DEVELOPING GUIDELINES FOR DESIGNING A DESIGN-DECISION SUPPORT SYSTEM TO ENHANCE REQUIREMENT IDENTIFICATION IN HELICOPTER INDUSTRY

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ABSTRACT

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Requirements identification is a critical process in product design and development as it affects the product's life cycle in terms of many factors such as specifications, design quality, cost, production, and marketing. Requirements identification in the helicopter industry has many complexities due to the active participation of the stakeholders involved and the decision-making processes that require cooperation among the stakeholders. This process can be supported by the contribution of digital technologies, especially decision support systems as examples of computer-supported cooperative work. This thesis aims to explore the design requirements of a design-decision support system that can be used to improve requirements identification processes. For this purpose, semi-structured interviews were conducted with six requirements engineers, five managers and two representatives of external stakeholders within a company operating in the helicopter industry. Throughout the interviews, opinions and insights were gathered about the problems faced in requirements identification processes and how these processes can be improved and supported. A prototype design-decision support system was presented to the participants, and feedback was gathered on its use and qualities. This thesis identifies the design requirements of design-decision support systems that can be developed for use in the helicopter industry concerning the issues faced in practice.

Keywords: design-decision support system, computer supported cooperative work, helicopter design, requirement identification

ÖZ

HELİKOPTER ENDÜSTRİSİNDE GEREKSİNİM BELİRLEMEK AMAÇLI BİR TASARIM KARAR DESTEK SİSTEMİ TASARLANMASI İÇİN KILAVUZ GELİŞTİRİLMESİ

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Ürün tasarım ve geliştirme süreçlerinde gereksinim belirleme süreci, spesifikasyonlar, tasarım kalitesi, maliyet, üretim ve pazarlama gibi birçok faktör açısından ürünün yaşam döngüsünü etkilediği için kritik bir süreçtir. Helikopter endüstrisinde gereksinimlerin belirlenmesi, paydaşların aktif katılımı ve paydaşlar arasında işbirliği gerektiren karar alma süreçleri nedeniyle birçok karmaşıklığa sahiptir. Bu süreç, dijital teknolojilerin, özellikle bilgisayar destekli işbirlikli çalışmalara örnek olabilecek karar destek sistemlerinin katkısıyla desteklenebilir. Bu tez, gereksinimleri belirleme süreçlerini iyileştirmek için kullanılabilecek bir tasarım-karar destek sisteminin tasarım gereksinimlerini keşfetmeyi amaçlamaktadır. Bu amaçla helikopter sektöründe faaliyet gösteren bir firma bünyesinde altı gereksinim mühendisi, beş yönetici ve iki dış paydaş temsilcisi ile yarı yapılandırılmış görüşmeler yapılmıştır. Görüşmeler boyunca, ihtiyaç belirleme süreçlerinde yaşanan sorunlar ve bu süreçlerin nasıl iyileştirilebileceği ve desteklenebileceği konusunda görüşler ve içgörüler toplanmıştır. Prototip bir tasarım-karar destek sistemi katılımcılara sunulmuş, kullanımı ve nitelikleri

hakkında geri bildirim alınmıştır. Bu tez, helikopter endüstrisinde kullanılmak üzere geliştirilebilecek tasarım-karar destek sistemlerinin tasarım gereksinimlerini, pratikte karşılaşılan sorunlarla ilişkili olarak belirlemiştir.

Anahtar Kelimeler: tasarım karar destek sistemi, bilgisayar destekli işbirlikçi çalışma, helikopter tasarımı, gereksinim tanımlama

To the future of Anarres...

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Lastly, I would like to pay tribute to my uncle, Mehmet Coşkun, who became a victim of a negligence of occupational health and safety. May he rest in peace.

[a] See Ü. Töngür, S. Hsu, and A. Y. Elveren, "Military expenditures and political regimes: Evidence from global data, 1963–2000," *Economic Modelling*, vol. 44, pp. 68–79, 2015.

[b] See N. Yentürk, "Vergi adaleti, yoksullukla ve iklim kriziyle mücadele için kaynak var mı?: Bütçeyi konuşmaya başlamak," *Birikim*, vol. 406-407, pp. 67-76, 2023.

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CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CDR	Critical Design Review
ConOps	Concept of Operations
CSCW	Computer Supported Cooperative Work
DDSS	Design-Decision Support System
DoD	US Department of Defense
DoE	US Department of Energy
EASA	European Union Aviation Safety Agency
FPDA	Flat Plate Drag Area
HIGE	Hover In Ground Effect
HOGE	Hover Out of Ground Effect
MOE	Measures of Effectiveness
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
OpsCon	Operational Concept
PDR	Preliminary Design Review
PLM	Product Lifecycle Management
PTD	Project Technical Document
RFI	Request for Information
RFP	Request for Proposal
SOE	State-Owned Enterprise
SPS	System Performance Specifications

SRR	System Requirements Review
SSS	System/Subsystem Specification
IDEF	Integration Definition
ISO	International Organization for Standardization
INCOSE	International Council on Systems Engineering
VDI	Verein Deutscher Ingenieure (The Association of German Engineers)

CHAPTER 1

INTRODUCTION

Product design and development is a process consisting of a life cycle with multiple phases starting from market demands to after-usage scenarios. This process becomes more multidisciplinary and hence more complex in heavy industry products such as transportation, energy, construction, aviation, defense, *etc.* The complex nature of these products requires the requirements stated in the design brief to be monitored throughout the whole design process. Since requirements have a significant role to shape the design process, the identification of the requirements *per se* becomes an essential part of the whole design and development process [24, 25, 26]. Requirement identification in heavy industries usually occurs among different stakeholders like customers, clients, users, contractors, and designers. This thesis intends to explore the problems during the requirement identification in the helicopter industry among different stakeholders, then evaluates a supportive information system that can be used in this phase, and introduces guidelines on how to design such a system, namely a design-decision support system.

The scope of the terms *design* and *design requirements* has a wide range in different industries depending on the scope and fidelity of the work. For instance, in helicopter design, design may refer to both the aerodynamic design of the fuselage, and control grip design for the pilot. There are differing requirements for those design activities. This difference in requirements are defined using levels and decomposition activities in requirements analysis. Requirements form a hierarchical structure with the highest level requirements such as customer requirements [27]. These high-level requirements are analyzed and decomposed into performance requirements and functional requirements about a system or set of systems. These decomposed requirements are further decomposed into requirements about elements and subsystems.

As the scope of the design work narrows down to single systems or objects in the vehicle, the level of the requirement is said to be lower. For the lower design requirements, the fidelity needed for the outcome of the design becomes higher. The design requirements of a control grip can be considered as an example for lower level requirements. The outcome of such a design work is the final product refined by the testing procedure with the pilots. This includes detailing in terms of physical and cognitive ergonomics. These considerations can be examples of high fidelity outcomes. In contrast, higher level design requirements deal with the general attributes and properties of the product or system. For instance, performance parameters of a helicopter such as speed, endurance and payload can be considered as higher level requirements, specifically these requirements are placed at the top as they deal with the helicopter in a holistic manner. Therefore, they are also called as *helicopter level* design requirements. The outcome of this type of design work usually has lower fidelity, specifying certain ranges in those parameters and deciding general configuration of the helicopter.

There are several types of requirements such as customer requirements, functional requirements, performance requirements, derived requirements and allocated requirements [28]. Customer requirements refer to the facts and assumptions stated by the customer to define mission objectives and operational requirements. Functional requirements refer to the required activity to be accomplished. Performance requirements define the extent to which a mission should be executed. Derived requirements refer to the requirements decomposed from higher-level requirements. Allocated requirements are formed by dividing a higher-level requirement into multiple lower-level requirements. There is another significant classification of requirements as functional and non-functional requirements. Non-functional requirements refer to the attributes of a system [29]. Performance requirements such as speed and volume, and *ilities* such as reliability and usability are treated as attributes of a system. Ilities are properties that become observable after the system is started to be used [30].

In this thesis, the scope of the design requirements regarding a helicopter are bounded by higher level requirements in a requirements decomposition approach. On the other hand, the design requirements to be explored about the design-decision support system are non-functional requirements aiming to guide the design of this system.

This chapter first defines the problem from multiple perspectives, the complexity of helicopter requirement identification, issues related to the design methods being used in the helicopter industry, and communication gaps among different stakeholders who have active agency in decision-making processes during requirement identification. The aim of the study, research questions guided the study, and the outline of the thesis is presented under corresponding titles.

1.1 Problem Definition

The problem that this study focuses on emerges from multiple sources. These sources are mainly related to methodology studies, and particularly, requirements identification processes. Those sources also have intertwined relations with each other. The intersection of those sources mainly lay in the briefing process of a design project. In this section, there will be a brief background information about the helicopter industry, and its status in Turkey, before the details of the problem.

1.1.1 Brief Background about Decision Making in Helicopter Industry

Design and development of a helicopter requires multidimensional and multidisciplinary[1] approaches, since a helicopter consists of numerous different subsystems which have to work in harmony. This multidimensional nature of the product is reflected in its design briefs or contracts as a complex list of requirements, and the design organizations as numerous departments and managers. In addition to the complexity inside the design organization, other stakeholders such as the client organi-

[1] This narrow definition of multidisciplinarity also includes crossdisciplinary, interdisciplinary and transdisciplinary approaches. The coexistence of several engineering disciplines, such as aerospace, mechanical, electronic and software engineering, as well as industrial designers as experts in ergonomics and human-machine interaction, is essential in the technical development of a helicopter. This coexistence requires a crossdisciplinary relationship in an equal hierarchical organizational structure. However, a multidisciplinary approach where engineering disciplines are treated as sovereign disciplines can be observed in the contractor company. Technical groups, in which industrial designers are located, report to the engineering management. These disciplines are usually treated as a division of systems engineering. It is sometimes confused that any kind of cooperation and collaboration between disciplines is called interdisciplinary practice.

zation and customer organization also increase the complexity of the requirement elicitation process.

In the case of Turkey, the mainstream national helicopter industry is shaped around three institutions. The designer and manufacturer company is Turkish Aerospace, Inc. which will be called as the contractor company. The client institution is Defence Industry Agency[2] (Undersecretariat of Defence Industries), and the major customer institution [3] of the end-products with its pilots and personnel, is Turkish Armed Forces. The client institution also owns 45.45% of Turkish Aerospace, Inc.[33] The major shareholder of the contractor company is owned by Turkish Armed Forces Foundation with 54.49%. This foundation was founded under law no: 3388 [34]. Its board of trustees and the executive board consists of high level bureaucrats and statesmen including the president of defence industries [35].

The fact that the client owns a significant portion of the contractor company adds an extra complexity layer of patron client relationship [36, 37] to the aforementioned complex structure of client-contractor relation. Hence, the design organizations may not follow the most rational decision making strategies. If the ownership structure is considered at a higher level, it can be observed that the state owns all three institutions which means there will also be non-productive objectives[4] such as public interest and politics [38, 39, 40, 41, 42]. Hence, the requirement identification process in this industry also includes those interests.

The formal interaction before and during the design of a product occurs between the contractor and the client. The contractor company employs its own test pilots for potential user interaction. This type of user may play a role of *virtual customer* [21]. This is a hypothetical end-user created by the company. Companies also create some hypotheses concerning the design requirement. Those hypothetical design requirements are expected to be fulfilled to achieve the satisfaction of the virtual customer [21].Thus, the limited interaction between the end-user may lead to inaccuracies concerning the design requirements. This should also be taken into consideration while

[2] Institution is also called as Presidency of Defence Industries. It is directly affiliated to the Presidency of Republic [31, 32].

[3] The term, customer, was used deliberately; instead of user. Since, the user reminds mostly the end-user; on the other hand, the customer reminds an institutionalized type of agent who purchases and consumes the product.

[4] Non-productive objectives: objectives that are not focused solely on financial profit or advantage.

analyzing the requirement elicitation process.

Decision making in the helicopter industry formally follows a systems engineering procedure with quality function deployment, house of quality, Pugh matrix, functional decomposition and N-squared diagrams where the concerns of decision are able to be transformed into parameters of those methods [43]. There are occasions where the concerns are not quantifiable, such as the dynamic nature of international agreements on supply-chain where the uncertainty is high [44, 45, 46]. Hence, it may be considered as economically stable to construct a state-ownership model especially for national security interests [47]. On the other hand, state-ownership has its consequences on decision-making via political interference [48]. Furthermore, *organizational design* may cause integration issues emphasized by Spector [49]. Integration issues in an organization may cause lack of cooperation and communication among divisions. This lack of communication can also stem from the power relations in an organization, since an expert may gain a power position over the superiors as long as the superiors are dependent upon the expert for access to particular information by making the "decision-making" a political process [50]. This lack of cooperation may further deepen the issue of insufficient and inconsistent design requirements.

1.1.2 Requirements Identification and Briefing

Helicopter design is a field of vehicle design which requires a large amount of time in terms of product development. The design and development process is initiated by market analysis or design appeals published by client institutions. Requirements are being elaborated as the design progresses from conceptual design to detail design [5]. The duration may take years starting from market analysis to the first certified flight.[5] Therefore, the decision-making in terms of design should be carried out in a rigorous fashion to prevent large drawbacks that may delay the product design and development process. The most crucial phases of helicopter design in terms of design decisions are the initial phases in which the requirements are being negotiated, and

[5] NHIndustries NH90 Helicopter's development negotiations started in 1985, the helicopter made its first flight in 1995 [51]. It took 8 years for Sikorsky S-92 to make its first flight in 1998 [52], since the initiation of conceptual design in 1990 [53]. Development of the Agusta A129 Mangusta helicopter started in early 1970s, it made its first flight in 1983 [54]. Preliminary design studies of TAI T625 Gökbey began in 2010 [55], and it made its first flight in 2018 [56].

the general configuration still needs to be finalized. The decisions made during the development of a product are committed about 70% to 80% of the total life-cycle cost; whereas, the incurred costs are oppositely low, around 5-7%, at those stages [20, 57]. Requirements phase has lower costs at both classification of committed costs and incurred costs [58]; therefore, it is much cheaper to make changes during this stage.

Having emphasized the significance of requirements identification, the briefing procedure of the requirements should also be taken into consideration. In the briefing phase, design requirements including technical specifications and demands from the client or customer are transformed into a formal agreement or contract in written form. This contract can be treated as the design brief, since it includes project deadlines, organizational details, and design requirements. Constructing the design brief is a significant part of the design process, as it guides the following stages. Moreover, as Walsh et al. [59] mention that the briefing phase may need to include initial design phases like conceptual design, in order to define the brief in a neater manner. Blyth [60] states that, in the early phases, the briefing phase may extend into the concept development phase/conceptualization and even into the design and planning phase. The current trend is to consider the briefing as a part of the entire process, rather than a part of an early stage [60].

Helicopter industry is a part of the aerospace industry, and those industries have a market share in both the civil transportation and cargo market, and military market. Requirements stemming from the demands of those markets are not always in perfect alignment. For example, in the case of Sikorsky S-92 [53], demands regarding the version of the helicopter may be dictated by the client. The coexistence of both military and civil markets may also result in challenges to capture and define the requirements [53]. Identification and analysis of conflicting requirements is an important part of requirements elicitation [61, 62]. Conflicts in requirements may result in inconsistent and insufficient design briefs, as it was observed in the case of Boeing-Sikorsky RAH-66 Comanche helicopter. The Comanche helicopter was required to be heavily armed, agile, and cheap enough to replace Bell AH-1 Cobra and Bell OH-58 Kiowa helicopters [51, 63]. On top of that, it was required to have stealth characteristics which was uncommon for rotorcrafts. Stealth and agility requires the lowest weight possible which directly opposes the armory wanted to be carried. Moreover, stealth requires ammunition to be carried inside which increases the volume of the helicopter. The increased volume contradicts with the agility. The resulting *development hell* cost $6.9 billion, and the project was canceled [64]. This is a multi-dimensional problem whose sources and dimensions will construct the main structure of this chapter.

The issue about inconsistent and insufficient requirements is not unique for the helicopter industry. Ryd [65] discussed the consequences of insufficient design briefs in the construction industry. Similar to the helicopter industry, construction is another multi-party stakeholder business with architects as designers. The inadequate relation among the stakeholders and insufficient design briefs caused significant time and resources to be spent until a clear understanding of the brief. Yang and Renda [66] had explored similar issues in the biomedical industry, focusing on telehealthcare devices. It was reported by innovation directors, product managers and project managers that there were too many costly design changes at the later stages. Investigation of the study was conducted with 30 telehealthcare devices. 63% of the major design changes occurred after the design solution was generated, tested and approved by the project authorities. 73% of those changes were due to new requirements from the client. Apart from engineering dominated heavy industry products or construction objects, comparatively autonomous design fields such as graphic design was investigated with similar research perspectives, and the importance of design brief in terms of consistency and sufficiency found to be incontrovertible [67]. Inadequate design briefs usually stem from the lack of involvement of the graphic designers into the briefing process, and these briefs may evoke frustration which leads to unproductivity [67].

1.1.3 Issues Stemming from Design Methods used in Helicopter Industry

Helicopter industry is largely dominated by engineering disciplines. This can be observed through the fact that systems engineering methods had been used as the principal methods to follow during design and development procedures of decision making and design methods. In terms of design methods, gated waterfall method has been used commonly in the helicopter industry [53], as well as other heavy industry and complex products that require large organizations [68, 69].

The gated waterfall method follows the philosophy of defining strict borders between design phases such as the requirement elicitation phase and preliminary design phase. The meetings or review boards between the stages aim to put an irreversible end to the previous stage, and sustain a linear and sequential way as much as possible. Having the requirement phase as a nearly independent stage before any design work, as if the requirement phase is not a part of it, limits the interaction between those stages. Consequently, poorly written requirements or misunderstood requirements that need further design work to be comprehended face the danger of slipping through the cracks.

1.1.4 Communication Gaps among Decision-Makers

Decision making in the helicopter industry consists of multiple stakeholders. Customer, client and contractor institutions are the institutional representatives of this structure. The number of stakeholders increases when one considers the internal structure of each institution. The contractor company has its own requirements engineers whose main objective is to capture the requirements as accurately as possible. Designers and managers who assess and evaluate the requirements, on the other hand may have their own perspective on this process. As the organizations and the product get larger and more complex, the number of stakeholders increases, and the communication among them becomes more important. Complex products and large organizations become one of the main sources for communication gaps [70]. These issues regarding communications among multiple stakeholders with their costly consequences on end-products can be solved by the contribution of computer supported cooperative work (CSCW) tools [71].

Communication gaps among different stakeholders include the use of language in terms of notation and conceptualization, mostly in technical terms. Technical capability of the participants in a requirements discussion is another issue related to language-based gaps. Therefore the stakeholder selection by the authority inside an organization becomes a major issue that was investigated [72]. Coughlan and Macredie [72] also classified culture, politics and the techniques used in requirement elicitation as potential domains that may lead to communication gaps. Having investigated the dimensions of the problem, possible intervention areas for the solution will be elucidated.

Usage of design-decision support systems in order to prevent this type of inconsistencies during requirements phase or briefing phase was suggested by Zeiler, Savanovic and Quanjel [73] The conflicting nature of decision making at early phases without detailed knowledge or foresight for the design was defined as influence/information contradiction [73]. Even though the concept of influence/information contradiction was investigated for the construction and architecture projects, the reasons and consequences are similar to heavy industry products like helicopters, considering the complexity and length of the projects. It was repeatedly discussed and reported that preliminary design work which may include conceptual sketches, schematics may be required to increase the level of detail and comprehensibility of the design brief [59, 74, 75], and decomposing higher-level requirements into lower-level requirements.

In helicopter industry, systems that have the potential to be used as a design-decision support systems were developed in various institutions such as Deutsches Zentrum für Luft-und Raumfahrt (German Aerospace Center, DLR) to automatize preliminary design engineering processes [76] dealing with higher-level design requirements. Lier et al. [76] have constructed dynamic modeling tools that utilizes empirical helicopter performance estimation approaches in a computer-aided design medium. This tool estimates how geometrical changes on the helicopter fuselage may affect overall performance. Nevertheless, the system developed by Lier et al. [76] was solely proposed on design estimations in order to enhance future design stages, it was not presenting trade-offs or similar decision-supports for the design to be conducted. On the other hand, similar approaches including empirical performance estimation regarding helicopter-level requirements with an automated geometry creation tool can also be used as a design-decision support system (DDSS) [77, 78]. Estimated design solutions for given design specifications can be accumulated in a statistical pool, and the relations between requirements and possible design solutions can be presented to the stakeholders of decision-making processes during requirements elicitation. This type of a system can be used as a supportive decision making tool in order to enhance requirements identification and elicitation processes in the helicopter industry. Nonetheless, Ibacoglu et al. [77, 78], did not consider the perspective difference among different stakeholders and decision-maker agents, for the design of the DDSS.

This thesis will explore the design requirements for DDSS supporting design brief stage in the helicopter development process, minding the communication gaps and needs of different stakeholders.

1.2 Aim of the Study

This study aims to explore the design requirements of a design-decision support system in order to be used for a requirement identification process of a helicopter as a complex, large-scale, heavy industry product. Findings and results of this study aims to support the requirements identification processes of helicopter design. The findings can also contribute to the briefing procedures as they explore some issues faced in the industry. The results of the study will mainly be beneficial for the practitioners in the helicopter industry. Also, the overall insights and exploration of the issues in requirements identification processes contribute to the academic literature on requirements studies in helicopter design.

1.3 Research Questions

The research questions used as guides in line with the aim, are as follows:

- How can the requirements identification processes dealing with higher level requirements in helicopter design be supported by a design-decision support system?
  - What are the issues and problems faced in these processes?
  - What are the design requirements for a design-decision support system which aims to assist the requirements identification?

    * What are the dimensions that the stakeholders (customers, users, clients, contractor managers and requirements engineers) consider about such a system?

  - How can those requirements be satisfied?

1.4 Structure of the Thesis

This thesis comprises five chapters whose content were briefly introduced below.

The first chapter, *Introduction*, briefly explains the problem focused in the study with its major sources that are investigated further. The scope of the study in terms of problem sources was outlined. The aim and the research questions that were used throughout the study were listed.

The second chapter, *Literature Review*, reviews the related literature under several titles. Requirements engineering is a major field, mostly within systems engineering. Design methods that were studied under systems engineering and their usage in engineering-dominated fields are assessed in a broader product design and development perspective. Communication gaps which were studied mostly in software engineering are reviewed, and the usage of CSCW tools are explored. A sample design specification document is analyzed. Computer supported cooperative work literature, especially with a focus on design-decision support systems are explored.

The third chapter, *Methodology*, firstly explains how the design-decision support system used in the study, as an apparatus, works. This system was used during interviews, and tested by interviewees. The interviews were conducted with requirements engineers, managers, designers and engineers inside the contractor company, representatives from client and customer institutions. The questions and the themes followed by those questions are listed.

The fourth chapter, *Findings and Results*, reports the insights about the issues faced in the requirement identification processes in the industry, and feedback regarding the proposed design of the design-decision support system with the major and minor dimensions that were captured during the interviews. Those findings include a qualitative analysis of the interviews. The analysis results are discussed under a separate section.

The fifth chapter, *Conclusion*, concludes the analyses regarding the findings and the dimensions found for the design requirements of the design-decision support system. This chapter draws the borders of the study with the limitations, and proposes recommendations for further research regarding the field investigated in the thesis, and the fields that were excluded.

CHAPTER 2

LITERATURE REVIEW

Decision making in product design and development is interrelated with the conditions of market, design organization, and the product itself. Therefore, the existing studies regarding this thesis are mainly located in the intersections of design methodology, project management and design management.

Implementation of a DDSS has nexuses with the applied design method as it posits itself as a boundary object between several design phases such as requirement phase and conceptual design dealing with numerous stakeholders. This chapter will review the design methods discussed and conceptualized in the perspectives of industrial design, systems engineering, and their intersections. Then the scale will be shrunk onto the earlier stages concerning design requirements as design brief development and requirements engineering with their issues, especially regarding communication issues among different stakeholders. Then, literature review will cover the boundary object concepts in CSCW, and how DDSS applications position themselves in this field. Lastly, there will be a final discussion and conclusion regarding the topics covered in this chapter.

2.1 Methodical Approaches to Product Design and Development

Product development, especially new product development, is a term that deals with a product's whole life-cycle from the market needs to its after-life. Roozenburg and Eekels [4] positioned product design as a part of product development which was described as a more comprehensive process as a development of a new business activity around a new product. On the other hand, product design is used as a broader term that intersects business, marketing and management related stages in product development [79]; consequently, it is not an easy task to separate these concepts from each other.

There are numerous studies about design methods and models from multiple perspectives such as industrial design, architectural design, and engineering design. Every model and approach has both advantages and disadvantages concerning project management and design management. Helicopter industry mostly utilizes engineering design approaches in product design. On the other hand, there are several criticisms [80, 81] about how those methods are structured, and how they cause some issues regarding product development processes. This section of the thesis explores how some of the issues regarding requirement identification are related to design methods and design process models from different perspectives.

2.1.1 Multiple Perspectives on Product Design Methods

Multiple disciplines have contributed to the literature on design methods. Despite having common origins, engineering design and industrial design methods have diverged regarding several topics. Before investigating some process models and their development, it would be useful to mention some of the critics and comparisons between these disciplinary approaches.

Holmes et al. [81] compared the industrial design process with the engineering design process which was taken from Pahl et al. [5]. According to Holmes et al., there is less feedback among different stages of design compared to engineering design. From a broader perspective on the differences between engineering design models and industrial design -as well as architectural design- models; it can be said that, the nature of engineering models are linear and sequential; whereas, the nature of architectural and industrial design models are spiral and cyclic. Engineering models emphasize the sequence of stages during a project; on the other hand, architectural/industrial design emphasizes the cognitive process that the designer is having. Engineering models are more prescriptive, architectural/industrial design models are more descriptive[80]. This may be due to the educational differences and the resulting mindset differences between industrial designers and engineers, where the industrial designers are said to have a more divergent mind, compared to engineers who are said to have a more convergent mind [82]. Similar arguments are stated by Lawson [83] who found architecture education more solution-focused compared to engineering's problem-focused education.

Engineering design methods and industrial design methods were discussed in an alignment where proposals of the two fields were close, synthesis of the solution concepts were defined after the problem analysis phase. This paradigm still continues in engineering design; however, architectural design methodologists started to stress the importance of solution generation early in the design process. Engineering design approaches the problems in a tree-like approach where the problem can be broken down into definite sub-problems. This was also the case in architecture and city planning initially as advocated by Alexander [84]; nevertheless, Alexander rejected the view by stating that "A city is not a tree" [85], and the paradigm changed in city and regional planning, architecture and industrial design disciplines.

Requirement identification approach as well as the definition and attributes of requirements are one of the differences between industrial design and engineering design. This can be observed clearly in the principles of axiomatic design which is one of the renowned approaches in engineering design. Axiomatic design intends to map functional requirements from functional domain into a set of design parameters in physical domain [86]. There are two fundamental axioms in this approach, and the first one requires the independence of the functional requirements [87]. This is a considerably hard assumption to achieve in the perspective of industrial design. Methods discussed in industrial design and architecture often call design problems as wicked problems [88]. Wicked problems consist of interdependent problems and problem sources that may seem impossible to solve at the same time. Rittel and Webber [88], further stated that there is no definitive formula for a wicked problem; directly opposed to what Suh [87] formulated the requirement process in matrix form. It was also stated by Roozenburg and Cross [80] that architects and industrial designers rely more on trial and error procedures compared to engineers who rely on engineering sciences. Architects and industrial designers view their problems as inherently ill-defined; on the other hand, engineers assume that the problems are usually well-defined.

