F: Not applicable

L: 18. Does the system has/have any critical part/parts?
F: Yes.

L: 19. What is critical part?
F: Design parameters.

L: 20. Which is/are the critical part/parts of the system?
F: No single critical parts, because if you for example lose one bolt or lose one mirror glass or something, then you would still be able to, for a short time, depend on the rest.

L: 21. How is risk associated with the critical part / parts identified and handled?
F: Yes, there are risks associated, but it's not here we judge if it's a lethal risk or a functionality risk, or if it's a workshop risk. And, in this case, we see it in the way that we design.

We design that we should have no lethal risk, so there should be no risk that we completely lose visibility for example, that all mirrors fall out at the same time, and you don't see anything, and you have to do a panic stop.

But you would still see the road ahead of you. And then, nothing is attached with only one screw, so that if that one blew, then everything would fall off.

That's how we design towards avoiding critical things. But, for a mirror as a functionality there are a lot of aspects that are critical, as like, soiling, vibrations, and so to have a long list of requirements.

L: 22. Which is/are the critical performance related parameter/parameters of the system which govern the design?
F: The top five would be:

1. **Vibrations**
2. **Direct visibility,** meaning that we have too big mirrors and don't see anything.
3. **Legal requirement**
4. **Wind,** the drag of the mirrors themselves is a problem, and they need to be stable.

Figure C.17: Interview Group A , Page 3 of 5

5. **Soiling**. This is when for example, if you have a dirty windscreen, and you don't see anything out, you take the washer/wipers, to spray and to clean. That spray could for example end up on the mirrors, and then you don't see anything in the mirrors, because they are wet. And then it takes some time before the water blows away, or dries, or anything like that. And then they have a loss of function temporarily due to soiling.

L: 23. Is the design concept for the system new?
F: Yes

L:24. Are there any coupling parameter/parameters from other systems affecting the current system? And what are they?
F: In the case of soiling, some of these things, you must more or less accept, that this will happen. If you want to clean the windscreen, in this case, efficient, then we will have a lot of water spraying all around there.

So, then you more or less validate that this is not a huge problem, but only a small problem. Then we do simulations on how the air moves, and so on. The soiling can be somehow related to the spraying system as one coupling parameter

Vibration can also be a coupling parameter -- Yeah. -- from the chassis and some suspension systems

I already mentioned the one with the direct visibility, versus indirect visibility. Too big mirrors will make you not see anything. For mirrors we have features, which are very important for a mirror. And we have many features across the truck, and some of them are important for the mirror, such as durability, vibrations, and things like that. Some of them are really contradicting each other. For example, product design wants something that looks like a very sleek design, very narrow things and everything. And that is contradicting to vibration. Because if we don't have a very robust design, we will have vibrations.

So, when we have couplings between all of these, they themselves have contradictions, so in this case, product design is something we decide ourselves, it's not an engineering or a mechanical issue.

It's something more of a when you combine solutions, you want product design to give this.

L:25. Is the knowledge about the existence of dependency referred to all? How is it done?
F: If you discover that there is this issue with the soiling effect, you know it, the newcomer doesn't know it. So how do you transfer your knowledge with these coupling parameters?

Because coupling parameters are tricky, they just come and, you know, you spend hours and hours into a design and then realize that there's nothing wrong with this system, it's because of this parameter from the other system. This one is not done well. Now that we have a community of practice, the rest of the community of practice knows this. Only in the mirror design team?

Everybody in the mirror section would know about this? They would know, but then for every feature, for product design, for soiling, there is one person responsible for that feature.

They know it as well, but they don't care. Product design doesn't care about durability.

While the feature leader for durability cares a lot. So, if I only talk to product design and not talk to the other one, I would not understand that these are contradicting each other. So, in the

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Figure C.18: Interview Group A , Page 4 of 5

beginning of a project, I will get contradicting requirements from all. If I was a design engineer, I would see that what you say, and what you say, I cannot fix this. So, these contradictions will normally evolve or be clear quite early, but some of the tricky ones where we maybe have no feature leader, those ones would be more difficult and that would be up to the experience of the community. It would be hard to. I know how I would try to find them. Try to look for previous failures, in projects, to see what kind of problems they had at that point. But that could be like a completely different concept, and not comparable to mine. So, there is no formal handover, because I can't really think of everything when I hand over. When I hand over my knowledge, it would normally be related only to a project, and I would have more knowledge that I cannot hand over because I cannot empty my brain at once.

L:26 Is the system compatible with other system/systems/subsystems?
F: This is how we design, we design for it to be one of those parts that has no deviation, so it should be the same always. So, there are other variants that must adapt to us. the mirror has internal variants. Such as heating, no heating, adjusting automatically or manually. But otherwise, since all trucks have mirrors, everyone has to adapt to us, so we find our interface inside, that this is a set interface, no one can touch this interface.