It should be noted that there are various approaches in requirement elicitation and identification processes in different methods discussed in both industrial design and engineering design. One of the approaches in engineering design that studies complex products designed in large design organizations with a special focus on requirement identification is systems engineering approach. This approach divides the product into systems and the systems into subsystems that relate and communicate with each other. Those definitions are dynamic, one design group may address a system which is defined as a subsystem by another group, or as a supersystem by yet a third group [89]. This approach recognizes the interrelated nature of a design problem, and attaches a significant amount of importance to the definition of design problem, and requirement identification processes under the title of requirements engineering.

In addition to the conceptual differences about the nature of the requirements, between engineering design and industrial design approaches, some structural differences were also studied. In the design process classification by Bruce et al. there are sequential, iterative and multidisciplinary approaches to a product design process [90]. Sequential design process is said to be observed in large scale companies, especially engineering companies. There are distinct functional departments with their own expertise and hierarchy. Those departments work as if they are in a relay race [91]. The project goes sequentially: concept development; feasibility testing; product design and tooling; pilot production and full production. Winstanley and Francis [92] stated that this structure copes badly with modern pressures on rapid product development. Their survey of engineering companies showed that the division prevented communication between different areas. Ineffective communication may result in impractical or expensive designs being thrown over the wall to other departments for them to sort out. Iterative and multidisciplinary approaches, in spite of the connotation, are both iterative processes. Iterative process imitates the volleyball game where there are continuous returns between departments. There are feedback interfaces between departments for correction or re-evaluation. This type of approach is widely discussed in industrial design methods [80]. The iterative approach was asserted to be time-consuming if the communication between the departments is poor. The third approach called multidisciplinary approach was defined similar to a rugby game, where there are still iterations like in volleyball, but with good communication and a common goal. This approach can be discussed aligned with design thinking communities where different disciplines take simultaneous roles in the design process.

2.1.2 Review of Models of the Design Process

"All models are wrong,
but some are useful."

George E. P. Box, 1987
[93, p. 424]

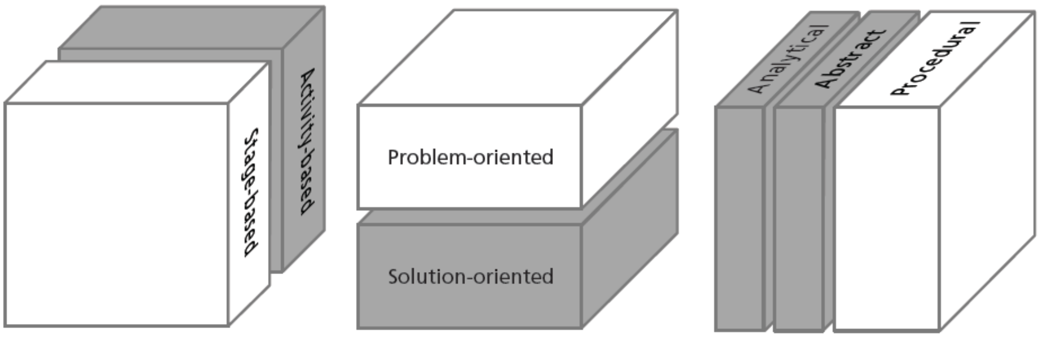
Requirement identification processes are affected by the design process models used according to how it is defined and placed inside the design and development process. Therefore, this subsection investigates some of the process models introduced with different concerns, and how those models approach the requirement identification in product design. The models are explained and investigated following certain taxonomic approaches.

2.1.2.1 Taxonomies of Design Process Models

Design processes have been classified in numerous ways, and studied in the field of design methodology. The classifications are structured based on working modes, strategies of the active subject, type and attributes of the object, etc. This subsection will provide a brief summary of different classification types, and then review some of the models which will be called phase models.

Strategies during the early stages of the design process were studied by von der Weth [94], citing Fricke's classification of the design process with respect to modes of working [95]. According to Fricke, there are step-oriented and function-oriented modes of working. The step-oriented strategy is heavily based on Pahl and Beitz's [5] model. This strategy follows particular steps describing design activities. The emphasis on each step may be adjusted according to the task at hand, or the product to be designed. The function-oriented strategy, on the other hand, divides the design problem into sub-problems; then, puts them in an order of importance. The most important sub-problem is solved first, and other solutions aiming to solve other sub-problems are adjusted accordingly. This requires a sequential approach that may lead the function-oriented designer to make important decisions early in the design process, without a detailed analysis of the problem [94].

Wynn and Clarkson [1] asserted that there are multiple dimensions while classifying design models. They conceptualized those dimensions mostly in dualities. The dimensions are stage vs. activity-based models, solution-oriented vs. problem-oriented literature, and the dimension where abstract, analytical and procedural approaches are classified. This taxonomy is visualized as in Figure 2.1.



(a) Activity-based vs. Stage-based

(b) Problem-oriented vs. Solution-oriented

(c) Analytical, Abstract, and Procedural

Figure 2.1: Wynn and Clarkson's Taxonomy of Design Models [1, p. 37]

2.1.2.2 Activity-based vs. Stage-based Models

Classification based on if the process is stage-based or activity-based was defined by Blessing [96] . This dimension is based on Hall's two dimensional perspective [97] where one of the dimensions is the phase-based structure of the product life-cycle, and the other one is the iterative problem-solving process[1](Figure 2.2), and Asimow's contribution which conceptualizes the morphological dimension of design [98]. Purely stage-based activities offer a linear sequential process across stages. Only iteration-like loops may happen as feedback loops between stages. On the con-

[1] This two dimensional systems engineering approach will construct the base of which the consensus model in engineering design is based on [80].

trary, purely activity-based models stipulate a cyclic model where there are no predefined stages. Blessing also defined combined models of these two; for instance, there may be well-structured iterations, like a coil spring, inside each stage. Those iterations may be formed via a stage-based approach to get a more converged design solution as the stages pass, like a screw.

	Steps of the Fine Structure	1	2	3	4	5	6	7
	logic → / Phases of the Coarse Structure (time ↓)	Problem Definition	Value System Design (develop objectives & criterion)	Systems Synthesis (collect & invent alternatives)	Systems Analysis (deduce consequences of alternatives)	Optimization of ea Alternative (iteration of steps 1-4 plus modeling	Decision Making (application of value system	Planning for Action (to implement next phase)
1	Program Planning	a_{11}	a_{12}				a_{16}	a_{17}
2	Project Planning (and preliminary design)	a_{21}						
3	System Development (implement project plan)							a_{37}
4	Production (or construction)				a_{44}			
5	Distribution (and phase in)							
6	Operations (or consumption)	a_{61}						
7	Retirement (and phase out)	a_{71}	a_{72}				a_{76}	a_{77}

Figure 2.2: Hall's Systems Engineering Activity Matrix [2, p. 157]

Modeling the design process using stages also requires determinant definitions and boundaries of stages. This definitive approach conceptually limits the required amount of interaction between stages in a design activity. Blessing's combination approach [96] can be helpful considering the complexity of a creative activity and project management requirements fostering stage-based approaches, as it was emphasized in Hall's vertical axis [97] in Figure 2.2.

2.1.2.3 Problem-oriented vs. Solution-oriented Models

Another framework about the classification is solution-oriented approaches and problem-oriented approaches as it can be seen in Figure 2.1b. This framework is commonly used; since, it also suggests and implies many components of different design philosophies concerning morphological and disciplinary differences. In a solution-oriented approach, a solution is proposed initially, and modified as the boundaries of the design problem are explored hand in hand with the design itself. In comparison, a problem-oriented approach explores the problem in detail before any solution [1].

This difference is observable between the educational programs of architecture disciplines and engineering disciplines [83]. Although, engineering education and science-focused education yields an expectation for a problem-focused approach, issues such as problem/solution bias was discussed as problems in requirement development process [21]. This contradicts with the focus on problem analysis in requirements engineering and systems engineering (Section 2.1.3 and Section 2.2.2). Both extreme points in this dichotomy can affect the design process in different manners. Purely problem-oriented approach may result in the breakdown type analysis of the problem overlooking the creative procedure of design in order to analyze the problem. On the other hand, purely solution-oriented approaches may result in biases in the creative process as fixations to initial design solutions. This bias may articulate to the patron-client relationship in helicopter industry as solution biases from the client or the customer, affecting and directing the design for their behalf.

2.1.2.4 Analytical, Abstract, and Procedural Models

The third set of categories proposed by Wynn and Clarkson [1] is classifying design processes as abstract approaches, procedural approaches, and analytical approaches (Figure 2.1c). Abstract models are said to be typically activity-based models with a high level of abstraction. These models can be solution-oriented and problem-oriented. Common examples of solution oriented abstract processes are Darke's problem solving model in architectural design [99], March's production-deduction-induction (PDI) model [100]. Darke conceptualizes three creative phases, namely generator, conjecture and analysis. It was asserted that the designer generates multiple solutions, then tries to reduce the possibilities considering conjectures. This leads to a better understanding of design requirements in which the solution is tested accordingly. March's model emphasized the highly cyclic nature of the creative process. The three phases of PDI do not lie in a sequential or linear order, rather there is a triangular relation among them. In production, data models are used to describe design; in deduction, design theories are utilized to predict the performance of each design; and in induction, design characteristics are evaluated. Those phases are not necessarily staged in this manner. Induction may lead to deduction, or production.

2.1.2.4.1 Abstract Models

Abstract models can also be problem-oriented such as Jones' design process [101] and Cross's model of design process [102]. Problem-oriented models in abstract approaches are typically linear. Jones identified three renowned phases of design as analysis-synthesis-evaluation. Analysis phase includes the analysis studies on the problem itself, before entering into creating design proposals. Synthesis phase is the phase where multiple design alternatives as a solution to the problem is created, and in the evaluation phase, the proposals are assessed and evaluated, critically. Cross's model is identified within four stages, namely exploration-generation-evaluation-communication. Exploration phase is similar to Cross' analysis phase. It is where the ill-defined problem field is explored. Generation phase is where the possible design solutions are generated. In the evaluation phase, solution alternatives proposed in the generation phase are evaluated according to the design brief and constraints. There may be some re-design required after this phase; therefore, there is a feedback loop between evaluation and generation phases. The fourth phase, communication, conceptualizes the design communication to the manufacturing process or some system-level integration to some other systems.

Abstracts models can be said to be aligned with activity-based approaches, since they remain distant from creating distinct and determinant stages. On the other hand, they lack the detail to be implemented in large design organizations where project calendars are monitored by project management professionals. Considering the stakeholder structure of the helicopter industry, this monitoring is also conducted by the client and the customer. Those stakeholders requires detailed information about the current situation of the design project in order to ensure funding and non-productive objectives they seek. Therefore, procedural models are preferred more, and they were suggested by some state organizations in the case of USA (Section 2.1.3).

2.1.2.4.2 Procedural Models

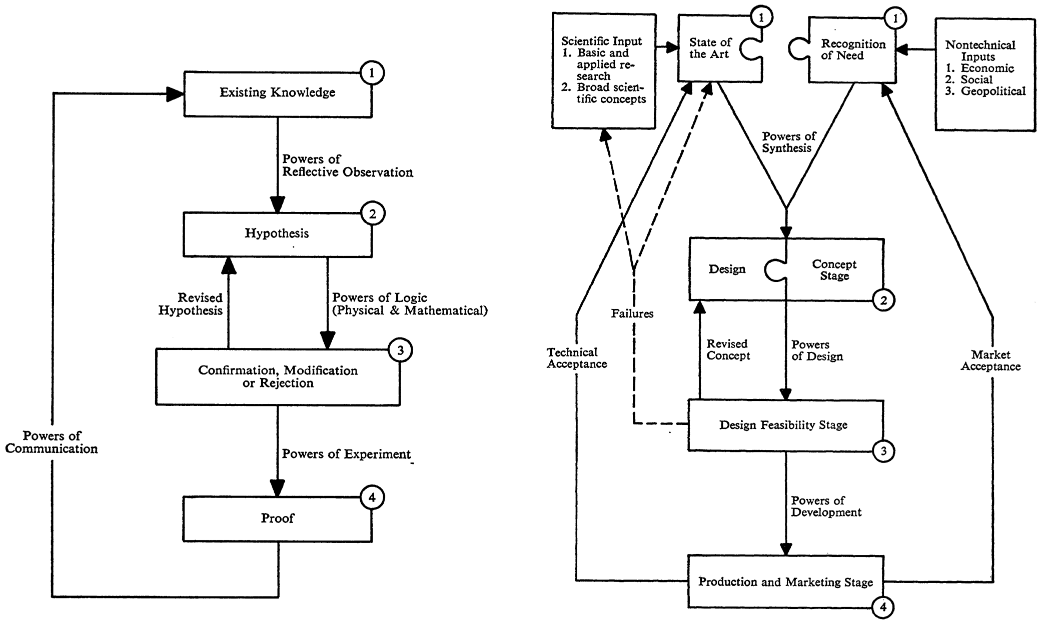
Procedural approaches are said to be more strictly structured compared to abstract approaches. They are more prescriptive, focusing on specific audiences and industry sectors rather than being descriptive [103]. Procedural approaches are further divided into two sub-categories, namely design-focused models and project-focused models. Design-focused models are asserted to be focused on the product design aspect of a design process; on the other hand, project-focused models focus management of the design process.

2.1.2.4.2 Design-focused Procedural Models

Design-focused procedural models typically present certain, structured stages of design activity as steps needed to be taken in order to progress through the design process. Those models are typically stage-based models focusing on the product design aspect of the product development process. Roozenberg and Eekels have identified a typical sequence of function-function structure-solution principle-embodied design with documents marking a *phase* in the design process. Hence, these types of design process models are also called *phase models* [4]. The phase models share similar major phases such as clarification of the task, conceptual design, embodiment design, and detail design as also pointed out by Roozenburg and Cross [80]. This structure of the design process model is said to have achieved a consensus. Hence, the general view of those models is called the *consensus model*.

- **McCrory's Design Model Based on the Scientific Hypothesis Testing**

One of the motivations to create design process models is to scientify the design activity. McCrory [3] generated a design model based on the scientific hypothesis testing. The scientific method Figure 2.3a starts from existing knowledge, and a hypothesis is asserted stemming from this existing knowledge. With the powers of logic, conformation, modification or rejection of the hypothesis occurs. Then, using the powers of experiment, a proof is introduced which will be added to the existing knowledge. McCrory's design method Figure 2.3b makes analogies between the existing knowledge and state of the art. There are certain deficiencies in the state of the art which are the needs. Recognition of the need comes from both market and nontechnical inputs like economic, social and geopolitical considerations. Like the powers of logic, with the powers of synthesis, design or designs are generated. Then, with the powers of design, the concept is tested regarding its feasibility. Similar to the powers of experiment, utilizing the powers of development, the design is produced and marketed. The marketed product then adds knowledge to the state of the art and newly generated needs.



(a) Scientific Method (b) Design Method

Figure 2.3: McCrory's Design Model in analogy with Scientific Method [3, p. 160-162]

- **Evans' Spiral Model**

Unlike the sequential or quasi-sequential design models that propose that each stage is visited once, Evans [104] proposes a spiral-like model where the stages lie around a spiral, and the process follows those stages repeatedly. Evans' model further propounds that design cannot be achieved through a linear process; by giving the example of bridge design where the structure should be designed to carry a certain weight, but the weight is unknown unless the structure is designed. This is a typical issue in vehicle design where weight is one of the most fundamental parameters. In helicopter design, the dynamic systems consisting of the rotors and powerplant mainly targets to produce enough thrust to carry the weight of the helicopter. On the other hand, those dynamic systems themselves are one of the major items in overall weight of the vehicle. Evans conceptualized the spiral model via ship design. Major design stages considering significant design parameters such as general arrangement, displacement and trim, form coefficient, floodable length, and structural design are placed as a circle. Then a spiral moves from one station to another, as well as shrinking its diameter. The stages are visited again and again; however, the spiral converges to a point where it is the center of the circle, and it is the final design where the iteration halts. The diameter of the spiral also symbolizes the uncertain nature of the design parameters, and as the diameter shrinks, design variables are refined, gradually. Evan also stated that the effort needed to improve the design process increases as the design converges.

- **French's Model**

In contrast to Evan's spiral model, French proposed *a quasi-sequential stage-based model* [105]. French's model acknowledges market needs as the initiation point. With the analysis of the market focusing on the analysis of the problem, a problem statement is proposed which becomes the initial data for the conceptual design stage. Several alternatives are generated in conceptual design. Those alternatives may create feedback, for the analysis of problem, that enables a feedback loop between those stages. An alternative is evaluated and selected for the embodiment procedure where the abstract concept is solidified. This stage may also generate feedback for the analysis stage. After the embodiment, detailing work can be conducted for the manufacturing process, and the overall output like technical drawings *et cetera* are created.

- **Roozenburg and Eekel's Basic Design Cycle**

French's model can be regarded as a reference frame for other phase models, or as an initial step to deduce to the consensus model. Another example may be Roozenburg and Eekel's basic design cycle [4], although its intention was to propose an attempt to re-integrate the two different types of models [80], namely engineering design and industrial design. The fundamental nature is deliberate, in order to set a frame of reference for the discussion. The basic design cycle is derived from De Groot's empirical cycle [106] as the basic model for problem-solving[2]. This cycle is adjusted to design problems which is named as the basic design cycle. The empirical cycle follows the phases of observation-supposition-expectation-testing-evaluation. The problem-solver observes the situation in which the subject acts. Then one supposes the actions that might solve the problem. The effects of the supposed solution are expected effects on the problem. The expected effects are tested and compared with the desired outcomes. Finally, the result of this thought process is evaluated. These phases occur like a spiral, in a cyclic manner. The basic design cycle asserts that every design activity follows the phases defined in this cycle, and the cyclic nature of the process progresses as the solution and problem increase spirally. It begins with a function to be analyzed. The analysis results in the criteria to be met with the design solution. Synthesis step generates design alternatives, and ends with a provisional design. This provisional design is tested in the simulation phase, and the expected properties are gathered as an output of this stage. Then, they are evaluated according to the criteria obtained before. As a result of the evaluation, the value of the design is determined in order to make a decision. The decision may be going back to analysis or synthesis stages. If the decision is made in a confirmatory manner, then the design is said to be an approved design. The schematic of the basic design cycle can be seen in Figure 2.4.

The basic design cycle is a broadscale model as it is applicable for every function in a system or subsystem. Abstract definitions such as function and value of the design make it broadscale as it can be tailored to specific instances or industries. On the other hand, it lacks the project and business aspects of design as it is typical among design-focused procedural models.

[2] The empirical cycle is also stated to be the foundation of problem-solving model in systems engineering [4].

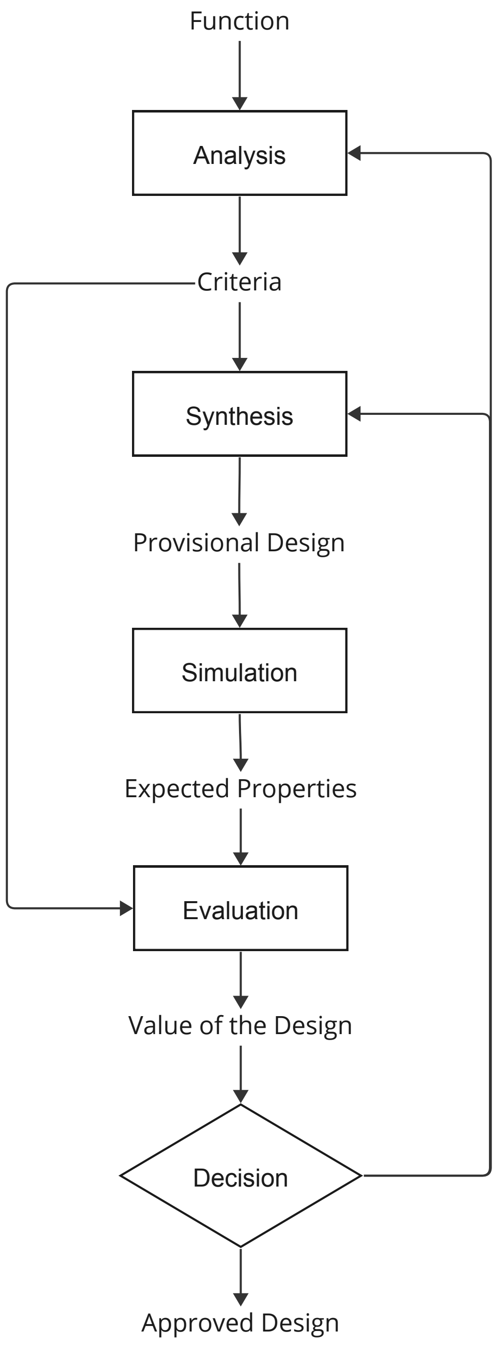


Figure 2.4: The Basic Design Cycle (Reproduced from [4, p. 88])

- **Hubka's General Procedural Model**

A detailed model to the contrary of the elementary approach of the basic design cycle, Hubka [107] proposed a model called the general procedural model. This model starts with the problem assignment. This assignment is elaborated and further clarified into a set of design specifications. There is a two-staged conceptual design phase occurring after the foundation of design specifications. The inner stages of conceptual design are establishing functional structure consisting of technological principle and technical process, and establishing concepts dealing with basic arrangement. Both these stages are evaluated and verified according to both design specification and problem assignment, if necessary. The optimal concept is obtained after the conceptual design phase. Third major phase is laying out. This stage also has two inner stages, namely preliminary layout and dimensional layout. During the preliminary layout stage, form-giving and partial dimensioning are conducted as well as deciding on the materials and manufacturing methods to be used. In the dimensional layout stage, those preliminary studies are progressed in higher resolution; then, there is a release for detailing. The fourth and final phase is called elaboration, completing the dimensioning process as well as material selection. Tolerances are set for manufacturing, and assembly procedures are decided. The final product of the model is machine system representation. Hubka placed those stages in a spiral form with different emphasized design activities at each stage, and each stage has different considerations as its internal dimensions.

Hubka's model [107] can be said to be focusing on mechanical design aiming to manufacture certain parts of a system. Dimensionining operation is placed at the center with manufacturing and assembly operations were given certain amount of emphasis. The spiral form and the detailed description of conceptual design are important aspects for emphasizing requirement definition process. However, the following procedures may be insufficient to be implemented in higher level design work with low fidelity design solutions where manufacturing is usually omitted. In those design efforts, the spiral can be concluded with the conceptual design without any dimensioning.

- **Dym and Little's Prescriptive Model**

Following very similar fundamentals to other procedural methods, Dym and Little [108] have proposed a five-stage prescriptive model in a spiral manner. In spite of the spiral investigation, each stage has definite inputs and outputs to be covered as a checklist. Those stages are problem definition, conceptual design, preliminary design or embodiment of schemes, detailed design, and design communication. Problem definition is about framing the problem by studying the client's objectives, constraints and principal functions. Conceptual design aims to transform customer requirements into engineering specifications. It has three inner parts of analysis. These are objectives analysis, constraints analysis and functional analysis. The output of this stage is stated as a chosen design; however, it was noted that two or more designs may be produced in order to prevent an early commitment or fixation to a design idea. Preliminary design and detailed design stages are identified as more technical stages compared to conceptual design's highly creative nature. These are similar to Hubka's preliminary layout and dimensional layout, respectively. In the detailed design stage, standards, databases, handbooks and catalogs are used in order to finalize the manufacturing details. The final stage, design communication, consists of reporting and presenting the final design to the client. The spiral nature of their model was justified by acknowledging the linear models are in contrast to what happens in practice. Design unfolds as the phases are completed, and they are referred-back regularly.

Comparing the prescriptive model with Hubka's model [107], the prescriptive model can be said to capture the reality observed in practice. Design communication is an emphasized procedure that makes the prescriptive model authentic. The outcome does not have be manufacturing plans or assembly plans as they were in Hubka's model. The relation between the highly creative nature of the conceptual design with requirements development is also appearent in the prescriptive model.

- **Pahl and Beitz's Model**

One of the most referred design process models is the model proposed by Pahl and Beitz [5]. The model was referred as *operational guidelines for action*, instead of a generalized design process model. It was acknowledged that it must be adapted to specific situations.The sequential form of the model was set as a fundamental attribute; however, it was noted that sequences may be adapted and they should be flexible according to particular design cases. The sequential form was not defined as purely sequential, it also includes iterations wherever it is needed. Nevertheless, it was stated that the amount of iterations should be minimized in order to achieve an efficient design process. The principal tasks involve planning and clarification of the task to identify the required functions, elaboration process on principal solution, construction of the modular structures and documentation. Those tasks were based on Verein Deutscher Ingenieure (The Association of German Engineers, VDI) Guidelines 2221 [7], and 2222 [6]. Another division of phases was introduced as planning and task clarification, conceptual design, embodiment design and detail design. Planning and clarifying the task is the intermediate step between a marketing team or other specialized team planning the business and designers involved in direct design. The design team elaborates and specifies the requirements of the design project in this phase. During the conceptual design phase, a principal solution is created. There may be more than one principal solution, and some feedback loops may be needed for the clarification phase. Embodiment and detail design phases are similar to what was discussed in other procedural process models. It should be noted that feedback loops may be needed at every stage as they were indicated with arrows at every stage. There are also tasks conducted nearly every phase such as information gathering. Those tasks and phases are also covered with main themes of the design work conducted throughout the process. These are optimization of principle which is the main theme of the earlier phases from clarification to embodiment design, optimization of layout that is emphasized during embodiment design and detail design, and optimization of production which is prioritized during the late stages of the process. The overall schematic of the proposed model can be seen in Figure 2.5.

- **VDI Models**

Most of the phase models describing a design process aims to bring a systematic approach. There have been numerous studies with the name systematic design by VDI, and they were published as guidelines. VDI 2222 guideline was published in 1973 by the design methodology committee whose members include Gerhard Pahl and Wolf-

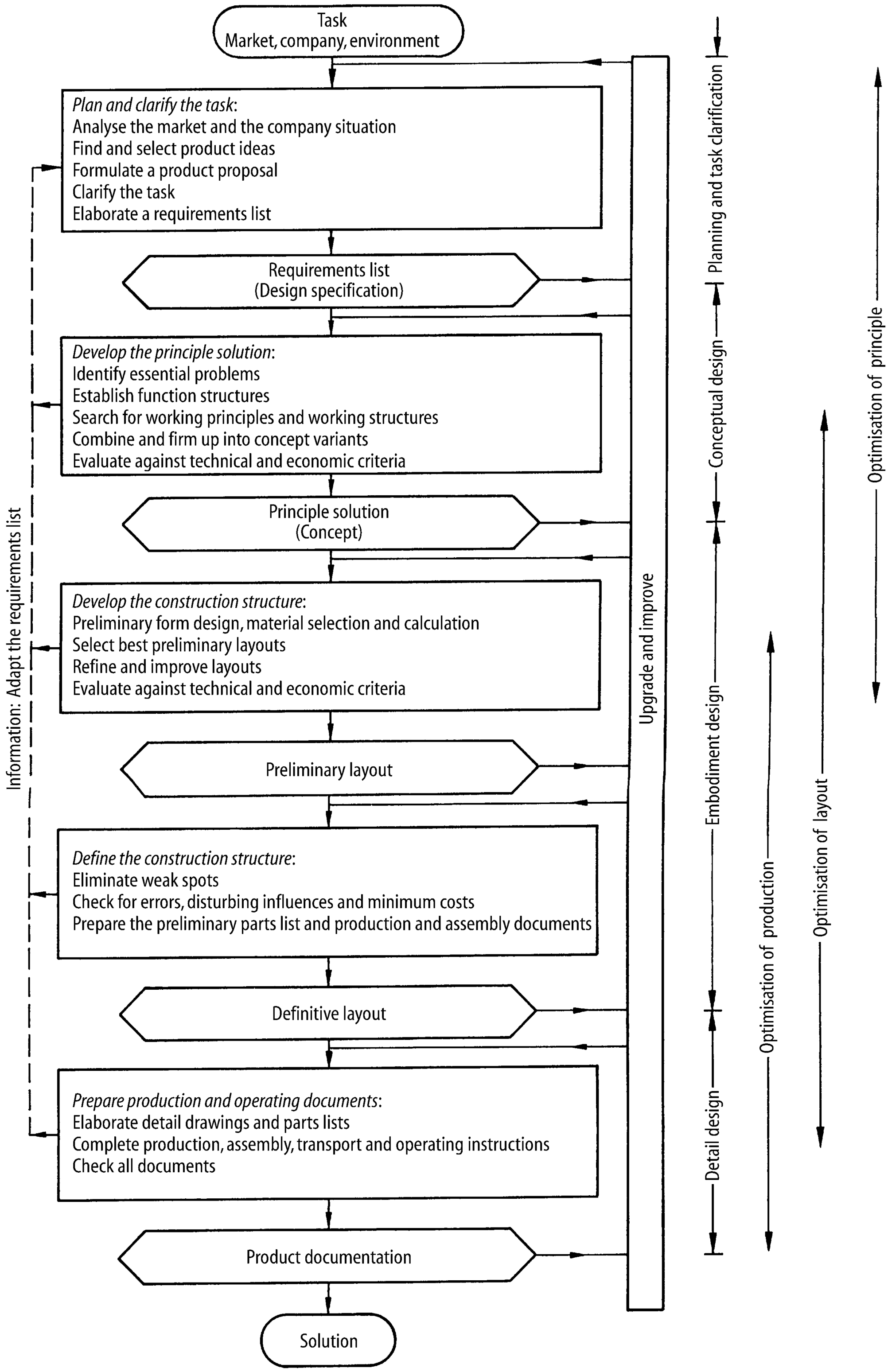


Figure 2.5: Steps of the Planning and Design Process by Pahl & Beitz [5, p. 130]

gang Beitz. VDI 2222 guideline constructs the model including considerations on problem-solving [8]. The phases of conceptual design, embodiment design and detailing involves their own convergence-divergence type of design models [4]. Those approaches were visualized as in Figure 2.6. This guideline was replaced by VDI 2221 in 1993 with the advancements in technology such as computer aided design (CAD). VDI 2221 guideline is based on systems engineering approach [8]. Interrelations among the results of the stages are emphasized. The visualization of VDI 2222 can be seen in Figure 2.7. Stage and phase structure of VDI 2222 is similar to that of VDI 2221 in Figure 2.6.

VDI models and Pahl and Beitz's model represent the main stages repeated in the consensus models as conceptual design, embodiment design and detailed design. Pahl and Beitz's model also have a definition of conceptual design regarding where it starts and where it ends. Conceptual design was conceptualized distinctly from requirement development. It should also be noted that, although clarifying the task was given a certain amount of importance, requirements development was not mentioned as apparent as it was in Dym and Little's prescriptive model [108]. The iterations and possible loops were schematized at every stage. This models can be said to focus on the conceptual design phase, and they lack focus and detail between embodiment design and detail design including the detail difference between those stages.

After the examination of those models, two additional models are also examined. These models have some transitional aspects from being design-focused to being project-focused.

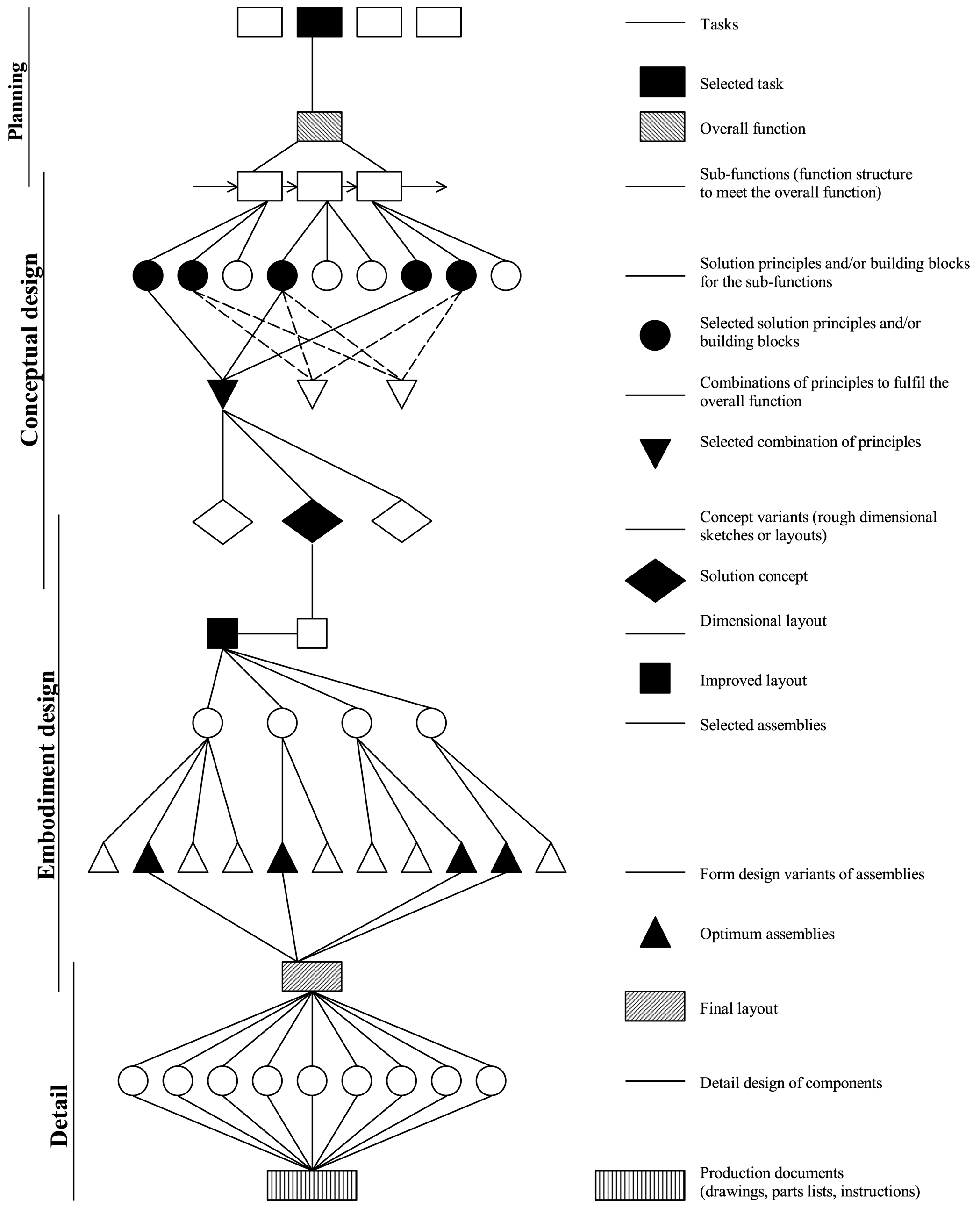


Figure 2.6: Divergence-Convergence in VDI 2222 [6] as cited in [4, p. 110]

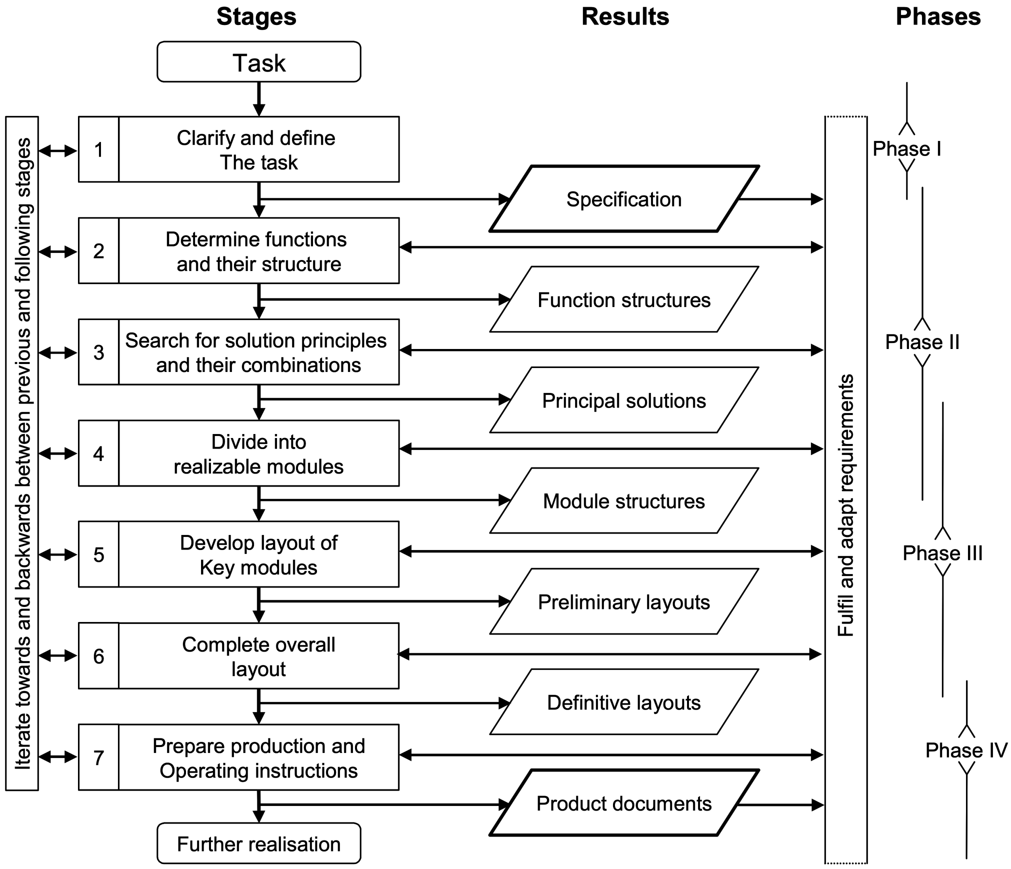


Figure 2.7: Schematic of VDI 2221 Guideline [7] as cited in [8, p.49]

- **Pugh's Method of Total Design**

Design-focused procedural models are said to have the greatest emphasis on the design activity where the tangible product's attributes are being discussed, drawn, or prepared to be manufactured. Other considerations including market needs, organizational needs and external factors are usually included in project-focused models where the product design is seen as more like a business model. It should be noted that the transition between a design-focused model and a project-focused model is not an abrupt one; rather, it would be wiser to define a transitional category where both attributes of the categories can be observed. One of the most discussed methods which can be studied as a transitional model is Pugh's method of total design [109]. Total design gives great emphasis to market analysis and the generation of the product design specifications. The narrow definition of design activity[3] discussed in most of the design-focused procedural models were named as *partial design* opposed to total design. There are six main stages starting from the market stage which leads to specifications stage. Conceptual design and detail design occurs after the product design specification document or the brief is generated. The brief acts as the control for the design activity as a whole. The activity between conceptual design and detail design is considered as the main design flow. Manufacturing takes place after the detail design phase, and the final stage is to sell the product. Each phase has its own iteration structure and sub-elements to follow. Those tasks were sorted according to an importance order. The design activity model described the design process in a three dimensional way to make the internal processes and elements visible which can be seen in Figure 2.8. Pugh further acknowledged the business factors that affect this model by providing more inputs such as finance, purchasing and sales [9]. Those types of information are also gathered at the end of the design process regarding technology and technique. Those are utilized for the redesign or the following design process. The business design boundary that encapsulates the inner three dimensional structure can be seen in Figure 2.9. The business related factors were schematized as they cover every aspect of design activity as an outer capsule.

Acknowledging multi-dimensions in design process with its external factors such as the business design activity in Figure 2.9, makes this model broadscale. Requirement identification process can be said to be modeled within specification stage before concept design. This also shows the interaction between market analysis and concept design, having the specifications as the interface. The influence of the outer effects on these process are acknowledged but lacks detail as they have interrelations among each other.

[3] One of the reasons why design was defined in a way that excludes many other aspects regarding manufacturing and business-related activities, is that British Standard 7000 had proposed a three-stage design process model: design-production-operation [110, 111]. In this model; design's result is manufacturing instructions, and production is a separate activity than design.

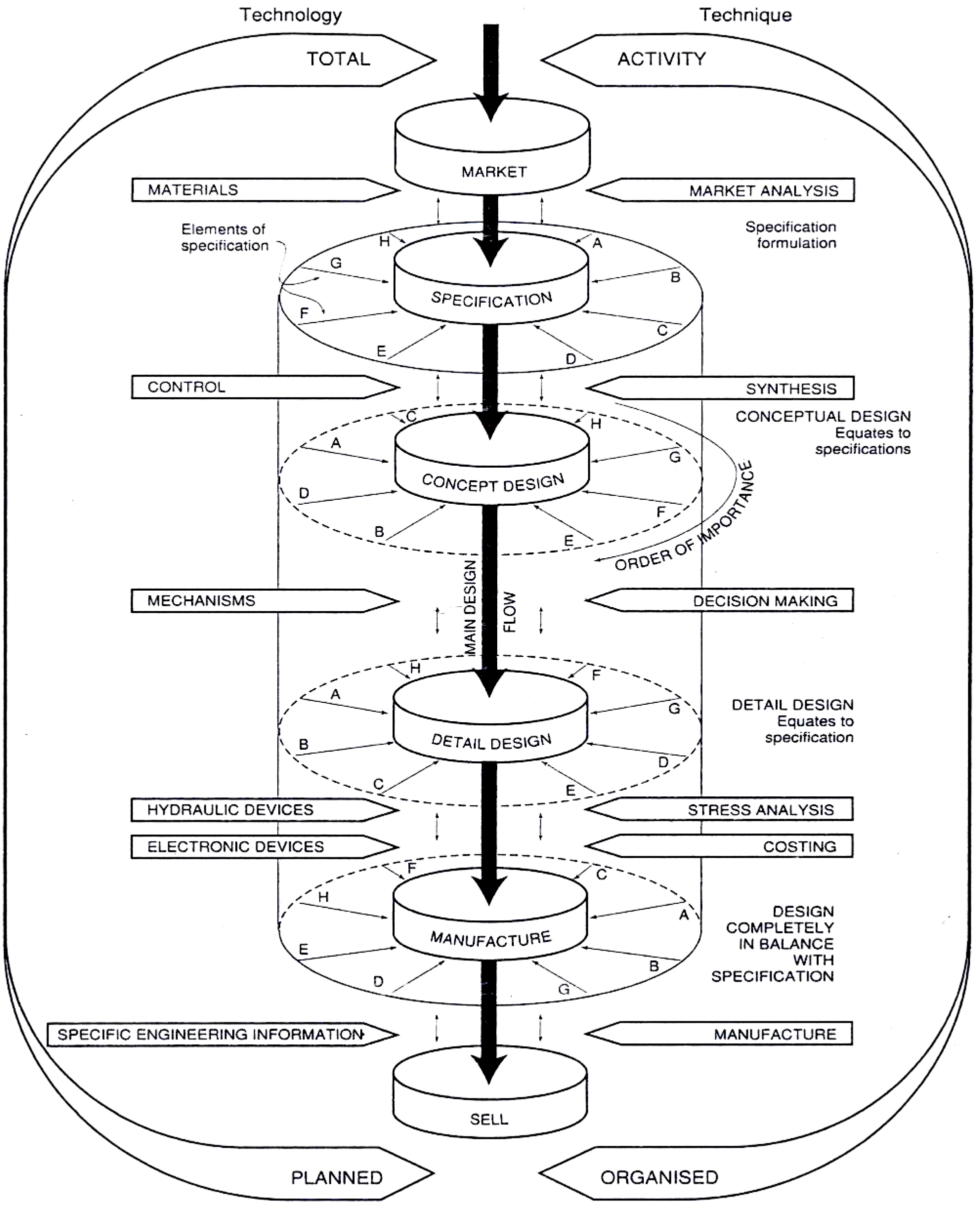


Figure 2.8: Pugh's Design Activity Model [9, p. 170]

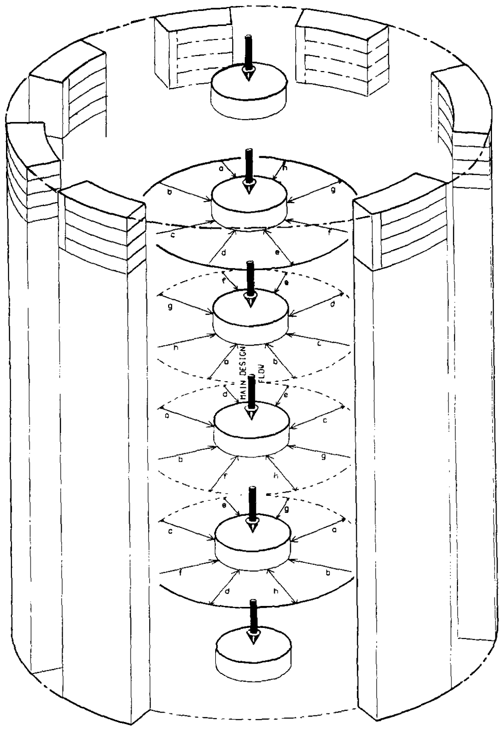


Figure 2.9: The Business Design Activity Model [9, p. 172]

- **Ullman's Mechanical Design Process**

Phase models can also be expanded on sub-phases that are internal phase models of each phase in an overall model. An example was proposed by Ullman which can be seen as a transitional model between design-focused procedural models and project-focused procedural models. Ullman's model [20] can be perceived as a model which is very similar to a generic waterfall model paying more focus on the earlier phases. There are three stages before the conceptual design phase, namely; product discovery, project planning and product definition. Product development and product support stages are defined after the conceptual design stage. Ullman named this model as the mechanical design process or the six-phase design process. Market and business conditions are mentioned as an essential part of the need for design; hence, those factors were also included in the design process. Technology push, market pull and product change were listed as primary sources for design projects. The needs are observed and product ideas are generated in the product discovery phase. There is an important decision point in this stage which is the selection of the project to work on. This may require further knowledge to be gathered or produced for the product; therefore, sometimes it is placed further in the design process, after conceptual design. Project planning stage acknowledges and emphasizes the business side of the design process. This stage and product discovery stage are main differences that make the model positioned in a transition between a design-focused approach and project-focused approach. Since design is conducted within limited resources, the planning and allocation of the resources are also a part of the design. Ullman asserts that forming the design team is also a part of this planning phase. Costs are estimated and the tasks to be fulfilled and the sequence of them are generated as the output of this phase. Product definition stage is similar to the requirement identification phase as mentioned in most of the phase models. This stage covers identifying customers, generating the customer's requirements and the transition of these requirements into engineering specifications. The targets that will be considered for the quality of the design are set in this stage, too. Conceptual design stage is defined with an inner feedback loop with a decision node. After generating concepts and evaluating them, a decision whether or not the concept will become the principal concept is made. The design plan is refined according to the selected concept, and the final approval is made considering the plans set in the previous stage. The decision node may suggest refining specifications, proceeding to product design, or even, canceling the project. The detailed design stage is called the product development phase in Ullman's model. This definition is a narrow one; since, product development is usually referred to a much wider context which embodies the other stages, too. Ullman also points out that, there are commonly bad practices in the industry in which the design process starts with this product development stage without conducting the prior stages emphasized in the model. The output of this stage is ready-to-be-manufactured documentation of the product. Supporting vendors and customers, solving possible operational problems with design interventions are mentioned as the product support. Retirement of the product was positioned as the final stage of this process.

2.1.2.4.2 Project-focused Procedural Models

Apart from design-focused process models, there is another sub-category inside procedural design process models which is named as project-focused models. These models approach design more like a business activity and acknowledges the marketing, risk management and product planning activities. The project-focused literature is also treated as product development processes, since it also considers distribution and sales [4]. As a process starting usually from human (user) and ending with human (customer), it can also be regarded as an activity that encompasses product, process, people and organization [109].

In project-focused models, manufacturing and marketing processes are given relatively higher emphasis, compared to design-focused models. A typical example of this phenomenon is constructed by Andreasen and Hein [112] as integrated product design. In integrated product design; sales, product design and production are three simultaneous processes that start from *the need*. Sales and production processes have their own stages similar to design having investigation and preparation phases.

- **Archer's Product Development Programme**

One of the most prominent design process models in this category belongs to Archer [113]. Archer's model incorporates a company's strategic plans in a market in which it wants to compete. This approach emphasizes the differences regarding the initial stimuli that start the design process. This initial stimulus was appointed as the need or the problem in most of the design-focused process models. In Archer's model, the company or the business' policies in the market plays the initiator role. There are six main stages, and they are strategic planning, research, design, development, manufacturing-marketing setup and production. In strategic planning, a policy formation takes place, including timetables and budgets. In the research phase, there are two stages: preliminary research and feasibility study. Problems are observed and needs are defined in the preliminary research stage. Market studies and consumer behavior analysis are placed in this stage. Technical and financial feasibility analyses and risk analysis are conducted in the feasibility study stage. Initial solution proposals are outlined in this stage. Design phase after the research phase consists of three stages, namely design development, prototype development and trading study. The design development stage resembles the conceptual design stage that was discussed in design-focused models. Specifications were studied in order to estimate performance of the product as well as the cost. Prototype development aims to conduct user tests with appropriate prototypes that need special design effort. Trading study creates feedback for the initial market studies. Market studies are reappraised according to the estimations gathered in terms of both cost and performance. Revisions are included in this stage. This stage is a junction between the marketing process and design process. The development phase consists of production development and production planning. These stages are similar to preliminary or embodiment design and detail design that was defined in design-focused procedural process models. Production plan includes the preparation of marketing plans, and designing production media such as jigs and tools. This stage is an intersection of marketing and production processes. After the development phase, the manufacturing-marketing setup phase takes place. In this phase, marketing and production processes are dominant. Construction of trial batches and testing are situated in the tooling and marketing preparation stage. The last phase is named production, and the stage affiliated with this phase is production and sale. In this phase, commence production and sales are conducted. Feedbacks for the second generation design are gathered from the user, market, repair and maintenance.

- **Hales' Engineering Design Process**

Design processes are said to be under the influence of numerous factors. Those factors might be in different influence scales, such as corporate, micro-economic and macro-economic scales. Hales and Gooch [10] provided a layered structure in which those influences act in design, project, management, company, market and environment. Those scales are under the influence of personal, project, corporate, microeconomic and macroeconomic levels, respectively. At the macroeconomic level; cultural, scientific and random influences are listed. Social issues, political climate, legal requirements, environmental concerns, and luck are typical macroeconomic level influences. At the microeconomic level, market, resource availability and customer are considered as influences. Those can be affiliated with the market studies, and competition in the market regarding supply and demand balance. At the corporate level, influences that affect the whole design and development process are listed as corporate structure, corporate systems, corporate strategy, shared values among stakeholders, management style, management skills of the managers, and the management staff themselves regarding their commitment, motivation and confidence.

Hales' model (Figure 2.10) can be analyzed in different scales and levels. There is a concentric[4] structure where the inner loop is about design and production. Activities conducted and the associated outputs are defined. Those activities and outputs are similar to the processes of consensus models. There are other inner loops such as marketing that are defined at the same level with engineering and design. Focusing on the design loop, the initial stage is called the task. This task is gathered from the brief which is at the project level, and the brief is structured by competition which is at company level; above design, project and management levels. Hales and Gooch's engineering design process acknowledges the difference between a customer and a user. Their intersecting relations are also incorporated into the model, mostly on the market level. The market is also shaped by some external influences discussed before.

The interrelations of the external factors are also shown to some extent. Layers imply some kind of hierarchy and encapsulating relation among them. Organizational issues such as personnel are also acknowledged compared to other project-focused process models.

- **The Consensus Model**

Most of the procedural models discussed up to this point had a problem-oriented approach with a linear progression through certain stages. These are similar attributes that are said to form the consensus model. This approach is utilized by numerous large-scale industrial corporations [114]. Another similarity in most of the mentioned models is to have pre-defined gates between the stages. The outputs of the gates are aligned and shaped to have compliance with industrial standards such as ISO 9000 [115]. The compliance of these standards are obligatory for companies to become an accredited supplier [1]. In spite of the obligations and commonness in the large-scale industrial market, the advantages of the gates between stages were questioned by Cooper [114]. The system and the process may become inefficient in a sense that some processes may stop if a necessary stage is unfinished. Cooper [114] defined a third-generation process with fluid stages that overlap each other with conditional

[4] Another usage of the term concentric can be seen in Roozenburg and Eekels [4]. They have defined the product development processes as *concentric development*.

decisions at gates. The systems should be more flexible for better resource management.

Selected procedural models were examined presenting the historical relations and evolution steps from basic models to more complex and broadscale models intended to include more concerns about design such as project management and business relations. Procedural models can be said to follow mostly a stage-based approach in defining the procedures in design process. The evolution of the stages being defined in a determinant fashion made the creation of the consensus model of engineering design more apparent. Although, the interactions of the requirement development with other stages or activities of design were emphasized in some of the design-focused models, theses interactions were said to be overlooked in project-focused models, since the emphasize was focused on the relations of the business and project-wise factors that affect the design process. Despite the fact that acknowledging the influence of those factors are essential for representing the complex nature of design process, they mostly lack the level of detail regarding the interrelations of those factors and how they evolved with respect to design projects.

The process models examined under abstract and procedural models did not investigate the decision-making process in detail. Analytical models not only try to scientify and mathematise the design process in a smaller scale of design, but also aim to present ways of decision-making in an analytical manner.

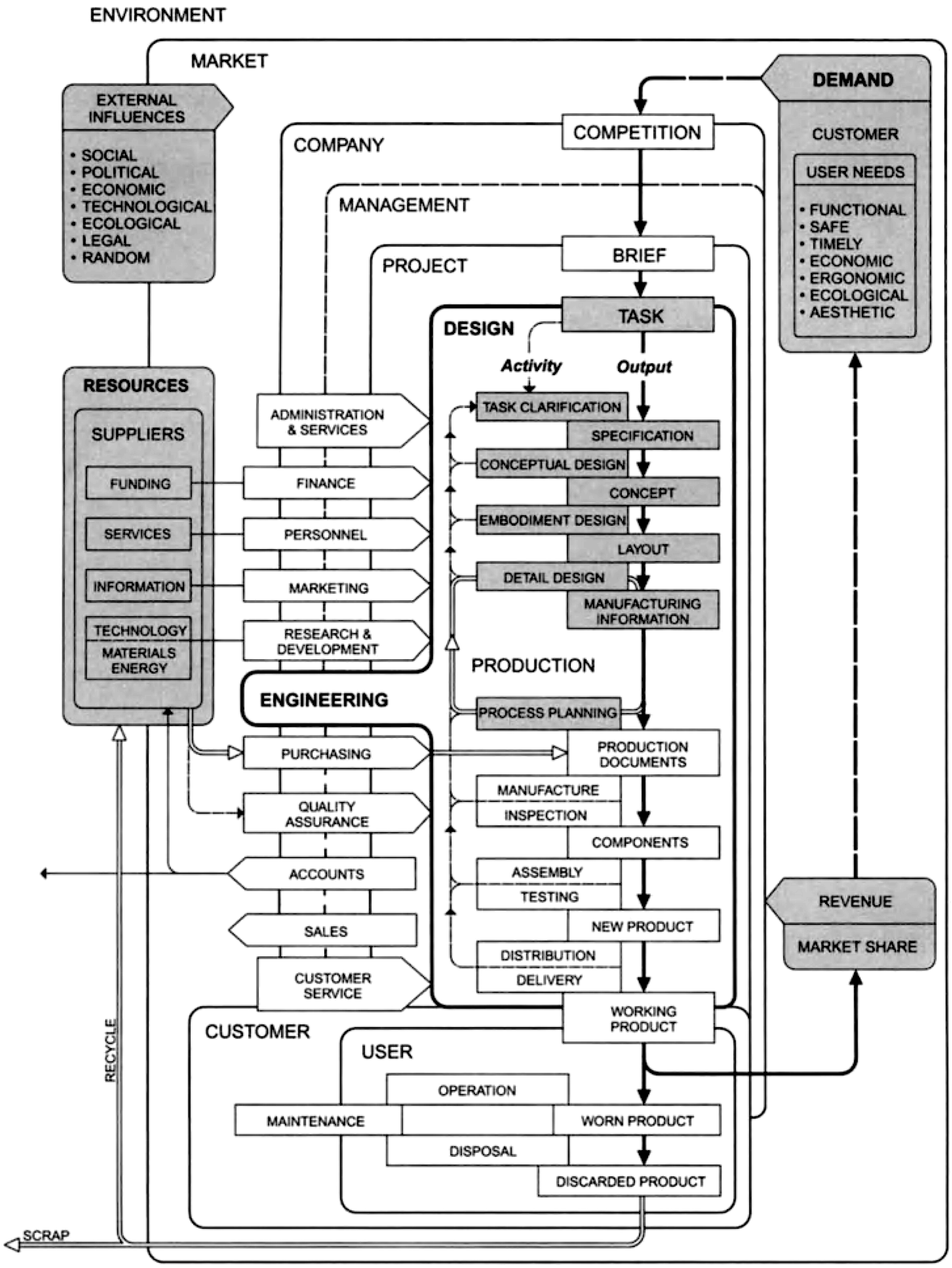


Figure 2.10: Hales' Engineering Design Process [10, p. 28]

2.1.2.4.3 Analytical Models

The third category under the categorization of design methods as abstract, procedural, and analytical is the analytical approaches. Analytical approaches aim to deal with the increasing complexity in large-scale engineering projects where there are professionals from different disciplines. These approaches acknowledge the unique nature of each design project. It can be said that the level of novelty increases as the project becomes more complex. Hence, the experience gained while working on similar projects is essential to set an appropriate design process model [18]. Due to the infrequency of certain projects, the initial planning in terms of process models may remain inadequate; thus, there is a need to allow dynamic planning in a design process model. Analytical models typically capture specific design processes rather than being prescriptive for all processes.