L:27 Do the ongoing market trend/trends affect variant selection?
F: Yes, in some cases, but not that much. These parts are not ones that we change that often. But legally-wise, we always look at the road map for legal requirements. Those are changed very slowly. These things happen, they change a legal requirement, and we need to redo the design, completely. Then we have no choice, we just must do whatever is required.

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Figure C.19: Interview Group A , Page 5 of 5

C.2.2 Group B

C.2.2.1 Software Design Engineer from Chalmers University

Interview

Details:

Expertise: Computer Science- Algorithms, logics and languages

Location: Chalmers University of Technology

Date: 18 April 2018

Duration:30 mins

Objective: Testing system architecture questions

Time: 14:00-14:30 pm

L: 0. Which frame of reference do you want to use for the interview?
S: Software developer.

L: 1. What is the system?
S: The system that we are talking about today is Sound.hs. It is a type of library module in Haskell which implements a software synthesizer.

L: 2. What purpose does the system serve?
S: This software synthesizer generates sound in the form of pulse code modulated (PCM) samples.

L: 3. What other system/ systems is it associated with?
S: The module Score is a test program which reads a musical score and generates sound.

L: 4. What other system/ systems is it dependent on for its functioning?
S: The synthesizer is very susceptible to chain dependencies due to involvement of variable languages like Feldspar language and Haskell language.

L: 5. Can system boundary/boundaries be defined?
S: Not totally but partially.

L: 6. What are the system boundaries?
S: The design is limited by the advanced programming interface "API" of the previous library.

L: 7. Does the design comply to the boundary definition? If not, what is done?
S: A test program is re-written to perform similar function according to the test case of the previous API. Subtle changes in the API can change the programming style which are acceptable to the library.

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Figure C.20: Interview Group B , Page 1 of 3

L: 8. What more aspects of the system's feature can be considered for the boundary definition? (If they exist)
S: Run time and hardware requirements can be considered.

L: 9. What is the environment of operation in which the system operates?
S: Underlying platform – hardware in which it performs and the operating system.

L: 10. Which are the environmental parameter/parameters the system sensitive to? (If they exist)
S: Versions of the C compiler can make the system sensitive. This is the most critical parameter of all.

L: 11. How does the environment affect the product design?
S: The product fails to run, and it can cause faulty behaviours in some circumstances.

L: 12. What is/are the input/ inputs to the system?
S: The API defines the inputs.

L: 13. Are any margin/margins associated to the input/inputs of the system?
S: Yes.

L: 14. What is /are margin/ margins associated to the input/inputs of the system?
S: Mathematically undefined or nonsensical parameters cannot be acceptable. For example, sound of -1 second of length cannot be acceptable.

L: 15. What is/are the output/outputs from the system? And what are they?
S: WAVE PCM sound file format is the output.

L: 16. Are any margin/margins associated to the output/outputs from the system?
S: Yes.

L: 17. What is /are margin/margins associated to the output/outputs from the system?
S: Amplitudes bounded by the maximum and minimum value assigned to a 16-bit signed integer.

L: 18. Does the system has/have any critical part/parts?
S: Yes.

L: 19. What is the critical part?
S: Design parameters.

L: 20. Which is/are the critical part/parts of the system?
S: Design paraments like the Feldspar type system of the programming code.

L: 21. How is risk associated with the critical part / parts identified and handled?
S: Either it does not work or results in bad performance.

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Figure C.21: Interview Group B , Page 2 of 3

L: 22. Which is/are the critical performance related parameter/parameters of the system which govern the design?
S: The type system of the programming code, data dependencies, algorithms used, compiler version and compatibility of language packages.

L: 27. Is the design concept for the system new?
S: Yes

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Figure C.22: Interview Group B , Page 3 of 3

C.2.2.2 IT Engineer from Chalmers University

Interview

Details

Expertise: IT

Location: Chalmers University of Technology

Date: 4 May 2018

Duration: 30 mins

Objective: Testing system architecture questions

Time: 12:00-12:30 pm

L: 0. Which frame of reference do you want to use for the interview?
N: IT service provider.

L: 1. (Who are you?) What is the system?
N: I am a system administrator (First Engineer) at Chalmers.

L: 2. (What do you do?) What purpose does the system serve?
N: I oversee if IT is running as it should. This includes taking care of servers, maintaining them, setting up new servers, maintaining network and so on.

L: 3. What other system/ systems is it associated with?
N: I am associations with the sections of the school, student union and different companies.

L: 4. What other system/ systems is it dependent on for its functioning? (Why?)
N: Student union (financial aid and leader management) and Chalmers IT (Internet provider).

L: 5. (Do you have boundaries?) Can system boundary/boundaries be defined?
N: Not more than financial boundaries and the boundaries that student union put on us.