Most of the analytical design process models serve as a platform to create and represent the dynamic process conducted inside a design organization such as the precedence diagramming method [116]. One of the commonly used analytical design process models is called Integration Definition (IDEF) proposed by the United States Air Force [18]. IDEF is a family of models, and the first and most prominent one is IDEF0 [11] which is observed to be in use by Airbus SE [18]. IDEF is said to present a graphical modeling language and it has its own syntax consisting of boxes and arrows, describing functions and input-output relations. The general way of usage can be seen in Figure 2.11.

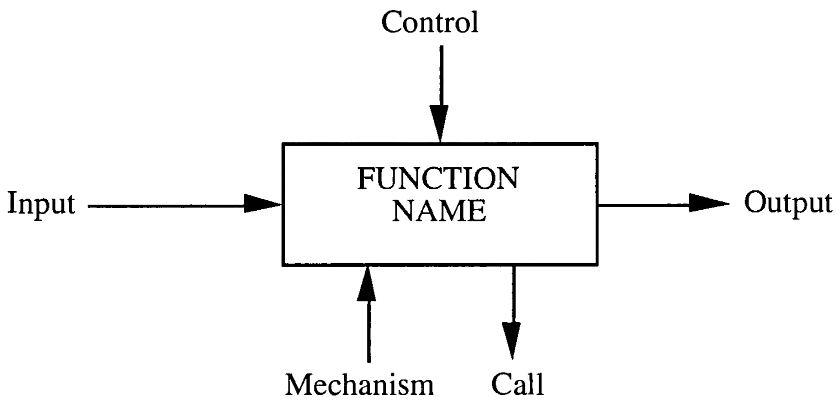
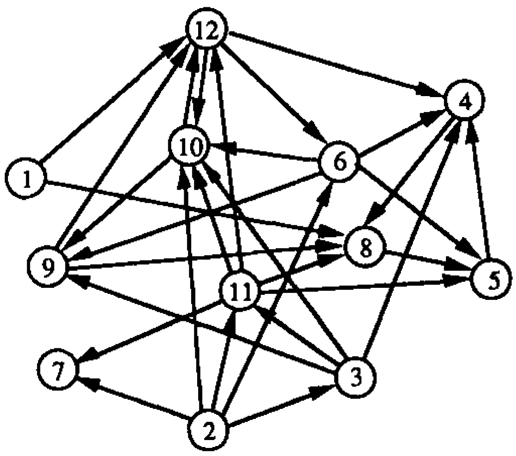


Figure 2.11: General Schematic of IDEF0 [11, p. 8]

Although IDEF0 does not necessarily propose a design process method, it still assumes a sequential and linear nature of a design problem, by setting rules based on a flowchart with basic input-output relations. The contradicting and intertwined nature of the design process is said to be emphasized by dependency structure matrix[5] (DSM). DSM is another modeling approach conceptualized by Steward [12]. The DSM method has been used in various sectors such as building construction and architecture, semiconductor, automotive, aerospace, telecom and electronics industries [117]. A typical DSM has matrix-like rows and columns, each representing an activity. The intersections of the related activities in corresponding boxes have some symbols. Those symbols indicate the relation between the activities. Those activities may be dependent, independent, or interdependent. The relations among activities may be directional, meaning that the matrix is not necessarily symmetric. An example of DSM with corresponding digraph can be seen in Figure 2.12.



	1	2	3	4	5	6	7	8	9	10	11	12
1	*											
2		*										
3		*	*									
4			*	*	*	*						*
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8	*			*				*	*		*	
9			*			*			*	*		
10		*	*			*				*	*	*
11		*	*								*	
12	*								*	*	*	*

Figure 2.12: Activities and corresponding dependency structure matrix [12] as cited in [13, p. 757]

Analytical design process methods emphasized the uniqueness of design projects. Therefore, it was needed to develop methods, specifically for a product or project. Signposting is a design support tool which also aims to develop a design process model for helicopter blade design[118] with the support of GKN Westland Helicopters Ltd[6]. As it was mentioned, helicopters consist of numerous subsystems that

[5] Other uses are design structure matrix and design precedence matrix, all having the same abbreviation, DSM.

[6] GKN Westland Helicopter Ltd merged into AgustaWestland S.p.A; then AgustaWestland S.p.A. merged

can be considered as separate product design projects. Rotor blades have their own design considerations in relation to different aspects of a helicopter. The fundamental philosophy is to utilize the knowledge of possible tasks as a basis for identifying or signposting the next task. The structure of signposting is that the design process can be considered as a series of tasks to identify, estimate and iterate refinement of key design and performance parameters. Clarkson and Hamilton had set the design evaluation parameter as the vibration levels transferred from helicopter blades to the pilot's seat. The tasks were signaled to the user as available or not; in order to guide novice designers. Possible list of tasks that can be conducted after the current tasks were also studied in order to set a guidance for the business managers in terms of costs and risks [121]. Like IDEF and Signposting, most of the analytical models were constructed as platforms to represent design process models. In addition to project-specific models, there are also discipline-specific models such as Booch [122] and OOSE (Object-Oriented Software Engineering) [123] used in software engineering. Large-scale mechanical engineering projects and complex software engineering projects are the interests of systems engineering. Product design and development processes are mostly referred to as life-cycle models in systems engineering. A general view of the systems engineering approach and design process models that are referred to in systems engineering literature will be reviewed in the next subsection.

Analytical design process models are more purposely-built models created specifically for certain projects or tasks. There is a scale difference of design between the design process modeled by analytical models and other models (abstract and procedural) in this category. Analytical models are usually built for more detailed design considerations such as individual parts of a system; on the other hand, abstract and procedural models aim to represent a system-level or product-level design. They give emphasis to the interrelations of different design concerns, which was mostly apparent in DSM. It can also be said that these models can be considered as tools to represent any part of design process; therefore, there is no certain emphasis on requirement identification.

into Leonardo S.p.A [119]. Leonardo S.p.A has close collaborations with Turkish Aerospace Industries, Inc. especially on TAI/AgustaWestland T129 ATAK project which was developed based on Agusta A129 Mangusta helicopter [120].

2.1.3 Systems Engineering Approach and Associated Life-Cycle Models

"Stop the life-cycle, I want to get off!"

G. R. Gladden, 1982

[124, p. 35]

Aerospace market, which includes the helicopter market, and defense markets mostly operate under make-to-order conditions [125] where production starts only after an order is placed. The US Department of Defense (DoD), as a customer in this industry, had mandated the application of systems engineering for its acquisition programs with the directive 5000.01 [43]. Therefore, systems engineering has become a prominent approach in product development activities in those industries. Having explained some process models from different perspectives such as architectural design, marketing, business, and engineering design in general; this section investigates systems engineering models with an emphasis due to its usage in the helicopter industry.

Systems engineering approach can be considered as a thinking approach called systems thinking. In this approach, a system is hierarchically broken down into other systems called sub-systems, and after the functions of those subsystems and the interfaces among them are fully defined, they are broken down further. This type of thinking is more common in electrical and software engineering disciplines compared to mechanical engineering [126]. Systems engineering processes and applications are standardized[7] by several institutions such as INCOSE and ISO. As a formal definition, INCOSE defines systems engineering as [128]:

> "... a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods."

This definition acknowledges the need to gather knowledge from a diverse scale of disciplines in order to cope with complex problems. On the other hand, the use of *transdisciplinarity* is a deliberate one; since it was stated that the processes involving

[7] It can also be said that knowledge production in this discipline is staked out and institutionalized by certain institutions, in a Foucaldian sense [127].

the contributions from experts across disciplines should be coordinated by the systems engineer, and the critical decision-making should be done by the systems engineer [15].

Buckle and Clarkson [111] stated that the emphasis in systems engineering is placed on the process, rather than the product. Product design and development processes are usually mentioned as system life cycle in systems engineering. Defining the system life cycle has great importance in ensuring the stakeholders' needs, orderly and efficiently. Moreover, *the gates* between stages are said to have importance in order to guarantee a readiness to move to the next stage [15].

Unlike the progression of the consensus models, ISO 15288 acknowledges that life cycles may vary according to the nature, purpose and the use of the system [129]. Nevertheless, some common characteristics were defined by INCOSE. Those characteristics are decision gates and the fact that there are multiple aspects of the life cycle. There are three aspects in a life cycle, namely business aspect or business case, budget aspect or funding, and the technical aspect or the product. The systems engineer's aim is said to be creating technical solutions in accordance with business case and funding constraints [15]. Another common characteristic is to include decision gates, also known as milestones or reviews. These gates aim to make a decision on design activities which are the prerequisite of some following design activities. Until the decision is made on these gates, the following activities are not pursued. They try to set the baselines of the technical and business aspects of the project on a level that verification and validation will be satisfied at a sufficient level. Typical decisions taken in those gates include to accept the design work up to that point, to accept the work with revisions and continue after responding to the revisions, to hold the design process, to return to the preceding stage or to hold the whole work in the project, or to terminate the project [15].

Design process of a product is acknowledged as the life cycle of that product in systems engineering approach. The conceptualization of the life cycle is a stage-based understanding, as the discussion is always referred to as *life cycle stages*. INCOSE refers to several life cycle stage models that share similar decision gates [15]. The base of the similarity discussion is based on the model introduced in ISO 24748-1

[130] which was repeated in ISO 15288 [129]. The life cycle model in ISO 24748-1 has 6 stages: concept, development, production, utilization, support and retirement. It was emphasized that due to the iterative nature of systems engineering, those stages are not strictly sequential, and a project may not follow those predetermined set of activities. Ironically, there are decision gates that enact the project to proceed to the next stage, or other decisions listed below. It was stated that those stages may be conducted in parallel, and in an overlapping fashion. It is not necessary to follow a serial and sequential approach.

There are 5 life cycle stage models reviewed in relation with that of ISO 15288 (Figure 2.13), 4 of them were taken from Forsberg, Mooz and Cotterman [14]. In addition to the stage-based models, there are 3 life cycle approaches in order to cope with the complexity, and to implement systems engineering methods for validation and verification.

- **ISO 15288 Model**

The first model is the baseline model of ISO 15288. In this model, the concept stage includes defining problem space, concept selection, identifying and refining stakeholders' needs, and proposing viable solutions. Related design activities are not in a linear and sequential process. In the development stage, system requirements are defined and refined, and the initial system is implemented as well as solution descriptions including architecture and design. Those stages are started to be validated and verified. After production, utilization which means the operation by the user, and support which means providing sustained system capability are conducted hand in hand, and in parallel. The final stage is the retirement where storing, archiving or disposing the system is discussed. Forsberg, Mooz and Cotterman [14] defined common periods that include one or more stages in the models analyzed. Those common periods are study period, implementation period and operations period. Concept stage of ISO 15288 is stated to be aligned with study period, development stage is shown to be aligned with implementation period, and the rest is acknowledged as operations period.

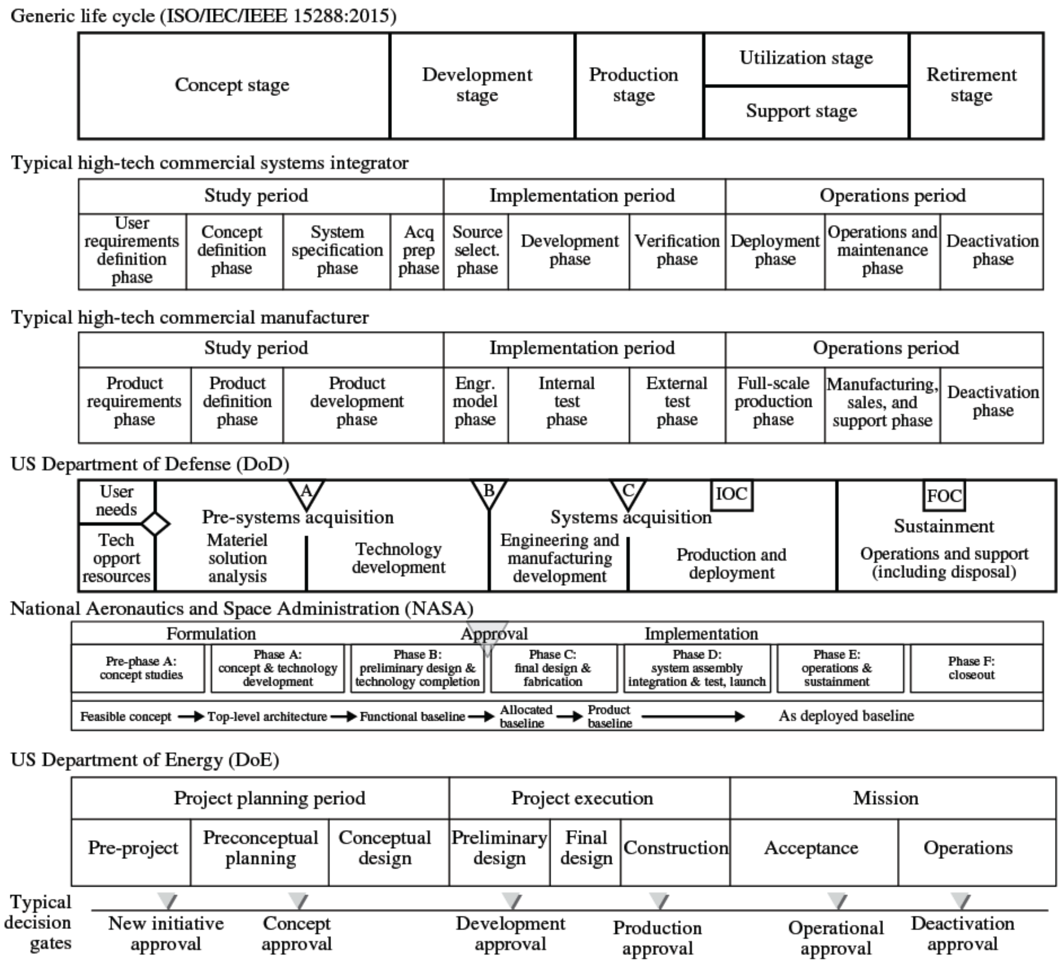

Figure 2.13: Comparison of Life-Cycle Models [14] as cited in [15, p. 29]

- **DoD Model**

The most similar life cycle model among the given studies to that of ISO 15288 is the one introduced by the US Department of Defense [131]. This model is for defense acquisition, technology and logistics. The DoD model has 3 stages inside the study period which corresponds to the concept stage of ISO 15288. The three stages inside the study period are determination of mission needs, concept refinement phase and technical development phase. The concept stage is very much linked to the needs and their interpretation as their refinement and technical development. Corresponding to the implementation period, there are system development and demonstration phase, and production and deployment phase. The operations period was defined in a single phase which is operations and support phase.

- **Forsberg's Model**

Forsberg et al. [14] have defined how a typical high-tech commercial business conducts project management, aligned with their three major phases. In the study phase, product requirements and product definition are determined. Product definition phase is divided into two, by a decision gate called system concept approval. Product development and tests including both internal and external tests are parts of the implementation period. Production, sales, support and disposal are the phases of operations period. On the other hand, Forsberg et al. construct their own project cycle template. The initial phase in their template is user requirements definition phase, then concept definition phase is conducted before the system concept approval gate. System specification and acquisition planning are the remaining phases inside the study period. Source selection, development and verification are inner phases of the implementation period. Deployment of production, operations, maintenance and disposal are the parts of the operations period. This template can be regarded as a modified version of what was observed in the helicopter industry, especially focusing on the initial phases of design and development.

- **NASA Model**

In comparison to the study-implementation-operations periodization, National Aeronautics and Space Administration (NASA) proposes two major periods which are formulation and implementation [132, 133] The NASA cycle uses letters for the names of the phases. There are phases A, B, C, D, E and F. Concept studies are named as pre-phase A, and the preliminary analysis phase is named as phase A. Phase B consists of system definition and preliminary design. Those 2+1 phases (phases A and B, plus pre-phase A) form the formulation period. In the implementation period, design and development are defined as two separate and sequential phases as phase C and D. Operations and disposal are basically phase E and F. These 4 phases form the implementation period.

- **DoE Model**

The fifth life cycle stage model in INCOSE [15] is that of the US Department of Energy (DoE). This is similar to the model proposed by NASA. There are three main periods: project planning, project execution and mission. In the project planning period, pre-project studies, pre-conceptual planning and conceptual design processes are held. In the project execution period; preliminary design, final design and construction stages are conducted. Finally, acceptance and operation form the mission period.

The models examined here mostly follows the principles stated in ISO 15288 [129]. Similar to the basic design cycle [4], they aim to represent the design process in broadscale regardless of the industry and complexity of the product and market. Requirement identification phase is mostly overlooked except for Forsberg's model [14]. It was mentioned in the concept stage or study period.

2.1.3.1 Prominent Life Cycle Approaches

Having introduced some reference models from NASA, DoD, DoE and Forsberg et al.[8], INCOSE identifies a life cycle model consisting of these stages: Pre-concept exploratory research, concept, development, production, utilization, support, retirement [15, 14]. The concept stage is mainly interested in the requirements and planning of the project in terms of organizational capabilities, financial budget and time restrictions. The significance of budget and cost issues during the concept phase is quite visible while comparing the committed and spent expenditures. This can be observed from an aerospace project as Achenbach [134] reported that NASA's Mars Rover project had to be delayed for 2 years due to technical issues, and that change resulted in nearly 35% of cost growth ($1.63 billion to $2.2 billion). It was asserted that the cost had quadrupled since the initial steps of the project. This gap between the committed and spent expenditures has been portrayed in Forsberg et al. as in Figure 2.14.

[8] It should be noted that the first author of [14], Kevin Forsberg, is among the editors of INCOSE Systems Engineering Handbook [15].

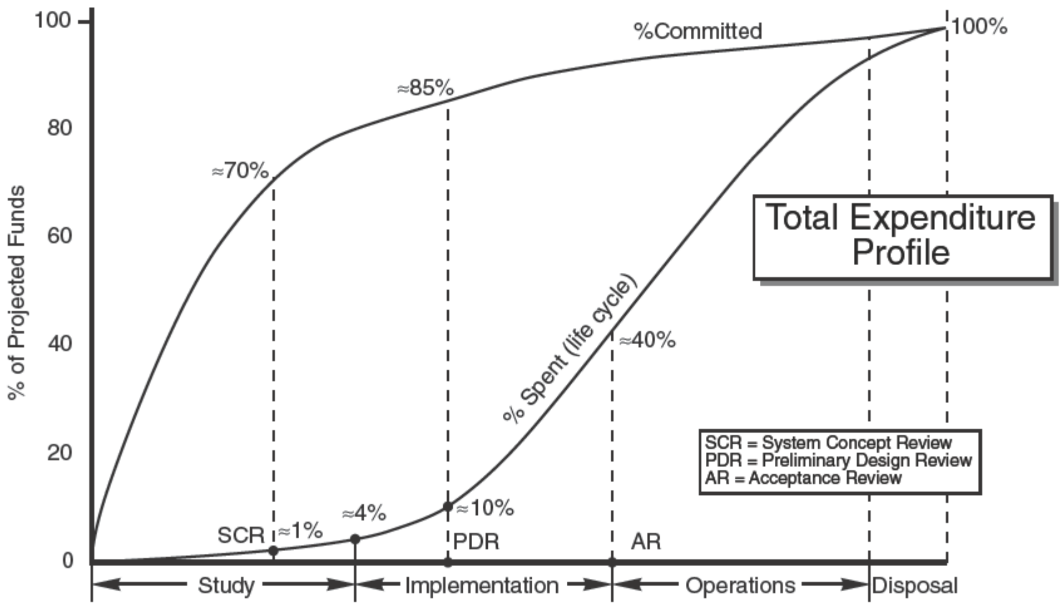

Figure 2.14: Typical expenditure profile: Committed versus spent [14, p. 90]

Business and mission needs, stakeholder requirements are refined as system requirements in the development stage of INCOSE's life cycle model [15]. System analyses are performed to optimize the design. Integration, verification and validation processes are conducted throughout the development stage. The details how these systems engineering processes are done are elaborated while discussing the life cycle approaches. Production stage is about the manufacturing of the product, utilization is the actualization by the user and support stage is where the manufacturer supports the life of the product. Retirement stage is the final stage dealing with disposal requirements.

Life cycle models reviewed by *de facto* systems engineering authority, INCOSE were criticized as they have the impression of being strictly linear. Nonetheless, an implementation of a model does not have to be always sequential. In order to unveil the iterative and recursive nature of design, some process models are introduced as templates. Those approaches serve more like a template, since the stages and processes are acknowledged to be dynamic and adaptive according to the needs, project, and organization. There are three main approaches discussed in systems engineering: waterfall, spiral and Vee models.

2.1.3.1.1 Waterfall Method

"The waterfall model is dead.
No, it isn't, but it should be."

Barry W. Boehm, 1988
[19, p. 61]

Waterfall method was repeated, modified and criticized numerous times throughout design literature. Royce [16] introduced the waterfall model as can be seen in Figure 2.15.

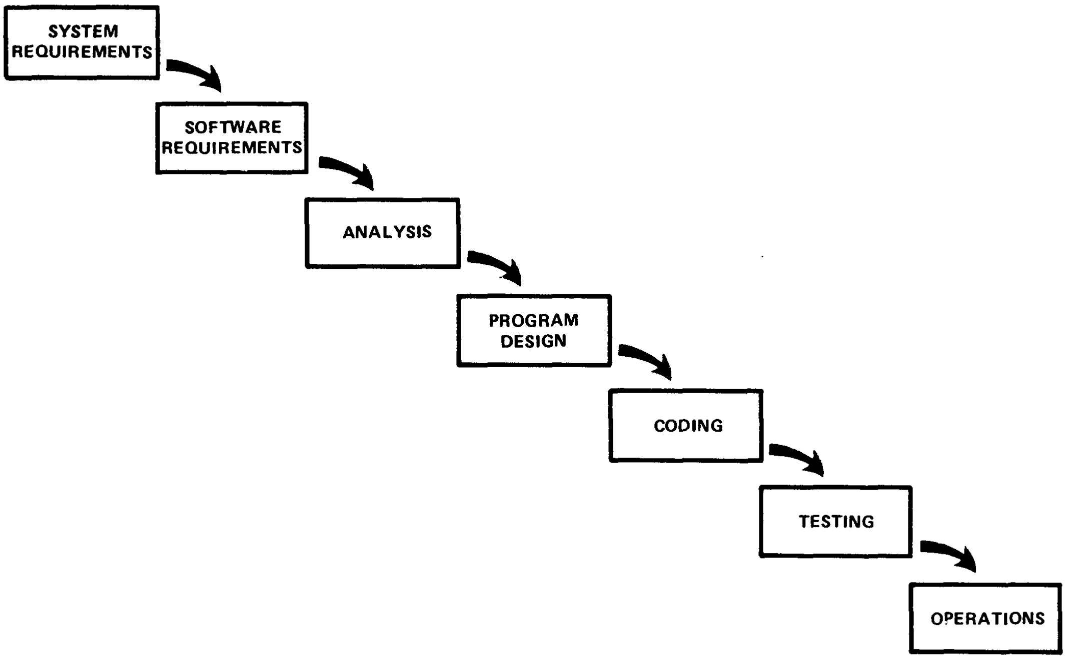

Figure 2.15: Waterfall approach to product life cycle [16, p. 329]

One of the criticisms was directed by Royce himself, right after the method was proposed. It was stated that this method would be risky to implement, since testing occurs lately in the design process. Royce proposed iterative models in which there are feedback loops between two consecutive stages, and greater feedback loops among testing, program design and software requirements. Customer involvement was emphasized, and it was proposed to happen during the elicitation of system requirements, preliminary design and analysis, and finally testing and operations for an approval.

Waterfall methods emphasize the verification and validation processes inside a project. Those design projects are mostly large-scale and complex projects. Therefore, it is not surprising to observe those methods being applied in engineering-dominated fields where the object to be designed needs multiple disciplines to contribute. An applied instance was introduced by the US Food and Drug Administration's Center for Devices and Radiological Health [135, 18]. Verification can be regarded as Royce's feedback loops inside the design, and validation can be seen as the total verification of the product with respect to the user needs. Later on, the US Food and Drug Administration updated the design cycle with a spiral-based model [17, 18], instead of a traditional sequential waterfall. This new, spiral model acknowledges the complex and intertwined nature of the collaboration among disciplines, and different perspectives to the project. Despite the fact that the sequential method is also considered a project-focused approach, the new approach includes marketing and post-marketing stages to the product life cycle. The spiral model can be seen in Figure 2.16.

2.1.3.1.2 The Vee Model

Verification, validation and other system engineering activities were placed in relation with different product life cycle stages. Increasing number of relations between design steps became nearly continuous from the start of the project. In order to represent those relations in a more comprehensive way, Forsberg and Mooz [136] developed the Vee model. This model also pictured the relation between systems engineering activities and design engineering activities. It can also be regarded as an improvement on the waterfall method [137]. Forsberg and Mooz criticize the traditional waterfall method due to the fact that it implies that the design activity after a decision gate cannot be conducted before that gate point was reached. That is, the traditional models have an impression as if no fabrication activity is not allowed before critical design review; on the other hand, there is a need of early prototyping in order to understand the user requirements thoroughly [136]. Early involvement of the technical disciplines was acknowledged as concurrent engineering.

The Vee model starts with user needs at the top left, and ends with a user-validated system at the top right. Left side of the model is similar to the waterfall model.

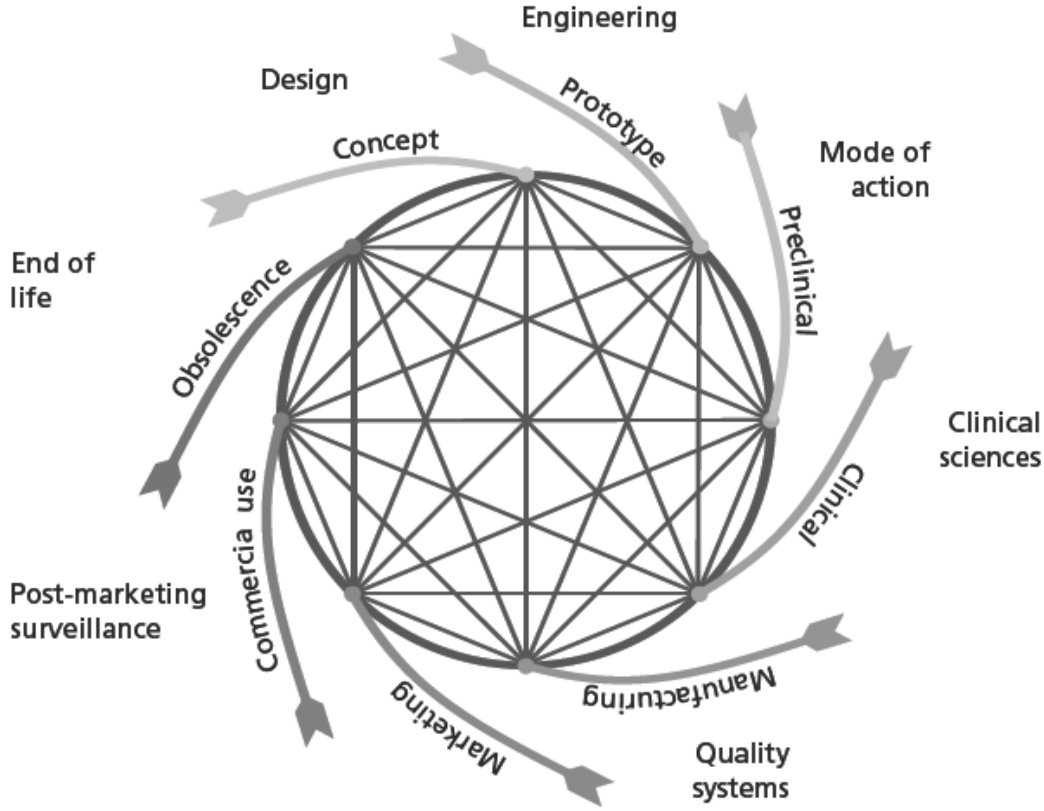

Figure 2.16: US Food and Drug Administration's spiral life cycle model [17] as cited in [18, p. 52]

The right side represents verification activities starting from subsystems, and cumulatively progressing to super-systems. The outline of the Vee model was influenced by NASA's Software Management and Assurance Program. The Vee model was also prepared as a compliance to DoD's MIL-STD 973 specification [138]. This specification was taken as a baseline, since the gates such as *System Requirements Review (SRR)*[9], *Preliminary Design Review (PDR)*[10] and *Critical Design Review (CDR)*[11] de-

[9] SRR: review conducted to evaluate the completeness and adequacy of the requirements defined for a system; to evaluate the system engineering process that produced those requirements; to assess the results of system engineering studies; and to evaluate system engineering plans [139, p. 455]

[10] PDR: review conducted to evaluate the progress, technical adequacy, and risk resolution of the selected design approach for one or more configuration items; to determine each design's compatibility with the requirements for the configuration item; to evaluate the degree of definition and assess the technical risk associated with the selected manufacturing methods and processes; to establish the existence and compatibility of the physical and functional interfaces among the configuration items and other items of equipment, facilities, software and personnel; and, as applicable, to evaluate the preliminary operational and support documents [139, p. 332]

[11] CDR: review conducted to verify that the detailed design of one or more configuration items satisfy specified requirements; to establish tho compatibility among the configuration items and other items of equipment, facilities, software, and personnel; to assess risk areas for each configuration item; and, as applicable, to assess the results

fined by DoD were also used by DoE and NASA [136]. The same convention is used in the helicopter industry in Turkey as well. Usage of those decision gates are so common and institutionalized that ISO published a glossary for them as a standard in ISO 24765 [139].

The Vee model, in fact, is a three dimensional model in which the depth dimension represents alternative concepts discussed. System Requirements Review gate, for instance, evaluates different design concepts with respect to user needs, and decides on a single concept [136] which is similar to the deduced concept as the principal solution after conceptual design in the model of Pahl and Beitz [5]. On the other hand, Vee model is usually represented as a two dimensional model for simplicity. A basic representation can be seen in Figure 2.17.

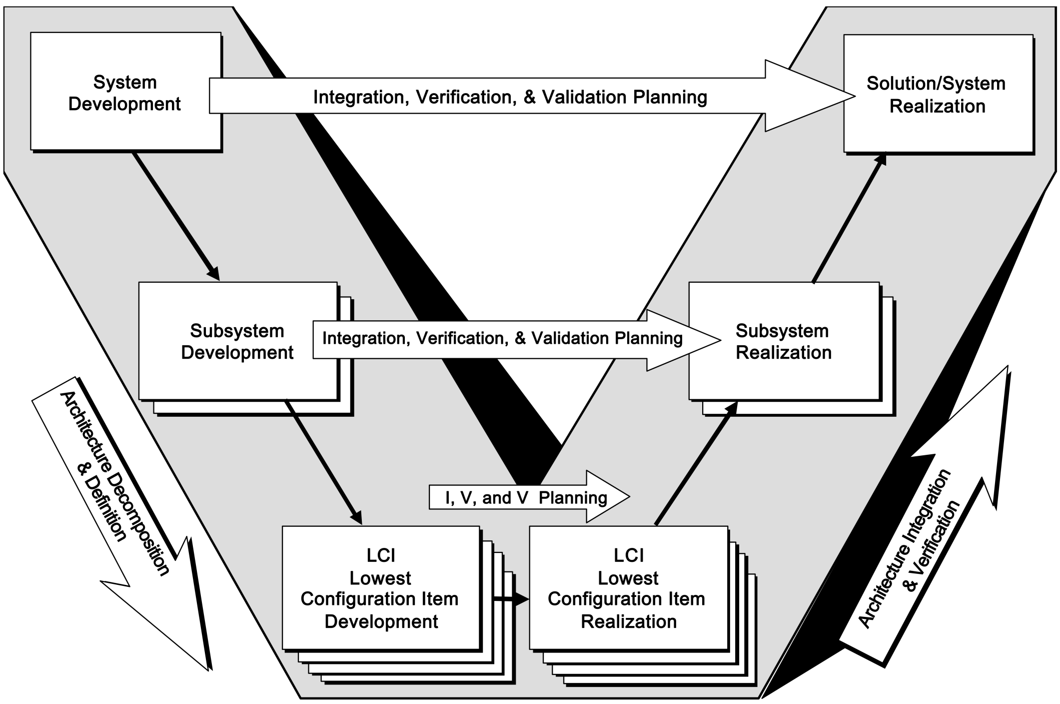

Figure 2.17: A basic schematic of the Vee model [14, p. 109]

Iterations with respect to user requirements are allowed until PDR gate; otherwise, updated user requirements may cause the project not to converge to a design solution. The updates after the PDR gate are reflected into the next project. If the changes or

of producibility analyses, review preliminary hardware product specifications, evaluate preliminary test planning, and evaluate the adequacy of preliminary operation and support documents [139, p. 109] updates are mandatory for some reason, then a new Vee cycle starts. If the requirements are too vague to define a complete Vee cycle, then an incremental development technique may be implemented which is formed by several Vee cycles that progress incrementally. The problematic situation where high iterations are needed with respect to user requirements can be foreseen after a decision gate between SRR and PDR, which is called *System Design Review*[12] This gate allocates design responsibility of each supersystem by dividing it into subsystems. It was stated that if the project passes those gates prematurely, some design requirements that cannot be built may be accepted. This is said to be the case when appropriate technical experts were not involved in those early stages of the project, which is systems engineer's responsibility [136].

2.1.3.1.3 The Spiral Model

The third approach in life cycles is the spiral model developed by Beohm [19]. The spiral model put its emphasis on defining the requirements thoroughly. To that end, a preliminary design solution is created, prototyped and evaluated in order to define the requirements for the next iteration. It is a risk-driven model that aims to resolve the deficiencies of the waterfall model [14]. A more structured and incremental version of this model is reported to be used by software organizations such as Microsoft Corp. [140]. The graphical representation of the spiral model can be seen in Figure 2.18.

The angular dimension in Figure 2.18 represents the stepwise progression in the design process; whereas, the radial dimension represents cumulative cost incurred by accomplishing those steps. Each cycle starts with objectives and constraints of the product. After the risk analysis in every circle, certain design steps which are very similar to that of the waterfall model take place. Each cycle is completed with a review gathering the people and organizations (stakeholders) involved in the project. This review is also the initial planning of the next cycle [19]. The biggest strength of this model is the risk evaluation at each cycle that is cautious against the dramatic changes that may be raised according to ever-changing user needs. Boehm et al. [141]

[12] System Design Review: review conducted to evaluate the manner in which the requirements for a system have been allocated to configuration items, the system engineering process that produced the allocation, the engineering planning for the next phase of the effort, manufacturing considerations, and the planning for production engineering [139, p. 453]

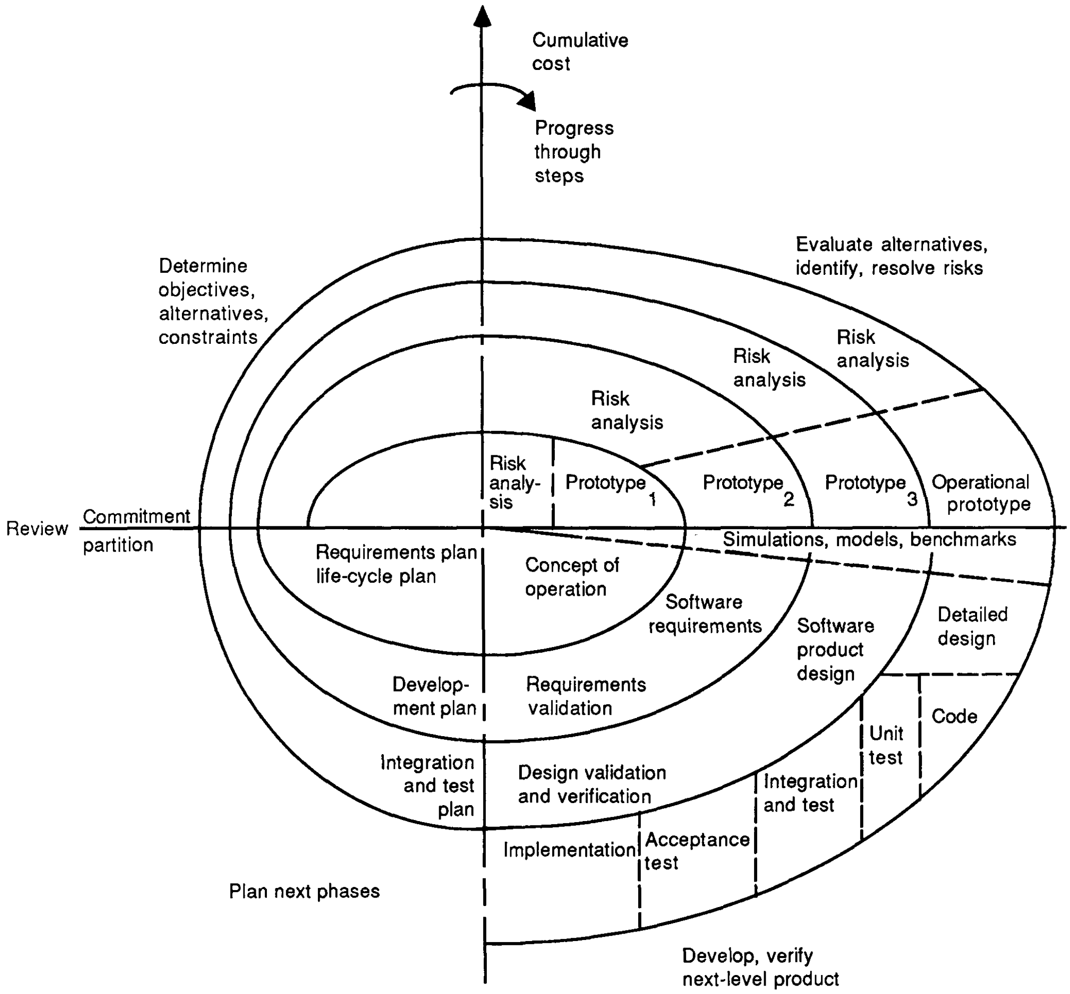

Figure 2.18: The Spiral model [19, p. 64]

later brought the strength of the Vee model about earlier verification and validation activities, and the risk-driven approach of the spiral model together in a model called Incremental Commitment Spiral Model.

The review regarding the design process models showed varying amounts of focus on the requirement identification and its relation with other stages or activities. It can be said that emphasize regarding the interactions between certain stages led the evolution of the Vee model from the waterfall method. However, the Vee model lacks representing the iterative nature of design. The spiral model puts great emphasize on this iterative nature compared to the Vee model.

2.2 Design Specifications in Helicopter Industry

Design specifications are derived from user needs and market demands under some constraints defined by aviation authorities such as Federal Aviation Administration (FAA) and European Union Aviation Safety Agency (EASA). Systems engineering approach, as it is the *standardized* approach in terms of design method, considers the process of analyzing the user needs and converting them into design specifications in particular steps. The elicitation and identification of the requirements are conducted within a discipline called *requirements engineering*. Requirements engineering defines a level hierarchy in which the high level requirements are related to high level super-systems that the user or the client is more interested in. On the other hand, lower level requirements are detailed versions of those high level requirements related to subsystems. These processes are both reviewed and agreed as a consensus with the stakeholders involved. Therefore, it is not so straightforward to match the concept of the design brief with one of the documents produced through this process. On the other hand, considering the brief as the very first document that the stakeholders agree on, it would be safer to say that the contract among the client, user, and the contractor can be considered as the design brief in the helicopter industry. This is nearly the most formal way of defining a contract according to Darlington and Culley [21]. Design formality was defined in a continuum in which one of the ends is a legally-binding agreement, and the other end is a verbal agreement or a simple handshake.

The contract is sometimes referred to as the agreement. For instance, a sample contract concerning a helicopter project has several parts. The design specifications are written as appendices. There are two parts in the appendix which explains the design specifications. One of them provides the equipment list that is demanded to be inside the helicopter for the phases[13] of the helicopter project. The other item in design specifications explains the demanded attributes and properties of the helicopter as bullet

[13] This definition of phase is slightly different than it is used in design process stages, or life cycle stages. Most projects in the helicopter industry are planned to have multiple configurations throughout its design, testing and certification processes. The main difference among the phases of the product is the equipment it has. The common dialect is that P0 refers to the very first product whose main objective is just to be able to fly. P0 products usually have the bare minimum of equipment installed; P1 products have sufficient levels of avionics equipment to be able to operate simple missions; P2, P3 products have the full equipment list demanded by the user or client.

points. These documents are also called as system performance specifications (SPS). In a sample SPS document, there are more than 200 bullet points. These bullets may include more than one requirement. There are basically two major sections. The first one specifies the type of the helicopter, whether it is a utility helicopter, search and rescue helicopter, or a combat and reconnaissance helicopter. This section provides the definitions that will be used in this part of the brief. The second section is titled as system requirements. It has 6 subsections. The first subsection is the general description. The product description given in the definitions section is explained further. For a combat type helicopter, how many pilots will operate the helicopter, in which seating configuration they will sit, how many of them will have the controls, how many engines will be installed and what type of engine will be used, helicopter configuration and rotor types are stated determinedly.

The second subsection under system requirements is operational and environmental concepts. This part directly refers to some standards from DoD, EASA etc. The target altitude is stated determinedly. The third part is titled as performance characteristics. This part can be treated as the main part of the SPS document; since, it defines most of the helicopter level requirements. Under this title, the duration of ground run is stated. The wheel/skid height is estimated. Under the performance characteristics, there is a part called mission scenarios. This part includes sample missions that the helicopter is demanded to be able to operate. These are called mission scenarios which are very similar to the concept of usage scenarios. In the mission scenarios, the profiles are fully defined. The payload[14] that the helicopter will carry, in which altitude and at which temperature the helicopter will fly, the configuration of the payload at the wing stations, rate of climb[15], durations of loiter[16] and hover[17], total distance that the helicopter will cover at cruise[18] speed are exactly stated. The maneuver limits of the helicopter, a minimum value of maximum velocity, and the target maximum velocity

[14] Payload is the total weight that is carried in order to operate the mission, and it is the main point to operate that mission. There is an analogy behind this term: Payload is the load in which the operator is paid. In a cargo mission, payload is the cargo; in a transport mission, payload is the total weight of the passengers and their luggages; in a combat mission, payload is the total weight of the ammunition and weaponry.

[15] In aviation, since there are multiple axes to define a velocity, there are special names given to them with respect to their axes. Rate of climb basically means the vertical speed.

[16] Loiter flight is the type of flight the aircraft wanders. It is common in search and rescue missions' search part.

[17] Hover flight is the type of flight when a helicopter stands still in the air. This is one of the main advantages of rotorcraft compared to fixed wing aircrafts. The other main advantage is vertical take-off and landing.

[18] Cruise flight is the type of flight when an aircraft flies at a constant velocity.

is stated. There are requirements concerning crashworthiness, maintainability including specifications related to the paint that will be used, placement of cables etc. If applicable, ballistic tolerances are defined explicitly, stating the type of armor piercing ammunition and its velocity. Landing gear specifications are stated as landing velocities. Minimum pilot view angles are specified.

The other subsections under system requirements after performance characteristics are functional area characteristics which give particular specifications for areas such as tail and nose, avionics system specifications which lists the equipment demanded and related standards those equipment should comply with. The last subsection lists other system specifications. Inside some demand bullets, there are optional things that are desired to have, but they are not mandatory. Seldomly, tables and figures are used in order to explain the demand comprehensively. Some of the mentioned decision gates such as SRR and PDR are used and cited in order to specify the time during the project.

In the following subsections, a review about the design brief, and how it should be written and designed will be presented. In another subsection, the approach of requirements engineering, and the methods it uses to conduct this elicitation and identification stages will be presented.

2.2.1 Design Brief

The basic definition of design brief can be the initiation of design and the agreement between the client and the designer on what will be designed. On the other hand, a design brief carries much more meaning than this definition. The design brief can be considered as the intermediate step between the fundamental product idea and the list of specifications and requirements that the product is expected to comply with [142]. It should also be noted that creating the brief is a dynamic process that needs special emphasis. Writing the brief is a part of the design. It is a creative activity. Bernsen [74] defines this process as *the design before the design*. It is a part of the creation process.

Design brief can also be considered as a basis of strategic planning of a company, as a basis for decisions in a political process, and a review of proposed solutions [65].The design brief is the fundamental and formal setting where the stakeholders meet and reach an agreement. Therefore, there are multiple perspectives on what the design brief is and how it is formulated, according to different stakeholders' perspectives. There are common tendencies among stakeholders; such as the fact that the customer is often forced to keep alternative options available until the final decision. On the other hand, the contractor is often assumed to want fixed specifications as early as possible [143]. In addition to the external stakeholders according to the design organization, internal stakeholders may have diverse backgrounds, and the communication among them may pose an issue [144]; since, they may have different mental models [145].

Ryd [65] investigated a construction project where the client regarded the brief as a complete work; but, the contractor regarded it as a *half-finished general contract*. Therefore, it is not surprising that the stakeholders' expectations vary. The contractor usually demands well-defined requirements. This fact has several reasons; one of them is the common problem in which the client is prone to make delayed decisions. As a reaction, the contractor wants the requirements and decisions to be fixed as early as possible.

Collier [75] lists the four factors that a good design brief should include: the goal, the context regarding user and scenario, the constraints as quantitative requirements, and the criteria as the qualitative attributes. Quantitative requirements may be called as design specifications where numerical constraints are stated, such as the range of a helicopter. The goal, the context and the constraints are stated in SPS as specifications. The criteria are flexible, they are used for judgment [142]. They are set by defining measures of effectiveness tables in the helicopter industry, which will be explained in the next subsection. The scope of the brief discussion is narrowed by excluding calendar criteria and legal regulations. Therefore, the product design specifications part of a design brief will be investigated.

Product design specifications can be regarded as a comprehensive document developed from the brief; since, it includes more precise limits for a complete range of performance specifications [75]. According to Pugh [146] product design specifications should include elements from patenting to shelf life, competition constraints to politics. On the other hand, specifications in a narrower definition can be divided into two: technical specifications and marketing specifications [147, 75]. Market research is essential for the marketing specifications part of a design brief, bad market research may lead the designer forward with false confidence [75]. The discussion regarding the marketing specifications is not completely applicable to the helicopter industry in Turkey. This is due to the client-customer-contractor relation in which there is no free market economy for marketing conditions to be applicable. The contractor does not need to do marketing research to market its product aiming for a fiscal profit motive. As it was explained in the first chapter, all three stakeholders are state institutions or state-led institutions. Marketing specifications are expected to state the issues among the user , purchaser and producer [147]; which are already set by law and state regulations. Hence, the discussion can be narrowed into the technical specifications only.

Technical specifications translate the requirements set in marketing specifications using quantitative measures and precise descriptions. Marketing specifications are said to state the attributes of the product, whereas technical specifications specify physical properties. Cross [148] defines the difference between attributes and properties, referring to consumer choice. The properties of a product are its weight, size, material, shape, speed, power, etc. Attributes rise from the properties, they are the embodiment of these properties as its performance, reliability, portability, appearance, etc. The purchaser makes a value judgment based on the benefits offered by the product. Those benefits rise from attributes [148]. Therefore the effect of the attributes on consumer choice is more dominant than that of properties. Attributes gain meaning in the context of the product. For instance, the green color of an automobile is the property of the product. If the green color is a particular green called British racing green (Hex code: #004225), on a British-manufactured car; it has a historical meaning, and it may evoke the impression of speed and motorsports. This chain of impressions is the fundamental basis for consumer choice. Marketing specifications are written in a relatively non-technical manner. The technical specifications translate those requirements including business requirements into more precise technical parameters, considering the feasibility if a compromise is required [59].

Roy, Walker and Cross [149] studied a British truck manufacturer. The brief of a design project was prepared including the overview of the market and design parameters including capacity, weight, speed, turning cycle etc. as the ideals of the customer. Then, design and production engineers translated those ideals into technical specifications, considering feasibility. Technical specifications are typically much longer than marketing specifications. British Rail's InterCity 225 project was said to have 30-page long marketing specifications; on the other hand, it has 200-page long technical specifications [59] which is very similar to the sample specifications explained in the helicopter industry.

Design specification also acts as a link between product planning and product evaluation. Desired attributes and performance requirements can also be treated as the evaluation criteria for the final product, or while comparing different design proposals. Thus, the specification document is a key item that has influence on the whole design process [147]. The design team may have to produce initial design concepts in order to assess and evaluate the customer's and the client's reaction, while developing the specifications. Trade-off studies and comparisons to other products in the market may be necessary to cover more aspects in the specification document. It is related to the knowledge gathering process about the design problem. Fischer and Ostwald [150] stated that a design problem cannot be understood without information about it. Meaningful information about the problem cannot be gathered without understanding it, and the problem cannot be understood without a concept of solution in mind. Moreover, Walsh et al. asserted that most briefs and specifications are generated with a design concept in mind [59]. This may easily become a problematic situation. There may be a chunk of references to a reference solution in the requirements. An existing artifact may be accepted as a design solution. This is conceptualized as *problem/solution bias* by Darlington and Culley [21]. Therefore, writing the design specifications is a rigorous process, and requires a significant amount of attention.

Design specifications state the limits of the properties. These limits should be in an appropriate range so that the designer would not lose their freedom to act. Direct statements such as "marble should be used" should be avoided. Direct references from existing products also cause this problem. It was acknowledged as a good practice to set limits rather than point requirements. For instance, if a height is acceptable at a range between 400 mm and 450 mm, then the specification should not state a height of 425 mm [147]. Creating the brief requires a balance or an optimization in a contradictory medium. If the brief is too prescriptive, then creativity while designing may be hindered. On the other hand, if the brief is too vague in terms of specifications, then the designer may not be able to decide whether their ideas are relevant to the client's needs [75]. This situation can be placed on an axis representing the prescriptiveness of a design brief as can be seen in Figure 2.19.

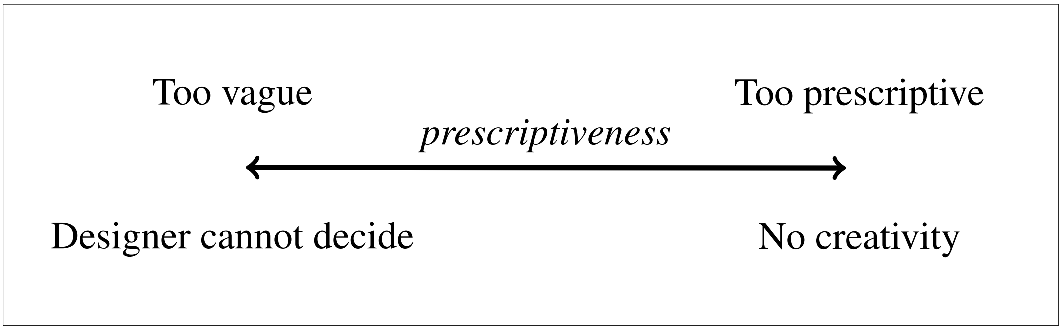

Figure 2.19: Prescriptiveness of a Design Brief

This phenomenon is also related to *the design process paradox* which basically points out the inverse relation between the knowledge about design problems and design freedom [20]. A graphical representation of this paradox can be seen in Figure 2.20. Nevertheless, there is a significant difference between the two phenomena. The circumscribed design freedom due to the progression of the design process is the nature of a design work. The restraint on freedom, stemming from the design brief can result in detrimental consequences in terms of project planning.

The goals stated at the design brief are not necessarily the final goals. It was suggested to revise the brief during the design process; hence, creating the brief should be considered a dynamic process [74]. Therefore, setting particular design specifications so prescriptively that the designer may not find any freedom; this situation may lead the design to be in a contradictory setting. Design specifications may list goals and guidelines to the designer; however, it is the designer who has to imagine and decide on the ways to achieve those goals. A good practice on product design specification includes the required performance without specifying a particular solution. It is about what the product must do, but not what it must be [75]. The product design specification and design brief specify the ends but not means [75, 147], they describe

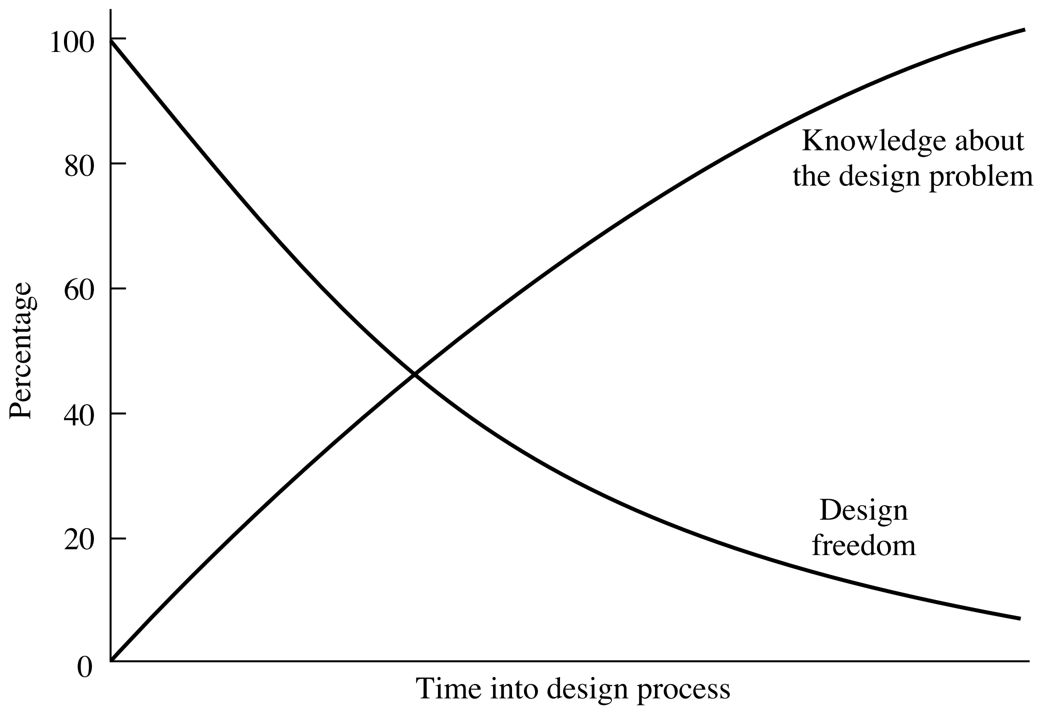

Figure 2.20: The Design Process Paradox [20, p. 19]

the wishes, and never the solution [74].