L: 6. What are the system boundaries?
N: Set of instructions or frame work of Chalmers IT

L: 7. (Does the service operate within the boundary) Does the design comply to the boundary definition? If not, what is done?
N: We have instructions or frame work that we must follow. We cannot do anything outside of those. The preliminary essence is to provide IT support within Chalmers and then may be to extend our services to the companies.

L: 8. What is the environment of operation in which the system operates?
N: We need a space (room), tools, reserves, stock (hardware) and a team.

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Figure C.23: Interview Group B , Page 1 of 2

L: 9. Which are the environmental parameter/parameters the system sensitive to? (If they exist)
N: We need to feel good. Room with things that motivates us or in short, the social aspect.

L: 10. How does the environment affect the product design?
N: The space for example the room induces a sense of security and openness which assists in the team's unity and functionality.

L: 11. What is/are the input/ inputs to the system?
N: Knowledge in general, SU and companies.

L: 14. Are any margin/margins associated to the input/inputs of the system?
N: Safe buffers in terms of hardware.

L: 15. What is /are margin/ margins associated to the input/inputs of the system?
N: We never want to assume something, redo, safe buffers in terms of hardware, an example of such safe buffer can be, we have access system that needs server or multiple servers, the company that provides servers gave options.

L: 16. What is/are the output/outputs from the system? And what are they?
N: It's maintenance and support.

L: 17. What is critical part?
N: It's basically the rules. If we don't follow the rules for Chalmers, they'll cut off.

L: 18. How is risk associated with the critical part / parts identified and handled?
N: Security systems, first of all. Systems that detect certain issues that would go towards that problem. We also have a good communication with Chalmers. To make sure that we are heading the right way. As well, as we have our old committee members. The ones who sat before me. We can always talk to them. If we need help, we just ask them, and they'll help us, with everything.

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Figure C.24: Interview Group B , Page 1 of 2

C.3 Gap Identification

Interview

Details

Expertise: Design engineer for mirror section.

Location: Volvo Trucks Technology

Date: 05 July 2018

Duration: 30 mins

Objective: Gap identification.

Time: 14:00-15:00 pm

L:1. What could have been a gap after going through the entire interview sessions?
F: When working with the mirrors, there's a lot of work with the supplier, so a lot *of* ***my knowledge comes to how to manage the supplier**. **And knowing: is it a good supplier? Can you trust them? What is important?***

L:2. But isn't this the part of duty of the procurement team?
F: No.

L:3. It is the duty of the design engineers?
F: In my case, what I am or was called, is a “lead engineer”. Design engineer sits in CAD and really designs the part. They are more of project engineers, they can be also design engineers. And then there's me, who is an “**SIPD leader**”, which means “**Supplier Involvement in Product Development**”.

I have more of a project manager scope. I do not design the mirror parts myself. I only put the requirements. So, I cannot say that this is a good radius, and this is not. And only a few of them works with suppliers in the way that I do. *That's the knowledge I don't think that you will have in your list.*

L:4. Is this knowledge an overlap of all the front-end sides?
F: No. It's not overlapping. Because you have all these requirements, but to take these requirements and make the supplier understand them. Because if it was only me, I could understand them. *I understand how we validate them and which is more important than the other.* But the supplier doesn't know. The supplier could be, for example, not at all used to working with Volvo. And then you need to get them on board on the Volvo way of working, and that's so much more than just a requirement.

L:4. How critical is this knowledge segment?
F: System designers have all the knowledge enough for integration and it is the supplier that have knowledge at the deeper level. Design at its early stage has a lot of supplier integration for example, in the start of a project, at least two suppliers will be selected. Here, the system designer’s key focus is to manage the supplier and negotiate. *This can be achieved via effective communicative and collaborative skills.*

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Figure C.25: Interview Gap Analysis , Page 1 of 2

Volvo Trucks, lays emphasis on performance and quality while Renault is more focussed on fuel and cost efficiency. This means that *Partnership with the supplier is key to keep up with the requirements specifications according to the parent company.*

The knowledge community relies on B2B or P2P relations for its knowledge database. *This also depends on the data transparencies of the supplier companies.*

For example, A frequent problem occurring was "EMC disturbances." Though collaborative communication, this check point was sent to suppliers to nullify the recurrent problem but there are times wherein a set of check points that's cannot be established like, Aerodynamics. This is rather a general team the check points established are 75% quantitative and 25% via subjective evaluation.

L:5. What is the mode of communication?
F: To get the part what a designer has designed for, *written documents* are used, and they are about 20 to 30 pages long. In each section the supplier must "*commit*" to the requirements. This is then stored in digital form and sent to all associated with the project.

Figure C.26: Interview Gap Analysis , Page 2 of 2