On the other extremum of the *prescriptiveness axis* (Figure 2.19) there is the vagueness problem. This may cause insufficient briefs. Insufficient briefings greatly increases the total cost of the product [65]. Inadequate briefing, such as failing to include key design parameters, can lead to problems. For instance, Bruce, Potter and Roy [151] investigated a case of car seat adjusters. The manufacturer did not mention a detail on loads which powered adjusters encounter. The design consultant designed a mechanism omitting that. The firm had to invest additional resources to produce a satisfactory design. It was also observed that the design process may start with incomplete data [152].

Inadequate briefing was considered as a poor design management practice. Successful companies have skills in integrating design into their organization. Best practices include clear project objectives, preparation of comprehensive design briefs, and regular communication between client and design companies. Project failures were the result of poor management, ill-defined objectives, poorly stated briefs and lack of budget planning. For the projects that were not implemented in the studies of Bruce, Potter and Roy, 27% of them faced technical difficulties in development, such as the fact that the designer was unable to meet specification. This type of problems affected engineering and product design projects more than graphics projects [151]. One of the suggested solutions is to maintain a holistic view where clients create a platform at an early stage for clear understandings of user needs. Because briefing is about communication; brief is the product of this communication, there is also the process within the communication which is briefing [65].

Briefing process includes understanding the problem. As Fischer and Ostwald [150] directly stated: "Designers solve problems. But apart from problems in school, most problems in real life are encountered, not given. For these problems, understanding the problem is the problem." Successful commercial design practice depends on the designer's approach to briefing. The designer should listen and define the essential information from what the client says. The brief is rarely a one-hit meeting, therefore there is a set of meetings in the briefing process. Early meetings are important, since the most important information is given in these meetings. The designer might be able to facilitate the discussion by asking open questions such as "have you thought about" questions to the brief-giver, because the client might need help to address their aspirations and requirements to the designer. To that end, the designer should understand the client comprehensively, and help them to express themselves better [75]; even though understanding and communicating with other stakeholders are usually seen as secondary tasks in a design work [153]. Through a project planning lens, 6 key factors affecting successful project outcome were listed. 3 of them are: clear objectives, comprehensive briefs, and regular communication [151]. This also shows the significance of brief and briefing.

Although the vagueness of the briefs and specifications may provide lots of freedom to designers, it often causes wasted time. This was because design time and effort had to be spent on defining the problem, often producing unsuitable designs which had to be modified, rather than on solving it [59]. Oakley [154] has shown that inadequate specifications often lead to delays in product development and designs that are costly to manufacture and ill-matched to customer needs. It was repeated numerously that a clear brief and a comprehensive specification are vital to successful product development [155, 154]. The British Standards Institution acknowledged the importance of design briefs in BS 7000, by stating the dangerous side of an inadequate design brief as it may show that the management does not know what they want and the designer is misinformed about what is required [110]. Nevertheless, the existence of a detailed brief or specification cannot guarantee a successful design and development process. There is a need for a collaborative team approach to product development in drawing up briefs and developing specifications [59]. The creative process of defining requirements in systems engineering environments is named as requirements engineering. This approach will be explained in the next subsection.

2.2.2 Requirements Engineering

Requirements engineering was defined in ISO 24765 as follows [139, p. 381]:

> "interdisciplinary function that mediates between the domains of acquirer and supplier to establish and maintain the requirements to be met by the system, software or service of interest"

Elicitation of requirements is a crucial part of design as it was covered in the context of design brief and design specifications. Origins of requirements engineering can be traced back to software systems [156]. Definitions of related concepts, work environment and requirement elicitation processes are standardized in ISO 29148 [157]. In this standard, communication was emphasized as one of the responsibilities of the requirements engineer. Requirements engineers set the platform to reach a consensus or a joint resolution with other stakeholders. These stakeholders may be acquirers (clients), customers, operators and suppliers (contractor). Requirements engineering also set the baseline to verify the designs, and validate the design outcome against needs. It is a crucial part of the system development process; since, it was reported that errors related to requirements cost approximately 100 times cheaper to correct during the requirement engineering phase, compared to after system delivery [158]. Although the three objectives of requirements engineers have an intertwined structure among each other, the processes while constructing the requirements as a consensus will be examined closer.

Pohl [159] emphasized that the requirements specification process can be analyzed as a life-cycle, and it involves social and cognitive concerns. Apart from the analytical approaches in engineering design that was discussed in Section 2.1.1, the social domain in which requirements engineering discipline has a significant share of intersection, plays an important role in this “life-cycle”. There are complex social processes where cooperation and communication is vital among the stakeholders [160]. The requirements communication is suggested to continue not only during the life-cycle of requirements development process, but throughout the whole product life-cycle [161]. Requirements engineering attaches importance to obtain a formal specification that is agreed by all stakeholders. This formal agreement is elicited and identified from informal, fuzzy statements. This process is hardly deterministic or straightforward [160].

Requirements engineering has its own “life-cycle” composed of four major stages in an iterative nature. Loucopoulos lists these stages as requirements elicitation, requirements negotiation, requirements specification and requirements validation [160]. Requirements elicitation is the initial stage where the needs for a system and its constraints are being understood. Negotiation stage aims to set an agreement via negotiations among different stakeholders. These stages should also allow for collaboration with all stakeholders [162]. The requirements specification stage is the stage where “abstract” needs are transformed and converted into real and “tangible” requirements. This tangibility is usually a measure of how the requirement in question can be broken down into sub requirements and assigned to the respective subsystems. Requirements validation is the validation process that was emphasized in systems engineering. It is the measurement stage of how the requirements *specified* correspond to the original user needs in a right way, rather than being only correct. This becomes a feedback to the requirements elicitation. Validation stage is a critical one in safety-critical applications such as aeronautical products. It was suggested to link the safety goals to the evidence, and to make the assumptions and justifications explicitly.

Traditional approaches in requirements engineering were stuck in *what* the system will do, while the proceeding approaches included the *why* dimension [163, 164]. This dimension is said to be a teleological one, aiming to justify the presence of the system and its meaning to the stakeholders. It can also be observed in the conceptualization of *concept of operations (ConOps)*[19] as an outline and projection of the enterprise strategy [15]. This strategy concerning enterprise goals can also be analyzed in hierarchies as the requirements engineering approach to the system requirements. This process is required to study an operationalization [165] which includes methods such as goal reduction. The relation between the strategic planning of an enterprise and the product to be designed is analyzed in the light of goal elaboration and scenario definition. A goal can be defined as something a stakeholder aims to achieve, whilst a scenario is about how this goal can be achieved.

Requirement specification is stated to be the focal point of the requirements engineering process. It is also the medium where the needs of the customer and user are being communicated by the diverse population of the stakeholders [160]. Hence, it also involves social and cognitive concerns [159]. The social domain incorporates complex social relations; thus, communication and cooperative interaction play a major role in the process. Communication dimension is an obvious one so that inefficient and incorrect communication leads to badly functioning systems was reported in the 1970s [166]. Design interventions regarding the required cooperation in this domain are usually classified under CSCW studies. The need for collaboration is much more apparent when people are not facing well-structured problems but ill-structured ones. In these cases, both the intended outcome and how to reach that outcome need to be specified accordingly [167, 168].

Apart from the social domain, and its processes; there is a formal specification process in requirements engineering. In the helicopter industry, as a safety-critical industry, the formality of the requirements as written agreements is an important factor. It is aimed to get a verified briefing process. This process is moderated by the in-house requirements engineers of the contractor company. They generate several documents in order to ensure the formality of the requirements engineering process. Contract among the client institution, contractor and customer institution; particularly SPS part of the contract is the inception point for requirement engineers. Although the number of documents produced throughout the requirements management process may change with respect to the nature of the project; in a sample project, an evaluation of

[19] ConOps: verbal and graphic statement, in broad outline, of an organization's assumptions or intent in regard to an operation or series of operations [139, p. 87]

an operational concept (OpsCon)[20] document is generated just before the operational concept document. Operational concept document studies and analyzes the mission profiles given in SPS according to other requirements mentioned in the brief. The main mission during the initial requirements engineering process is to create the first issue of system/subsystem specification (SSS) documents. This is because the SPS document usually leaves gray areas, and uncertain statements which need designer's involvement to be fully defined. Therefore, SSS can be considered as the *fully defined version of the design brief*. This process can be summarized as in Figure 2.21.

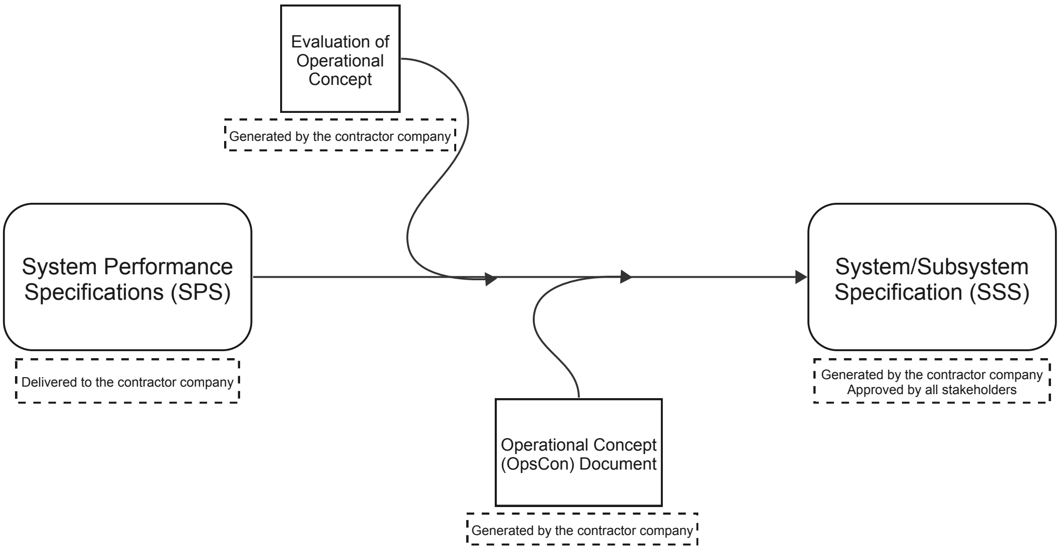

Figure 2.21: Formal Process of Design Brief Development in Requirements Engineering Practice

SSS document gives an item number to each particular requirement derived from the list of demands and expectations stated in the contract and during the meetings. This document provides the origins of the requirement and its allocation to design groups. Draft version of SSS is created right after the contract is signed. The generation of SSS is the formal part of the conceptual design process. It is the enhancement and understanding of the brief. When the initial, first issue of SSS is generated, a decision gate meeting SRR is held with the participation of stakeholders. The client institution and customer institution agree on the progress and the detailed version

[20] OpsCon: verbal and graphic statement of an organization's assumptions or intent in regard to an operation or series of operations of a system or a related set of systems [139, p. 302]. It is commonly confused with ConOps, and used interchangeably in the industry.

of the draft. Nevertheless, this is not the finalization of the SSS creation process. The SSS document is updated, and its issue number advances as the second issue, third issue etc. The refinement of the design brief, or SSS, is a continuous process throughout most of the life-cycle of the product.

It is important to review the processes as they are applied in the industry; since, it was reported that there are certain disparities between these requirements processes and formal design methods [169, 170]. Darlington and Culley [21] conducted an interview study in three different companies whose work areas are mostly related with mechanical engineering and electronics engineering. One of the first outcomes of the interviews conducted within the companies is that the issues faced and emphasized by the design engineers and managers are different. In one of the case studies which can be considered as an extreme case, the sales department prepares a wish-list, and an engineer conducts a conceptual design loop themselves. The outputs of this design loop influence the design requirements.

2.2.2.1 Factors in Requirements Development Process

Darlington and Culley [21] categorizes the customer needs with respect to the work needed to transform those user needs into design requirements. They introduce 3 levels: "haven't got a clue", "semi-developed", and "full specification". The aim of requirements engineering is said to set all the needs into full specifications. The factors that influence the requirements are mainly about the general nature of the product, the case-specific nature of the project, customer/designer relationship, the multiple roles of the design requirement. The case-specific nature of the product emphasizes the need for process analysis and influence factor studies, specified for the particular type of product and industry. Therefore, the analysis concerning helicopters in a defense and civil market is essential to observe what aspects are critical in requirements engineering processes. Requirement specifications, or design specifications are heavily based on technical needs; however it was stated that the politics and content in which the design and development works take place also influence the requirements [21]. Major factors influencing the design requirements are presented in Figure 2.22.

Design activity types such as parametric design and adaptive design, is another factor

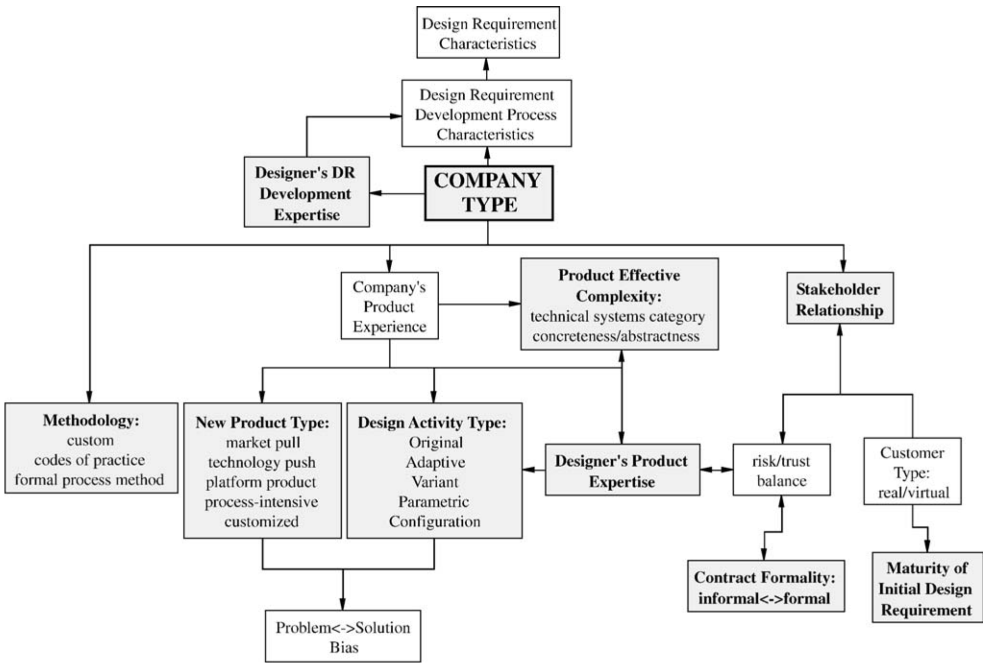

Figure 2.22: Factors Affecting Design Requirement Development Process and Design Requirements [21, p. 344]

that influences requirements. Customer type and maturity of initial design requirements are stated as sub-factors. Company type is placed at the center and focal point in which the other factors influencing requirements are in relation. The relationships between a company's products, workers and customers mostly define the company type, and the company itself. Maturity of the design requirement is a concept to define developed or enhanced requirements. This enhancement level is about how precise the requirement is expressed. Information presented in brief and expressed in the customer's point of view must be elaborated in a structured way, using more precise terms suited to the task of design. Ulrich and Eppinger [171] state that customer needs are expressed in the language of the customer typically characterized by subjective phrases. This may cause too much room for subjective interpretation. There is a need for translation into the quantitative language of technical specifications. On the other hand Luqi and Kordon [172] call this language as the natural language which is inescapable. This is the result of the fact that most of the communication with stakeholders is conducted in natural language.

2.2.2.1.1 Stakeholder Types

In Figure 2.22, it can be observed that stakeholder relationship is one of the major factors that affect design requirement development process. Wootton et al.[173] defines the term *stakeholder* as any agent with an interest in a new product. There are two types of stakeholders: external stakeholders and internal stakeholders. External stakeholders are customers, users, suppliers, distributors, subcontractors; whereas, internal stakeholders are marketing, engineering, manufacturing, sales, services, purchasing departments and related agents inside the contractor company. Darlington and Culley [21] extends this list of stakeholders by adding the designer. The designer usually conducts the requirements elicitation process by themselves and has a significant stake in the outcome of the design.

2.2.2.1.2 Complexity of the Product and Methods Used in Requirements Development

Another major factor in Figure 2.22 is the design activity type which was discussed in detail in related subsections under Section 2.1. It should be noted that the complexity of the product has a bearing on the complexity of the requirement development process and the level of detail requirement in the brief [21]. Hence, in the helicopter industry, a new product development process aiming to design a brand new helicopter, the level of complexity is much higher compared to mass production industrial products. Another consequence of system complexity is the fact that communication also gets more and more difficult as the systems scale up [172]. This complexity level is usually intended to be compensated by the use of systematic methods such as systems engineering; however, in most companies, *ad hoc* requirement capture methods are used [21]. Knowledge on requirement development activity is essential in addition to product design knowledge, in order to produce a useful design brief. Some companies are expected to embrace systematic and formal methodologies such as the defense industry, because they are influenced by issues of certification and quality assurance. Nevertheless, their requirement development processes appear to be loosely structured. Considering all the major and minor factors for requirement development activity, it can be said that there is no ultimate method or approach to manage these processes which is suitable for all companies [21].

2.2.2.2 Communication Gaps

Bjarnason, Wnuk and Regnell [70] emphasized the organizational and social character of the challenges in requirements engineering. They investigated the causes of the communication gaps and their effects on the requirements development process.

2.2.2.2.1 Stakeholder Participation

One of the issues, which is at the intersection of organizational and social domains, is the selection of stakeholders as individuals. Some people play the role of *information brokers*, they are key people who can both accelerate and decelerate the information flow [174]. There may also be unauthorized people causing missing communication [175]. Stakeholder participation and selection was also mentioned by Coughlan, Lycett and Macredie [162]. They also asserted that inappropriate people may affect the requirements engineering process negatively. Project managers were found to be essential in connecting with users, since their work requires strong communication skills that developers usually have difficulty with. Stakeholder participation issues have some subdimensions as task knowledge and skill, status and responsibility. In an ideal case, stakeholders should be selected on the basis of skills in domain knowledge. However, stakeholders are chosen on the basis of position and status.

Bjarnason et al. [70] identified four major causes of communication gaps. These are complex products and large organizations, low understanding of roles, gaps between roles over time and unclear vision of goal. In helicopter design, the product is a complex one, requiring a large organization to handle the design work. Therefore, the first cause is an inevitable one to have in this context. Unclear vision of goal may lead to power struggle among technical teams focusing on technical areas. Without constructive communication, this struggle may pit some teams against each other. This is also related to overscoping, or not having the same scope over the issues. Weak understanding of the other's work may also deepen the issue [176]. This issue is also related with the visibility of the design process model being used. Pugh

[109] suggests that if the operational structure becomes visible for everyone in the design organization, then a common understanding of what people are doing can be developed. Moreover, some stakeholders may be selected regardless of their domain knowledge on the particular subject. There are cases in which delegates and delegates of delegates may be selected to be representatives for requirements meetings when there are time restrictions for the real participants. This is also related to the effective status of the participant. Some delegates may not have the authority to make decisions and have to take it back to their managers. This also causes continuity issues [162]. These communication gaps may cause unclear requirements which then causes wasted effort. If one of the internal stakeholders' concerns are included in the requirements at a later stage, this may bring some of the requirements in an unstable phase; further, there may be conflicting requirements. Unstable requirements may also stem from weak communication between the customer and developer [177].

Communication gaps occurring between requirements engineering teams and development teams during the early phases of design have been reported to pave the way for requirements that could not be implemented [177, 161, 176]. Recalling the case of prescriptiveness of a design brief [75], a requirement that is too prescriptive may create an illusion that the need for requirements review is not needed. This illusion further deepens the communication gap [70, 177]. Communication gaps in requirements engineering processes have also been studied and classified by Coughlan et al. [162] and it was mentioned that culture gaps and basic semantic differences between users and designers resulting in communication gaps. Four dimensions were identified for the origins of the gaps. These are *stakeholder participation, stakeholder interaction, communication activities and techniques* [72].

2.2.2.2.2 Stakeholder Interaction

Having mentioned the details of stakeholder participation, stakeholder interaction is said to be related with the process of communication. It was found to have four sub-dimensions [162]. The first sub-dimension is culture and politics. In terms of organizational culture, Quinn and McGrath's model [178] was found to be relevant. In this model, there are four cultures of organizations. The first one is the rational culture operating within the rules of market[21]. The second culture is the ideological culture where an *adhocracy* works rather than a bureaucracy. The third one is the consensual one, and the medium resembles a clan. The last one is the hierarchical culture in which there is a strict hierarchy. The rules of a fully competitive market are not applicable to the conditions of the helicopter industry due to its strict connections to defense industry and political decision-making. Fundamental decision-making dynamics in the contractor company is a hierarchical one; on the other hand, depending on the political conditions of the country, industrial and strategic planning concerning defense industry may resemble an adhocracy even though there exists a bureaucratic state structure. Cultural differences should also be investigated through the lens of different nations especially during international collaborations. There are differences in procedures. Some stakeholders may prefer perfectly written procedures, compared to others who may not. Moreover, as an instance, in Eastern Europe, there is a blame culture in which the decision-makers are afraid to make decisions; because a wrong decision may be punished by the loss of their jobs.

The other sub-dimension of stakeholder interaction is communication schedule [162]. It is related to how the organization establishes direct communication links in relation to the former sub-dimension. The last one is about the roles of the managers concerning problem finding and problem solving approaches. The third sub-dimension is methodological approach that covers the issue of the gap between the prescription or the written format of how the requirements are elicited, and how it is done in reality. It was observed by Coughlan and Macredie's interviews [72] that there is a lack of methodological approach. The last one is about the roles of the managers concerning problem finding and problem solving approaches and managers may abuse their position by taking an autocratic role that inhibits communication.

2.2.2.2.3 Communication Activities

Communication activities focus on the activities carried out by design teams. According to Hartwick and Barki [179], there should be user participation. For reliable communication, there should be shared understanding. It can occur through coopera-

[21] It should be noted that rationality is one of the key ideas in economic models, commonly used in microeconomics. It assumes that people act rationally while deciding on economic decisions.

tion and negotiation. Communication activities occur in three stages: knowledge acquisition, knowledge negotiation and stakeholder acceptance. Coughlan et al. [162] have discovered several themes related to those stages. In the knowledge acquisition stage, there may be gaps between the level of detail required by technology and users' aspiration. It was reported that there exist biased practices, like a reaction to progressive agenda. In addition, there may be some redundant work which becomes invisible to the active agent and the commitment of stakeholders may vary. In the negotiation stage, information exchange plays an important role. To that end, some gamification techniques and analogies are used as familiar processes which intend to keep people's interest alive. Themes discovered under stakeholder acceptance include feedback's medium such as emails as poor practice. There is a fear factor meaning to fear to lose the job which inhibits the stakeholder from participating. There is a resistance to change as a backlash reaction of a new system by the user. This change's management heavily rests on the managers' accountability to manage the change.

2.2.2.2.4 Communication Techniques

The last dimension investigated by Coughlan et al. [162] is the communication techniques used in requirements engineering processes. Requirements elicitation through questionnaires and interviews were considered as traditional elicitation techniques. Brainstorming and workshops were categorized as group elicitation techniques. The effectiveness of each one over the other depends on the context. One-to-one interviews are advantageous compared to workshops concerning the level of details which can be gathered. There may be cases in which some stakeholders may require support for negotiating. In those cases, group sessions were found to be more effective in terms of support. Workshops are advantageous regarding the fact that stakeholders break their barriers. For instance, they get out of their environment and meet the users. The big picture can be constructed in workshops with the help of different stakeholders who play minor roles of which they come together. Inappropriate people may attend the workshops like inexperienced people who cannot make sufficient comments. Appropriate people may not find or create enough time to attend which is also related to stakeholder participation.

Luqi and Kordon [172] point out some issues stemming from requirements engineering processes, especially for the practice in complex systems. As it was sampled in Section 2.2, these systems have longer documents compared to simpler products. People may not be effective at finding widely separated connections in such long documents; although, they may be quite effective at analyzing small pieces of text in depth. Another issue is the language difference between the fuzzy needs of the stakeholders and the formal models used in design. Those fuzzy requirements should be redefined, and if there are conflicting requirements, then these should be reconciled by raising extra questions to the stakeholders. Luqi and Kordon pondered on systematic solutions in these communication gaps, and they asserted that interdisciplinary methods and tools are needed to go from natural language to accurate formal specifications. The implementation of this system requires efficient communication and iteration among stakeholders. Approaches including the usage of artificial intelligence can be utilized by creating prototypes which can be used in requirements engineering processes in order to develop and explore the requirements. Computer aided design (CAD) methods can be beneficial and theoretical results and complex mathematical ideas behind these systems can be hidden so that the practitioners do not have to fully understand the theory. It was also indicated that such a system should be user-friendly or easily maintainable. This type of system will be treated as a boundary object among stakeholders from different backgrounds.

2.3 Computer Supported Cooperative Work in Design and Development Environments

Organizations aiming to design and develop complex products need to bring different groups of people together to carry out multidisciplinary tasks. Therefore, the collaboration among groups has become an important issue. Computer supported cooperative work (CSCW) is a discipline focusing on the issues and solutions in this field. CSCW solutions include computer-based systems called *groupware* that provide an interface to groups of people to engage in a common task [180].

In large organizations, people are aimed and directed by the management to reach a common goal.[22] On the other hand, individuals may have different roles that are required to reach that goal. Although there are systems used in workplaces such as electronic mail or video-conferencing systems for communication and cooperation, it can be said that those systems do not contain organizational knowledge. Therefore, workflow management systems gained importance as *organizationally aware groupware* [181]. Workflow applications are said to be divided into two categories with respect to the nature of the processes that were aimed to be supported [182]. The first division deals with well-structured and repetitive processes [183]. The second one deals with ill-structured and *ad hoc* processes [184]. In many organizations, well-structured and ill-structured processes and workflows may coexist [185, 186]. In addition to this taxonomical approach, there are other classifications regarding CSCW characteristics such as information sharing, communication and coordination [187].

There are numerous examples of workflow analysis and management systems [188, 189]. Prominent examples include Askalon [190], INCONCERT [191], Triana [192], Taverna [193], SIBYL [194], Unicore 6 [195] and YAWL (Yet Another Workflow Language) [196]. Many of the workflow management systems aim to monitor and analyze workflows. Examples such as SIBYL also aim to contribute to decision-making processes by representing certain qualitative elements.[23] SIBYL includes decision graphs, which portrays the pros and cons of deciding among different alternatives in order to satisfy a particular goal. Another approach to decision-making support was developed by Rozinat et al. [198]. Rozinat el al. utilized YAWL system with historic decision logs to construct a simulation for near-future behaviors.

In manufacturing-oriented industries where multiple agents need to cooperate, product lifecycle management (PLM) systems were used to model workflow activities, and data from CAD and PLM systems were integrated into a CSCW infrastructure [199]. PLM systems are groupware that is used for the storage and organization of product data. They are used for coordination of life cycle activities [200]. Siller et al. [199] studied an integrated CAD/CAM application on a PLM system, PTC Windchill [201] which was found to satisfy the CSCW requirements of collaboration [202, 203, 204], to design and manufacture a product with the contribution of multiple enterprises.

[22] This goal can be productive, non-productive, or both.

[23] SIBYL is also the name of a countrywide management system in an anime named *Psycho-Pass* [197]. This system automatically decides on people's careers and even gubernatorial elections.

In a design and development environment where multiple enterprises contribute to the product in terms of its design, manufacturing, logistics; there is also an issue regarding change management. In industries where the products have very long life such as trains, aircrafts and similar capital-intensive products; change is considered inevitable because the life-cycle is so long to accommodate changes in technology, redesigns and retrofitting of parts [205]. In these industries where engineering change is commonly observed, *traceability* of the decisions should also become important in order to track how that change was decided. Matta and Ducellier [206] integrated cooperative decision-making logs into a PLM system (PTC Windchill [201]) to create project memory.

In addition to workflow and decision-tracking capability of groupwares, information flow in general is an important concept in large organizations. Subrahmanian et al. [207] underlined the potential deterioration of the common ground when there is an informational flow change in engineering organizations; since, the organizational structure and information flows determine the shared representations among different perspectives on design activity. Considering engineering as a social construction dealing with conflicting goals and interpretations from stakeholders with different approaches from different object worlds [208] the need for a *boundary object*[24] becomes necessary to create a nexus among those object worlds. Boundary objects can be artifacts, discourses and processes [210] as they serve groups consisting of participants or stakeholders who have partial knowledge and partial control over the interpretation of an object [211, 212]. In engineering work, prototypes and boundary objects have reciprocal definitions as they link different perspectives [207]. As a boundary object links multiple perspectives, it gains a prototypical role, and increasing number of links make it more tentative. According to this definition of connecting different perspectives, a design specification document can also be considered as a boundary object.

Creation of the links among different approaches also requires a study on the cognitive structures underlying a boundary object; hence, Subrahmanian et al. [207] also pointed out the need for a translator of the boundary object. Taylorism attached

[24] Boundary object was first conceptualized by Star and Griesemer [209] while observing dead birds being a boundary object between bird watchers and biologists.

importance to the minimization of this cognitive need via well-defined boundary objects. Although this approach has worked on mass production by the dynamics of economies of scale[25]; as Taylorism transformed itself by globalization and complexity, the dynamics of design and production have also changed, and well-defined boundary objects became insufficient for economies of scale. One of the main issues regarding this insufficiency is the lack of communicative efficacy around the boundary object [207]. It should be emphasized that the boundary object becomes a tool for knowledge communication, referring to Fischer and Ostwald [150]: "The interaction around a boundary object is what creates and communicates knowledge, not the object itself."

Boundary object is a wide concept in which "design" itself can also be considered as boundary object from a linguistic point of view [213]. The following subsection will discuss the concept of design-decision support system in relation with design support systems and decision support systems, through the lens of CSCW and as examples of boundary objects.

2.3.1 Design-Decision Support Systems

Design-decision support systems can be considered as decision support systems about design decisions. Decision support systems have been a field of research related to business and management disciplines as knowledge systems. Their possible implementation in architectural design was discussed [214]; however, the real impact stayed limited [215]. Several prototypes were developed for a wide range of contexts. Sagdic and Demirkan [216] presented an example for renovation architecture. Lee et al. [217] discussed an implementation for interior design, including the end-user and client in a cooperative system. This system aimed to estimate the application cost of a proposed design as a decision-making support for the client during the evaluation of design alternatives. Similarly, Zanni et al. [218] integrated cost data into building information modeling for assisting design-decision making.

DDSS is usually seen as a knowledge-based system, particularly focusing on design

[25] Economies of scale, in microeconomics, refers to the decreasing average cost, as the quantity of outputs increases.

knowledge. An example from the helicopter industry was presented by Beggs et al. from Boeing Helicopters[26] as a study within concurrent engineering [220]. Concurrent engineering was considered as an approach to improve design quality, by integrating multiple disciplines. Mentioning issues in the design process such as the fact that agents may have diverging ideas of the process, it was aimed to build a system containing relevant knowledge needed for a preliminary design environment. Due to the complexity of the product and the dynamic nature of the constraints, it was found impossible to work out the details of each design alternative. Hence, approximate methods were developed to assess design solutions. Design assessment was considered as a form of decision making under uncertainty. Uncertain information and its management play an important role in early design decisions. Furthermore, Beggs et al. [220] also acknowledged the interdependent structure of design decisions as an essential factor to be identified for concurrent engineering. One of the main objectives of this system was to assist the design engineer to account for supportability, operability and producibility requirements, promote design for X approach [221] such as design for producibility and design for supportability. The multidisciplinary nature of design causes an increasing amount of information to be exchanged; therefore, the decision-making becomes more complex [73].

Application of concurrent engineering with design for X approach was also discussed by Xu et al. [222]. Considering various elements of the product life cycle in early stages of product design and development was emphasized. On the other hand, it was acknowledged that lack of information, vague objectives are present at those stages, and these make it difficult to evaluate the design objectives in a quantifiable manner. However, it is required especially while comparing conflicting objectives such as material performance versus material cost. Xu et al. [222] developed a decision support system by quantifying some fuzzy statements like “kind of feasible” and “product sounds reliable” [223].

[26] It now operates as Boeing Vertical Lift division under Defense, Space & Security unit of The Boeing Company [219].

2.3.1.1 Design Requirements of DDSS

There are studies on how to design a DDSS, or design support system, or decision support system, focusing on the requirements of those systems. Rose et al. [224] conducted a systematic literature review on the factors that affect the design of a decision support system. Although their focus was the systems used in agriculture, there are generalized factors and attributes that may be both a success factor and barrier mentioned in the reviewed literature of 34 papers. Usability or user-interface design, being fit to workflow, trust and confidence in the system, integration with existing systems are among the most mentioned factors.

Knowledge-based systems and related design support systems also deal with the issue of information delivery. This issue becomes critical in the briefing stage since it has a significant effect on the whole design process as emphasized in Section 2.2.1. Conventional delivery methods were found impractical, and vague descriptions of product qualities with the lack of clarity in general were also listed among the issues of design briefs [225]. Töre-Yargın and Erbuğ [225] have listed required attributes of an information delivery system which can be used as a design support system, focusing on automotive design. Since it was desired to have the underlying reasons for the judgements in design [226, 227], informativeness of the system was found to be important. On the other hand, giving excessive information can have a negative impact; hence the information should be delivered in a concise manner. This requirement was conceptualized as concision by Töre-Yargın and Crilly [228] in a study focusing on the user requirements of a design support tool dealing with analogical design. Concision needs a balance between brevity and completeness [229]. Giving excessive information may harm the communication of the core principles needed [230, 227]; whereas, the information provided should be sufficient enough that the principle can be comprehended [230, 231].

The information provided to the user should also be open to interpretation. This is related to open-endedness of the information [228]. The content should not restrict the imagination of the designer; instead, it should provide an interpretability in which the designer will interact and interpret. Otherwise, if the content is provided in a closed and definitive manner; it may lead to fixation issues [230, 229]. In relation to open-endedness, abstraction was found to be a key attribute of the information in order to prevent limiting the creative stimuli [232, 233].

Exemplification was also emphasized [225, 228]; since, abstract concepts are found hard to communicate [229]. This was found useful for novice users [234, 235]. Provided information was suggested to have different modes of representation such as texts, drawings, photographs, animations etc. This helps the user to cover the information from different aspects and get a holistic portrait of it [236], and it was also found helpful to stimulate inspiration for practitioners dealing with biologically-inspired design [237]. Moreover; abstraction, open-endedness, concision and multiple modes of representation may be presented in multiple degrees referring to the multiplicity of the information [228].

Töre-Yargın and Erbuğ [225] also listed multidimensionality, in-depthness and sustainability qualities as requirements of the information in their design support system. Multidimensionality refers to the multiple perspectives contributing to the design including diverse users and other shareholders. Sustainability of the information is about contributing to the corporate memory of the design organization.

Interactivity and compatibility of the system with the current communication media which is being used by the organization was acknowledged as a significant attribute of the system [225]. This attribute is similar to the connectivity requirement explained by Töre-Yargın and Crilly [228] as the integration with other tools. It is an important aspect when concurrent engineering methods are considered, such as the synchronous usage of CAD tools and PLM softwares. Other qualities of interaction of a design support tool are accessibility, interactivity, transparency, shareability, restoration and adaptability [228]. Accessibility was listed as one of the fundamental qualities referring to the easy retrieval of the content. Interactivity is enabling the tool to respond to the user [238], and giving continuous feedback. Transparency is being transparent about how the system works, and preventing the misalignment of the conceptual model between that of the core of the system and the mind of the user. Successful modeling has its rewards in both usability and discoverability [69]. It also makes the user feel that they are directly interacting with the process [239].

Decision-making in design organizations have multiple perspectives including that of designers and managers. Martin [240] brought out the fact that executives prioritize reliability and consistency on design outcomes, whereas designers tend to value validity meaning the desired outcome. Therefore, Töre-Yargın and Erbuğ [241] also found out that the design decisions in a supportive system, should be persuasive by providing reliable data. Another perspective difference among internal stakeholders takes place between designers and marketing specialists. This difference can be observed in the design briefs prepared by marketing departments. Prioritization of problems stated by the users according to their experience can be utilized in order to guide the designers in terms of design requirements, supporting their design decision-making process [241]. Differing requirements due to multiple stakeholders are also related to shareability and adaptability requirements of a design support tool [228]. Making the content of the tool shareable among different stakeholders strengthens the communication and collaboration [242]. It should also be noted that the level of detail required by different stakeholders may differ [239]. Moreover, requirements of an expert designer and a novice designer may differ, too. The tool may be adaptable and customizable, considering those differences [238]. The last requirement in terms of interaction qualities is restoration. Being able to store the information and returning back to the previous stages were found effective and supportive during design [243].

There are also relations between some requirements concerning information qualities and interaction qualities of the design support system, such as conflict generating and conflict resolving [228]. For instance, exemplification may lead to fixation and it conflicts with open-endedness. In order to overcome this issue, multiplicity may be promoted; since, it supports open-endedness. Transparency and accessibility have a positive relation; because, transparency allows the user to comprehend how to interact with the tool. In contrast; open-endedness may conflict with accessibility, since it may risk clarity by making the content open to interpretation. Shareability also contributes to accessibility; on the other hand, interpretability and open-endedness may harm shareability, since it will be hard to have a common understanding when every user has their own interpretation on the content [244]. Accessibility can also be affected negatively with increasing levels of connectivity [228].

2.4 Discussion

"A city is not a tree."

Christopher W. J. Alexander, 1965

[245, p. 58]

Reviewed literature approached similar issues from two main perspectives: that of engineering and industrial design. Methodology studies in these two major disciplinary fields have common origins in initial attempts to scientify design methods. However, the definitions and concepts used in those methods diverged as the studies progressed [23]. Roozenburg and Eekels [4] had compared their basic design cycle (Figure 2.4) with Hall's systems engineering model (Figure 2.2). Horizontal dimension of Hall's cycle can be analyzed in these stages: problem definition, value system design, systems synthesis, systems analysis, selecting the best system (optimization and decision-making), and planning for action[27]. Problem definition covers the study of needs and environment. Value systems design is about stating the objectives and criteria for success. Systems synthesis is the stage where alternatives are generated. Systems analysis deduces the consequences of the alternatives. Selecting the best system is conducted by comparing consequences with the criteria set in the second stage. The final stage, planning for action, represents the progression to the next project phase. Comparing Hall's cycle with the basic design cycle, the basic design cycle concludes the synthesis step with one provisional design. Each alternative has its own cycle, it can be said that the basic design is more fundamental in this aspect. The basic design cycle does not include the implementation step, because it was considered to be yet another problem-solving process. Analysis is used as gathering information on a problem in industrial design terminology, not the other hand in engineering terminology, analysis means simulation or testing. The basic design cycle follows the industrial design terminology.

It can be said that Hall's cycle is for problem-solving in general; whereas, the basic design cycle is for design problems. This is apparent in the basic design cycle's

[27] Hall's two dimensional concept of systems engineering was also criticized as its logical dimension was overlooked, and the time dimension was emphasized by its practitioners [23].

initiation point as the function to be realized rather than a problem [4]. This conceptualization of the "problem" is one of the most important differentiations between the two disciplinary approaches. Moreover, in some engineering design models such as the high-tech commercial business model proposed by Forsberg et al. [14], problem definition was seen as a separate stage apart from product development. This deterministic approach further deepens the issue of the assumed well-defined problem as if the problem is not defined with the progression in design and development. Furthermore, design and development were defined separately in NASA models [132, 133] as design refers to the phases before the development as in Forsberg et al. [14].

It was discussed that the nature of the problem was defined differently as well-defined on one side, and ill-structured wicked problems on the other side. Starting from the assumptions on the independent structures of design problems in engineering literature [87, 86], systems engineering approached the analysis of the problem through a breakdown procedure. This breakdown approach resembles a tree structure that is assumed to be underlying the problem. In contrast, industrial/architectural design does not approach this issue in a deterministic fashion where the connections can be drawn apparently. Breakdown approach of systems engineering assumes the systems and subsystems of a design to be hierarchically structured. Complex problems are decomposed into sub-problems [23]. Nevertheless, the relations among the parts of a design are not necessarily in a tree-like structure [22]. This difference can be represented as in Figure 2.23.

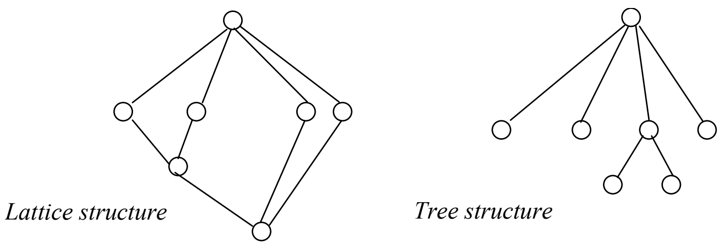

Figure 2.23: Lattice Structure vs. Tree Structure [22, p. 164]

Representing the systems in a tree-structure and analysis of systems by a breakdown procedure also projects onto requirements engineering processes such that the requirements will also be broken-down into sub-level requirements. On the other hand, it is also acknowledged that the interrelations among subsystems present a complex structure that a sub-discipline of systems engineering was created as systems interface management. Interface management responsibles aim to define the interfaces among the systems as early as possible starting from system requirements definition processes [15]. Interface management plays such an important role in systems engineering that in the organizational structure of the contractor company, systems interface management is a separate unit like requirements engineering under systems engineering. Hierarchical representation of systems and their requirements allows an analysis and classification approach in a relatively more straightforward and sequential manner. There are levels of systems to be analyzed in a top-down approach, and verified in a bottom-up approach as it coincides with the Vee model (Figure 2.17) [14, 15]. Consequently, this issue is directly related with the life-cycle model and design process model to be used in a design and development process. It should also be noted that the selection of design process models is usually a consequence of design management at the strategic level of the management of an organization or enterprise.

Large companies deliberately choose traditional, linear, gated waterfall methods[28] for the ease of management; since, allowing iterations become too expensive for an organization designing complex products [69]. Gates were also discussed to be useful in terms of designing management where complexity is a real issue such as aerospace engineering projects, and this complexity grows larger with the complexity of the product, processes and organization [22]. Decision gates are used in the life cycle model proposed in ISO 24748-1 [130]; however, they were not treated as mandatory to imply a sequential design process [15] as if the progression after a decision gate would be allowed to be in iteration enclosing the stages before that gate. This problem was also acknowledged by Forsberg et al. [14] that if a project passes preliminary decision gates such as SRR and PDR prematurely without sufficient contribution of technical experts, some design requirements that cannot be built may be accepted.

Another projection of the aforementioned top-down analysis and bottom-up verification can be seen in the problem solution method. Consensus model of engineering analyzes the design problem in abstract terms and gradually refines it. Moreover, the decomposed problem is assumed to be solved in a symmetrical manner, starting from

[28] It should be remembered that the Vee model is a representational variation of traditional waterfall method as discussed in Section 2.1.3.

sub-solutions to the overall synthesized solution [23]. This approach is also observable in functional decomposition and morphology (FDM) in which the problems are intended to be defined as solution-independent functions. However, this definition of problem function is also criticized emphasizing the dependency of the system's functional structure on the solutions [246, 247]. Similarities can be drawn between the Vee model and problem decomposition model introduced by VDI, as can be seen in Figure 2.24.

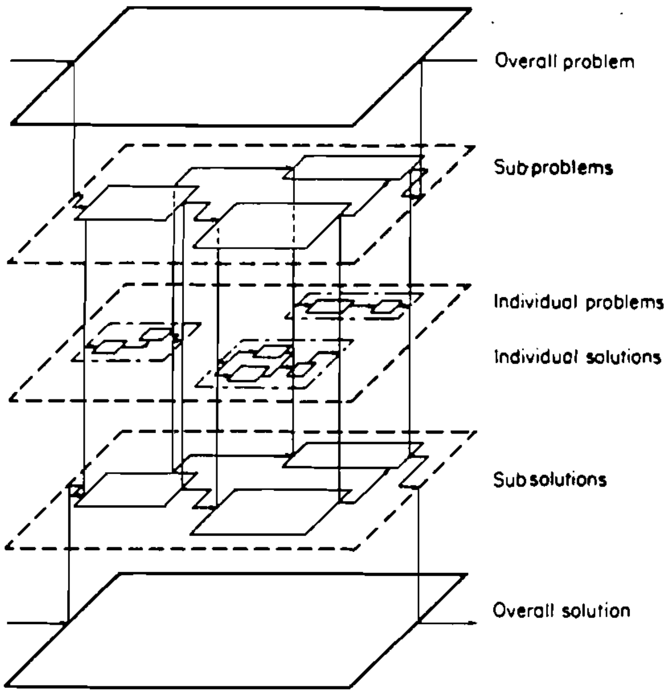

Figure 2.24: Problem Decomposition and Solution Synthesis by VDI [23, p. 328]

Problem decomposition and solution synthesis approach intends to make the problem-solving more efficient and effective for the designers, instead of an intuitive and unsystematic approach. However, it was criticized for being weak and heuristic; since, its foundations rely on weak knowledge on the insights being considered for design decisions, and it expects the designer to make sensible and informed interpretations regarding the problem [23]. Strong oppositions to the decomposition of problems were discussed under solution-oriented design methods such as Darke's [99] solution concepts as primary generators, and March's [100] productive reasoning instead of analytical, inductive or deductive reasoning. Therefore, design process models in architectural and industrial design were said to reject the linear, sequential, and analysis-synthesis-evaluation scheme of scientific method [23]. Acknowledging the drawbacks of the systematic approaches such as hindering of the ability to generate novel ideas [248], computer-supported aids (e.g. TRIZ[29]) are being integrated to overcome those issues [251].

The decomposition concept of problems into subproblems was also discussed during the introduction of function-oriented design methods. In those type design approaches, there needs to be an order of subproblems to be analyzed and solved. This raises the importance of some evaluator agent who decides the importance of the problem. The function-oriented strategy may have advantages and disadvantages. The apparent advantage is the fact that focusing on an *important* problem directly, may save a considerable amount of time [94]. Nonetheless, this focus may result in the lack of optimization when the design is considered in a more holistic manner, or as a supersystem, if the interfaces between sub-problems are not defined well. For instance, during a helicopter design project in which the engine selection is ambiguous, the transmission system gains importance due to its direct relation with the engine. If the design manager prioritizes the transmission with lack of analysis of the interfaces, an over-designed or over-engineered transmission system may increase the weight of the structure which holds it, and eventually increase the gross weight of the vehicle by snowball effect. Then, the resulting vehicle may pay a payload penalty in order to compensate for it. Moreover, as the design progresses and converges to a solution, the effort needed to improve it increases, as was indicated by Evans [104] during the introduction of the spiral model. This poses a significant issue in large-scale products such as a helicopter, since every step to be taken back may cost huge amounts of financial resources and labor.

It should also be noted that the consensus model of engineering stems from stage-based models; whereas the type model of architectural/industrial design [23] is more activity-based. Furthermore, problem-oriented and solution-oriented classification is also related to this dichotomy. Stage-based models are usually problem-oriented; on the other hand, activity-based models may adopt both of the strategies of being

[29] TRIZ stands for Teoriya Resheniya Izobretatelskikh Zadach (Theory of Inventive Problem Solving). It is a solution generation algorithm [249] which was reported to be used by several technology companies including The Boeing Company [250].

problem-oriented or solution-oriented [1]. Considering the advantage of early design concepts for the comprehension of the problem as discussed in Section 2.2.1, purely problem-oriented design strategy may also contribute to the snowball effect discussed above. As Frost [252] discussed, a convergent approach including both strategies may be useful, according to the individual conditions of each problem.

On top of the discussion concerning different models and methods in design literature, it is an ambiguous phenomenon whether those models are used in the industry. Differences between the practice in industry and discourses in academy were discussed [253, 170]. One of the reasons why industry does not completely implement design methods provided by design science was said to be the conservative market conditions. Designing something which is *more than incremental* carries a significant amount of risk in terms of errors in usage, re-training, unavailability of training, market rejection etc. Thus, the majority of products designed in industry are stereotypical [170]. This list of risks can be extended when safety-critical industries such as the helicopter industry is considered, even though the market conditions differ in the context of SOEs where the market and customer are already ready for the product. Although the expectation regarding the methods used in this type of industries is highly systematically such as the implementation of systems engineering methods; Darlington and Culley [21] pointed out the fact that ad hoc methods are used which was also acknowledged by Coughlan et al. [162] as the discrepancy between the formal techniques and how they are done in reality.

Organizational design was a major discussion affecting the requirement identification and elicitation processes in requirements engineering. It was also mentioned in Ullman's [20] mechanical design process as the fact that forming the design team is also a part of the process. This implies a dynamic organization, and deciding on the sequence of tasks implies a dynamic understanding of the design process. Dynamic understanding of a design process model can be studied with the help of previous design experiences and related data [18]. A design support system was also mentioned by Clarkson and Hamilton [118] to be utilized in order to select activities in an efficient way. The system was said to provide essential design data, as well as non-essential but potentially useful data. However, it should also be mentioned that the infrequency of helicopter projects is an important factor that makes the data gathering difficult, and people may not be eager to conduct process postmortems [18].

Dynamic organization according to the projects has similarities with integrated product design teams as applied in Sikorsky Aircraft Corporation[30] as investigated by DiNuccio [53]. Another intersection between the design process models and factors affecting the requirements identification was observed in Hales and Gooch's model [10] as macroeconomic level influences on the design which includes social issues and political climate. This was also the case in stakeholder interaction issues as discussed in Section 2.2.2.2.2 [72].

[30] It now operates as Sikorsky, a Lockheed Martin company as a subsidiary of Lockheed Martin Corp. [254]

CHAPTER 3

METHODOLOGY

This study explores the methods and approaches used for requirement identification in the helicopter industry, in order to support this process through design. As an exploration tool, a prototype DDSS was used in interviews conducted with different stakeholders involved in the requirements identification and elicitation processes. This chapter fundamentally explains the data collection and data analysis procedures. The first section, data collection, firstly explains the data collection procedure in the form of interviews. Then, it explains how the DDSS works that was used as a part of the data collection. Sampling, ethical considerations and the details of the interviews are explained according to the participants as requirements engineers, managers in the contractor company, and representatives who previously worked at the client institution and the customer institution. The second section explains how those data gathered from interviews were analyzed.

3.1 Data Collection

It was aimed to gather the insights concerning the requirements identification processes from the practice in the helicopter industry. Therefore, qualitative data were collected through semi-structured interviews. The target group of participants are decision makers who are currently working or had previously worked in the helicopter industry.

Data collection procedure followed an inverse sequence of hierarchy and business flow. Business flow starts from the customer institution, then goes through the client institution and the contractor company, respectively. Interviews were conducted starting from the contractor company, and going through the client and customer institutions. The reason was to get the picture in the industry, on a smaller scale first. Then, the scale was enlarged adding the concerns of other external stakeholders. Hierarchically inverse sequence means that the procedure was started with requirements engineers, then the managers were interviewed. The reason is, similarly, to constrain the concerns of other internal stakeholders in the first interviews.

General structure of the interviews focused on three themes; requirement identification process, issues faced in requirements engineering processes, and the usage of the supportive systems as well as feedback regarding the DDSS, in order to derive its requirements. Interview question consisted of 4 parts. The first part is the introductory part in which the participants introduce themselves and explain their job description. The second part is the introduction of the stakeholders involved in the requirements development processes. The third part explores the methods used, the ideal requirements identification method for the interviewee, and the issues faced before, during and after the requirements meetings. The fourth part focuses on the supportive systems used in those processes with their pros and cons. Finally, the interviewee uses the DDSS and discusses its potentials in requirements identification. Interview questions can be examined in Appendix B.

Data collection procedure was reported to the METU Human Subjects Ethics Committee, and it was approved by the committee with these protocol numbers; 0613-ODTÜİAEK-2022 and 0115-ODTÜİAEK-2023.

The following subsection explains the working principle of the prototype DDSS used in this study, what components it has, and which parameters it uses.

3.1.1 Working Principle of the Prototype DDSS

Performance requirements and specifications of a helicopter usually have conflicting tendencies among each other. For instance, if one demands longer ranges to operate, more fuel should be contained. This increases the gross weight of the helicopter which in turn, increases the fuel demand to satisfy the requirement. This is a common phenomenon in vehicle design that every performance demand requires a trade-off study due to the non-linear relations among them. The prototype DDSS used in this study aims to present those relations between particular performance parameters as its inputs and outputs.

The prototype DDSS operates within a macro-enabled Excel environment [255] written in Visual Basic for Applications (VBA) both developed by Microsoft Corporation. User interface of the prototype DDSS has three major components: inputs, outputs and a comparison chart. The general visual of the system can be seen in Figure 3.1.

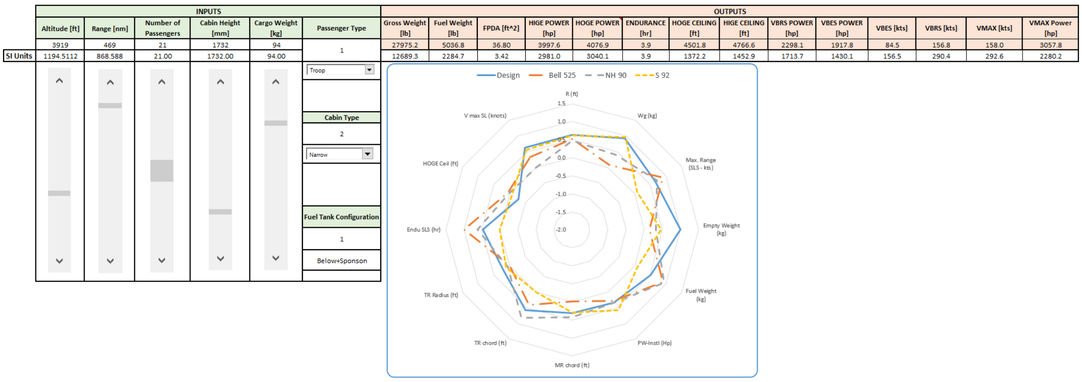

Figure 3.1: Overall User Interface of the Prototype DDSS

The green cells in Figure 3.1 are the place where the inputs are set. Red (more precisely something between almond and desert sand) cells represent the outputs, and under the red cells, the comparison chart as a spider chart can be seen. Inputs are set via slider bars, and the results are shown simultaneously. This particular system used in this study was developed for a utility type of helicopter. Utility helicopters serve a wide range of operations including cargo transportation, passenger transportation, search and rescue operations, ambulance missions including medevac (medical evacuation) and firefighting. Each operation needs a particular modification to be made on the helicopter. Those modifications are integrated on a base helicopter. It is common to see that base configurations are marketed through their transportation capability. For instance, Sikorsky S-70 (UH-60 Black Hawk) is promoted by Lockheed Martin for being capable of transporting 12 seated troops at 9979 kg (22000 lbs) maximum gross weight and customized for other missions [256]. Therefore, the utility content of the helicopter to be estimated via the DDSS was chosen to be a basic transport-mission.

The prototype DDSS works based on a pre-calculated design space. Design space refers to an abstract multi-dimensional space set by independent variables of a design. Even though the word "space" connotes 3 dimensions, there are dimensions in the number of independent variables as design inputs. There are numerous inputs that can be presented in a DDSS that affects the overall performance of the vehicle. On the other hand, increasing the number of inputs enlarges the design space exponentially; hence, makes the calculations even more time consuming. Therefore, variables about dynamic systems (engines, rotors and transmission) were preset for the sake of simplicity. Inputs presented for the user of the system are operational altitude, range, number of passengers, cabin height, cargo weight, passenger type, cabin type, and fuel tank configuration.[1]

Altitude, range, cabin height and cargo weight can be set in a continuous fashion including decimal numbers by typing the exact numbers into related cells or setting the bar in an exact location. Number of passengers input is naturally discrete. It can be set by a slider bar; however, the bar has predetermined locations on integer values. Passenger type, cabin type, and fuel tank configuration are discrete inputs with one or two options. They are selected via drop-down menus. Passenger type has two options as civilian and troop. These two options differ by seat size and estimated weight[2].

Cabin type has two options as wide and narrow. Wide cabin refers to a cabin in which passengers sit side-by-side on 4 to 5 seats like in AgustaWestland AW189 helicopter, and narrow option refers to a seating configuration of 2+1 in which 2 seats are placed side-by-side and another seat is placed after a predetermined aisle[3] like in Sikorsky S-92 (H-92 Superhawk). The seating configuration may also affect the placement of avionics in the cabin in the narrow cabin selection. If the number of passengers is not divided by 3, there will be inverted seats after the door, and the extra space created will be filled with avionics. The cabin type selection determines not only the seating configuration, but also the emergency exit doors and windows. Seating configuration in a wide cabin is aimed at quick exit scenarios during an emergency landing. If the number of seats requires an additional row after the sliding door, the additional row

[1] Thus, the design space that lies beneath the system is 8-dimensional.

[2] Troop type passenger implies greater weight due to military equipment; whereas, passenger-type seats are heavier than troop-type foldable seats in which comfort is a negligible concern.

[3] The width of the aisle is determined by EASA in CS-29 Large Rotorcraft safety standards depending on the total number of passengers [257].

of seats has another emergency exit.

Fuel tank configuration is an option than can be extended including more configurations between possible fuel tank locations that are below the cabin, behind the cabin, and inside the sponsons[4]. In the DDSS used, there are two options: "below" which places all the fuel below the cabin, "below + sponson" which places some fuel below the cabin up to a maximum thickness then places the rest on sponsons. Cabin type and fuel tank configuration inputs are not totally independent. If the user selects wide cabin type, sponson option becomes unavailable; since, there will be slider-type of doors that cover whole sides of the helicopter, and a sponson may restrict the passengers getting in and out easily. Inputs part of the prototype DDSS can be examined closely in Figure 3.2.

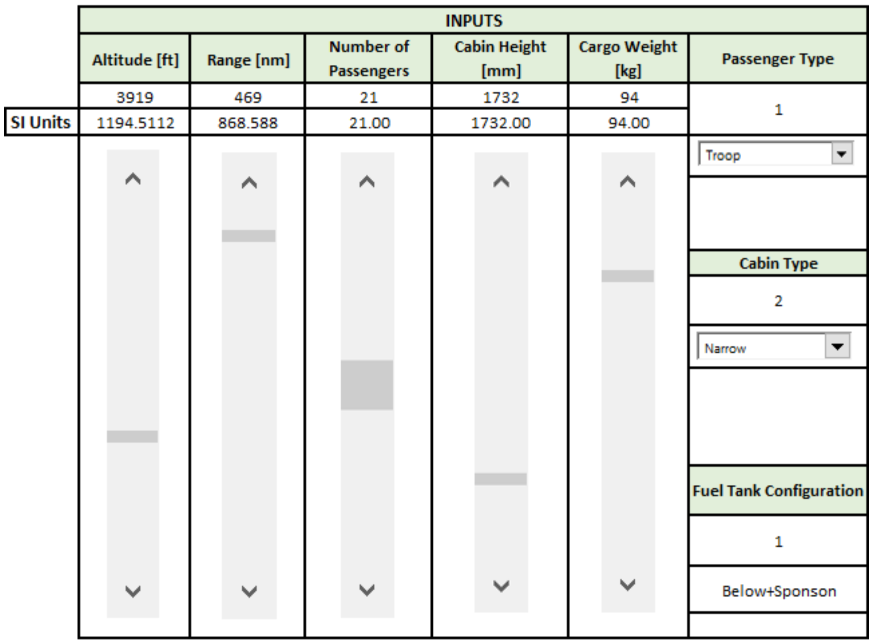

Figure 3.2: Close-up View of the Inputs of the Prototype DDSS

Outputs than can be examined are gross weight[5], fuel weight, flat plate drag area (FPDA)[6], required power for hover in ground effect (HIGE), required power for hover

[4] Sponson is like an external protrusion usually placed at the sides of the helicopter. They may contain landing gear, fuel and some avionics. They are usually the place where the retractable landing gear is hidden when the landing gear is retracted.

[5] Gross weight is the maximum weight at which the helicopter can take-off.

[6] FPDA is a measure of air drag, commonly used for rotorcraft. It is the equivalent area of a flat plate which has the same drag force.

out of ground effect (HOGE)[7], endurance, HOGE ceiling[8], HIGE ceiling, power required for best range speed, power required for best endurance speed, best endurance speed, best range speed, maximum speed, and power required for maximum speed. All the inputs (except for the discrete ones) and outputs are presented in both SI units and imperial units, since imperial units are more commonly used in aviation than SI units. If the user of the prototype DDSS gives inputs that may lead to power requirements that are not possible within the limitations of the preset dynamic systems, related output cells become red, indicating the problematic situation as can be seen in Figure 3.3.

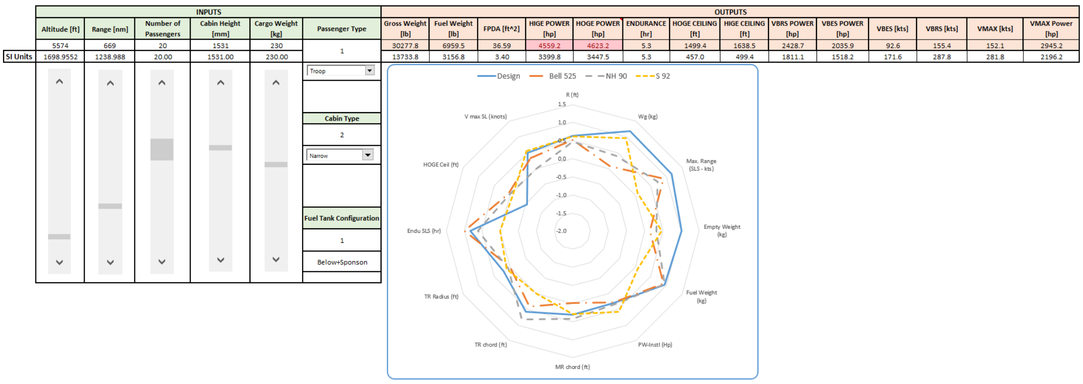

Figure 3.3: Indication of Limit Excess in Required Power

Underneath the numerical outputs, there is a comparison chart in the form of a spider chart. This chart compares several parameters of the helicopter to be designed with respect to some competitor helicopters in the market. Selected competitors are Bell 525 Relentless, Sikorsky S-92, and NHIndustries NH90. Specifications of those competitors are shown in different colors and by dotted lines; whereas, the helicopter to be designed is represented by a solid line. Spider chart compares radii and chord values of main rotor and tail rotor, gross weight, range, empty weight[9], fuel weight, installed power, endurance, HOGE ceiling and maximum speed. Comparison chart can be examined closely in Figure 3.4.

The calculations of the outputs are multi-layered. In the first layer, some outputs such as fuel weight are treated as inputs in order to calculate the range of the helicopter

[7] Ground effect is a phenomenon that occurs when an aircraft is near to the ground. In this type of flight, the aircraft consumes less power with the help of air which reflects from the ground.

[8] Ceiling refers to the maximum altitude that an aircraft can reach.

[9] Empty weight is the weight of the helicopter without fuel, crew and payload.

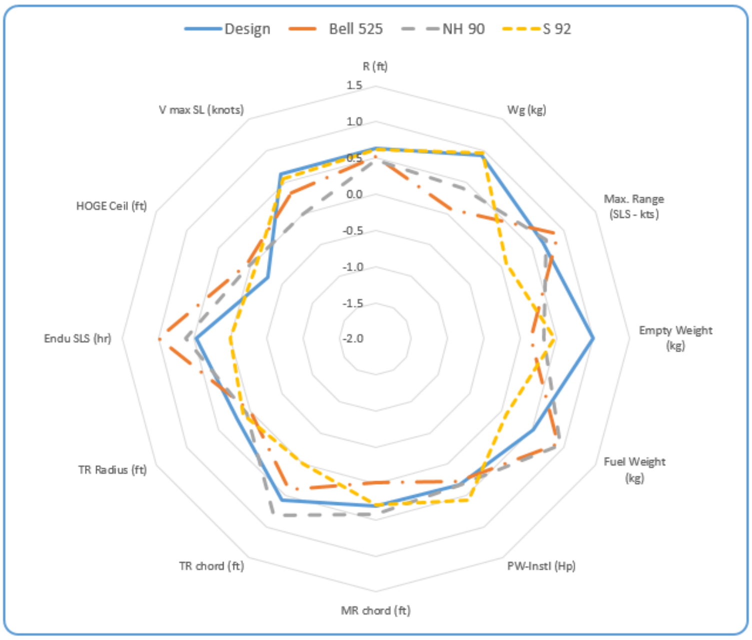

Figure 3.4: Close-up View of the Comparison Chart

with a given parameter set. Therefore, inputs and outputs are said to be interchangeable terms depending on the design perspective [78]. These calculations (also called as performance calculations) are conducted in several points of the design space, concerning each parameter set as a point in this space. Performance calculations use parameters such as gross weight, fuel weight and FPDA as inputs. Range, for instance, is calculated using those inputs. Then, in the second layer, range is represented as a polynomial function with the help of response surface methodology. In the third layer, a parametric CAD model is created that estimates system weights and FPDA values utilizing their geometric characteristics [77]. This CAD model iteratively calculates the outputs seen in the prototype DDSS.

Similar to the first layer, calculations are not conducted at every point of the design space. 3 points were selected from each altitude, range, cabin height and cargo mass intervals (continuous inputs). All 7 points of the selected interval of number of passengers are included, because it has a direct effect on the cabin shape and directly affects FPDA. 2 possible passenger types and 3 cabin type-fuel tank placement configurations are included in the response surface representation of the design space. Consequently, 3402 design points ($3^4 \times 7 \times 2 \times 3 = 3402$) were used in order to construct a response surface model. In the fourth layer, outputs seen in the prototype

DDSS are represented via response surfaces, and those formulae are embedded into a macro-enabled Excel file. This statistical approach enables the user to select every point inside the design space continuously, and get synchronous outputs as estimations. The penalty of this approach is the error of estimation compared to analytical results. The absolute value of error was kept under 10% in the construction of the prototype DDSS used in this study.

3.1.2 Sampling

The research was conducted in the helicopter industry operating in Turkey. Hence, the sample size is naturally limited considering the size of the industry in Turkey. On the other hand, small sample sizes in qualitative research are usually observed [258] with a purposive sampling method rather than a random one [259, 260]. Purposive sampling was found effective where the research resource is limited [261].

During the process of requirements development, numerous meetings are held. Depending on the stage of the product development process, these meetings involve several stakeholders. Certification institutions, airworthiness scrutineers may participate in requirements meetings when the product is being matured compared to the stages before contract signed. This study narrows its focus to the initial stages where the main stakeholders are the contractor, the client and the customer. Therefore, the sampling criteria were set according to these stakeholders. Sample groups of the requirements engineers and managers have variability regarding experience on requirements development, varying from less than a year to around 10 years and more. Therefore, it is possible to compare the perspective differences between novices and experts as well as executives and non-executives.

Participants of this study include 6 requirements engineers who work at the center of the requirement identification processes employed by the contractor company, 5 managerial people in the contractor company whose hierarchical position is at least manager. From other stakeholder institutions, there is one person who previously worked in the client institution and one person who previously worked in the customer institution, both with experience in requirements identification processes. Table 3.1 shows the general information about the participants. Job titles are the titles that the participant used while defining themselves.

3.1.3 Ethical Considerations and Transcription

After the approval of the data collection procedure by the ethics committee, the researcher requested permission from the responsible managers working in the contractor company, in order to conduct the research. After the permission of the managers, the researcher invited some of the participants verbally, and some of them via email depending on their availability. Before starting the interview; the aim of the study was explicitly explained to the participants, and a consent form was given (Consent form used in the study can be seen in Appendix A.). Some of the interviews were audiotaped. Permission for the voice recording was explicitly asked before any recording, and the recording device was given to participants in case they would like to stop the recording at any time. Some of the participants did not permit voice recording. During those interviews, the researcher noted down the statements of the participants; therefore, there are no full transcriptions for these interviews.

All interviews that were conducted via voice recording were transcribed without any supporting online tool or software, considering the possibility of the company's sensitive information that may have been given unwittingly by the participant. Member checking procedure was conducted. All transcripts were given to the interviewee again, allowing them to check and verify the text. Final approved texts were used for data analysis.

Following subsections explain the methods followed during different interviews, and the questions asked for the particular type of participant.

3.1.4 Interviews with Requirements Engineers

Interviews conducted with requirements engineers are mainly influenced by the studies of Coughlan et al. [162] and Bjarnason et al. [70]. Interview questions were tailored to the context of the helicopter industry, firstly from the perspective of the author who is also professionally working in this industry. Then, the questions were

Table 3.1: Participant Informations

Code Names	Job Title related to Requirements Development	Experience in that Title	Overall Experience
R1	Systems Engineer	Less than a year	No previous experience
R2	Systems Engineer	10 Years	No previous experience was mentioned
R3	Systems Engineer	3 Years	4 years of previous experience in other industries
R4	Systems Engineer	4 Years	No previous experience
R5	Requirements Engineer	Less than a year	No previous experience
R6	Specialist Engineer	Less than a year	5 years of previous experience in requirements engineering and project management Total 12 years of previous experience in other industries
M1	Manager	2 Years	8 years of previous experience as systems engineer Total 17 years in the contractor company
M2	Director	2 Years	2 years of previous experience as manager 11 years of previous experience in other industries
M3	Manager	2 Years	10 years of experience in the contractor company
M4	Manager	3 Years	14 years of experience in the contractor company
M5	Director	9 years	13 years of experience in the contractor company 9 years in the managerial roles
S1	Client	4 Years	Currently in the contractor company for 7 years 4 years of previous experience in another defense company 5 years of previous experience in automotive industry
C1	Customer	9 Years	22 years of previous experience in the customer institution 2 years of previous experience as manager in another defense company 2 years of previous experience as manager in the contractor company

assessed by the supervisor of the thesis evaluating their flow, comprehensibility, suitability and freedom allowed to the interviewee to further make comments. Another evaluation was conducted by the manager who approves the research, in terms of the appropriateness of the questions, especially concerning the information assurance. Those evaluation processes occurred iteratively, until a consensus was reached. This set of questions were used as the general structure of all interviews.

The interviews were conducted in the contractor company's private meeting rooms with a projector system. Durations of the interviews were between 45 minutes to 60 minutes. Participants used the DDSS via the computer already located in the meeting room, using the projector as the screen. After the interview, the DDSS files were shared with the participants for possible further feedback.

3.1.5 Interviews with Managers

After the interviews with requirements engineers, similar interviews were conducted with the managerial staff in the contractor company, as managers and directors. (It should be noted that "director" is a title which is hierarchically above "manager".) Since, their availability in terms of time is much limited compared to requirements engineers; duration of the interviews was decided to be shortened. Consequently, the questions exploring the issues around requirements meetings were excluded. Questions regarding the methods used in requirements identification processes were preserved. Then, the interviewees were directly asked about the supportive systems they used, and they were asked to discuss the usage of the DDSS. In the introductory part, the job description was not asked due to the fact that it may harm their anonymity. Instead, they were asked how they are related to the requirements identification processes.

Invitations to the interview were done via emails, explaining the aim and procedure of the study in an explicit manner. The DDSS files were shared within this invitation email. The interviews were conducted in the participants' rooms in the company where privacy is ensured naturally. Durations of the interviews were between 20 minutes to 30 minutes. Participants used the DDSS via their own computers.

3.1.6 Interviews with the Client and the Customer

Participants S1 and C1 have previous experiences in the client and customer institutions, respectively. They were reached within the professional networks of the managers in the contractor company. Due to the hardship of reaching volunteers in those public institutions, the number of participants is very limited. Nevertheless, it was aimed to grasp the perspectives of those stakeholders in the requirements development process and they are included in the study.

Interview structure followed nearly the same structure of the one conducted with requirements engineers. Only the introductory part was modified in which the participants were not asked directly about their job description in respective institutions. Participants were invited to the research first verbally, then via email. The DDSS files were shared within the invitation email.

As it was noted in Table 3.1, participants S1 and C1 had multiple perspectives on the same processes, since they worked at different sides of it. Due to their multiple perspectives on the same questions, and the increasing complexity regarding the business flow; these interviews took longer time than that of requirements engineers, despite having the same structure.

The interview with S1 was conducted in a private meeting room having the same conditions with that of the interviews conducted with requirements engineers. The interview took approximately 90 minutes.

The interview with C1 was conducted in the participant's room in the company as in the case of managers. This interview was conducted in two parts, in two different days. The first part took approximately 45 minutes, then it was decided to continue in the following workday. The second part took approximately 100 minutes, making the duration of the total interview approximately 145 minutes.

3.2 Data Analysis

Data collection and data analysis were conducted in a concurrent manner as much as possible. The analysis process was considered as an "ongoing, lively enterprise" that contributes to the following data collection phases [258, p. 78]. Final approved versions of the interview transcripts were considered as raw data. Those raw data were imported into MAXQDA [262] software. Words, phrases and sentences meaning or implying a symbolic meaning were highlighted and transformed into *codes* [258, 263, 264]. Coding was conducted in two cycles. The first cycle consisted of *descriptive coding* and *provisional coding* [263]. Provisional codes that are used focusing on the issues in the requirements identification processes were the themes explored by Darlington and Culley [21], Coughlan and Macredie [72], Coughlan et al. [162], Bjarnason et al. [70]. Provisional codes focusing on the requirements of DDSS were mainly taken from themes discussed by Töre-Yargın and Crilly [228]. These provisional codes are tabulated in Table 3.2. The second cycle of coding aimed to explore the patterns that exist among the codes.

Codes were generated in order to group similar themes mentioned in the interviews. Main codes generated are as follows:

- **Design process:** The participant gave information about the general process of design.
- **Requirements engineering:** The participant gave information about formal requirements engineering processes and insights specific to this discipline as well as issues faced in the practice.
- **Issues in meetings:** Issues mentioned by the participant were coded according to the ones explained in Section 2.2.2.
- **Solutions for issues:** Participants were asked how they overcome the issues they face in the meetings. The answers were analyzed under this code.
- **Existing tools:** Participants evaluated the existing supporting tools they have used.

- **Requirements of the DDSS:** The feedback gathered while the participants were using the DDSS were categorized under this code.

Table 3.2: Provisional Codes

Source	Code (Dimension and Sub-dimension)	
Darlington and Culley [21]	Product Effective Complexity	
	Problem/Solution Bias	
	Contract Formality	
Coughlan and Macredie [72]	Stakeholder Participation and Selection	Task Knowledge
		Status
Coughlan, Lycett and Macredie [162]	Stakeholder Interaction	Culture and Politics
		Communication Schedule
	Communication Activities	Gaps in Understanding
Bjarnason, Wnuk and Regnell [70]	Large Organization	
	Unclear Vision of Goal	
Töre-Yargın and Crilly [228]	Open-endedness	
	Accessibility	
	Interactivity	
	Transparency	

Assigning colors to the main coding systems, a document comparison chart was generated via MAXQDA, which can be seen in Figure 3.5.

In Figure 3.5, the lengths of the documents were standardized, in order to get an overall picture. It can be said that a significant amount of the interviews included the discussion about the requirements of a DDSS. The feedback regarding the prototype DDSS were stated mainly during testing. Some requirements are intertwined with the discussions of the existing tools. Design process and requirements engineering topics are mainly each other, and take a significant amount of place compared to the turquoise regions.

Main codes have several subcategories having both descriptive and provisional codes which are presented in findings and results. Code generation was also a dynamic process. Especially the codes regarding the requirements of the DDSS were reviewed,

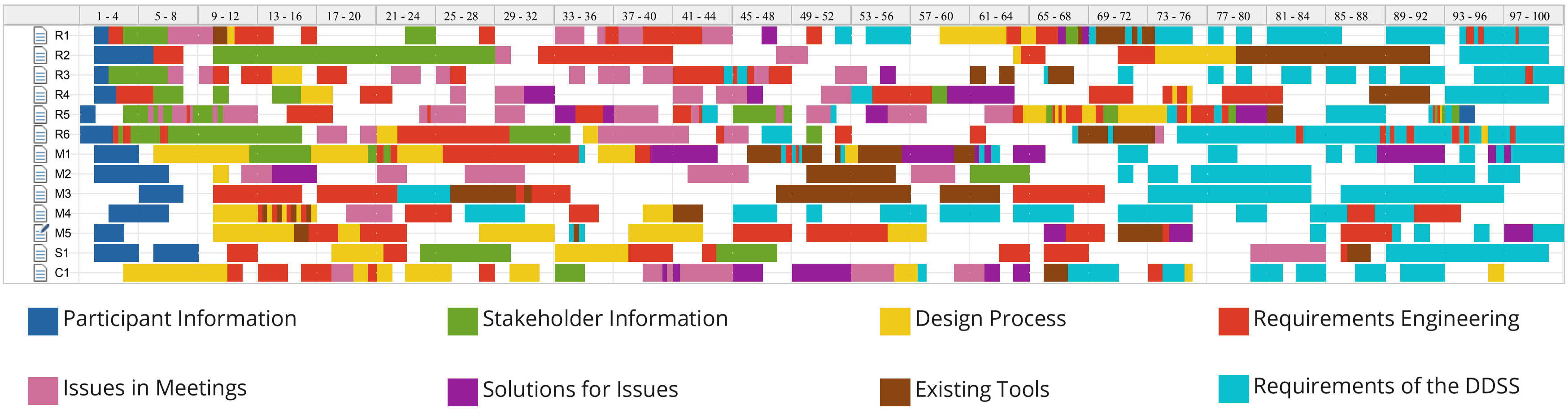

Figure 3.5: Document Comparison Chart with the Colors of Main Codes

generated and merged during the progression of the data analysis. Next chapter discusses the themes analyzed in this study, and their relations within themselves and the themes presented in the literature.

CHAPTER 4

FINDINGS AND RESULTS

This chapter reports the analysis results of the qualitative data obtained through interviews. Topics discussed throughout the interviews are spreaded broadly, and did not follow a strict pattern. The findings are categorized in a deductive manner in which the broadest discussion of requirements identification methods and related design processes are reported. Focusing on the requirements engineering processes, issues faced in the requirements development processes are discussed. Finally, the implementation and impacts of the DDSS with its requirements are presented. Quotations in this chapter are translated from their original in Turkish, and marked with reference numbers in parentheses. The original quotations in Turkish can be seen in Appendix C, following the reference number. Phrases or words in brackets are provided by the author, in order to ease the comprehension within the context of the discussion during the interview.

4.1 Requirements Identification Methods

Requirement identification is a critical phase in the design process. It is also related to how the design process is handled. In order to explore the intervention area of the DDSS, requirements development processes were asked to the participants. Participants answered these questions, mostly from their involvement practice in the overall design process. In this section, both the methods as applied in practice, and the ideal method with respect to the participants' point of view are reported.

4.1.1 Methods Used in Practice

Helicopter industry in Turkey can be examined within three institutional subjects; customer, client and contractor. Participant M2, who is a manager in the contractor company Turkish Aerospace, listed the customer institutions present in the market:

> "Commercial activities in our country and in our company proceed within the body of the Defence Industry Agency which was appointed by the state as the procurement unit[1]. Projects come from there. Customers of the Defence Industry Agency are the needs coming from Turkish Air Force, Land Forces, Naval Forces within the body of the Ministry of National Defense. In parallel, aviation tasks are performed by our Gendarmerie General Command and Turkish Police Aviation Department within the body of the Ministry of Interior. We build the aircraft they need." (M2.1)

In addition to this structure of the market, M1 added certification institutions as stakeholders. However, M1 also stated that their requirements are similar, definite, international requirements. Those are already defined by EASA, Federal Aviation Administration (FAA), and Directorate General of Civil Aviation. R6 mentioned an internal stakeholder who acts like an external stakeholder called Certification Assurance Board (CAB) founded to compensate for the lack of authority of Directorate General of Civil Aviation in defense projects. That company, also called as the certification institution, acts like an external stakeholder, too.

In order to model the requirements identification process conducted in practice, a sample process with Turkish Armed Forces as the customer was discussed since participants C1 and S1 had used this example.

Requirement identification regarding the specifications of a helicopter, or an aircraft, was considered at tactical level by C1, using the military terminology. In military terminology, tactics and strategy refers to different levels of mindset, according to Carl von Clausewitz [265, p. 173]: “*Tactics* is the theory of the use of military forces in combat. *Strategy* is the theory of the use of combats for the object of the war.” C1 stated that evaluations start from the strategic level whether or not there is a need for a helicopter. Going backwards, the customer states its need for an ability to be used in

[1] The client institution is sometimes called the *procurement authority*, in more formal terms. This usage is more common among high-ranked managers and state officials.

an operation, and this operation stems from the missions given to the Armed Forces by the constitution.

Participant C1 explains the chain of requirement identification at the strategic level. The capabilities needed for the Armed Forces are analyzed from the National Security Policy Document (also known as The Red Book) by the highest ranked commanders. Then, the Strategic Objectives Plan is prepared (*Stratejik Hedef Planı*, in Turkish). This plan prioritizes the needs of different branches of the army considering the limited resources, as procurement plans. Corresponding to the mission given to the particular unit of the army, it was expected to prepare a *concept of usage*[2] for a vehicle by that unit, explaining why they need this vehicle, how the training will be conducted, what the maintenance and sustainment plans are. The next step is a doctrine focusing on the field. Merging this process with the initial step stated in the interview with S1, workflow within the customer institution can be schematized as in Figure 4.1.

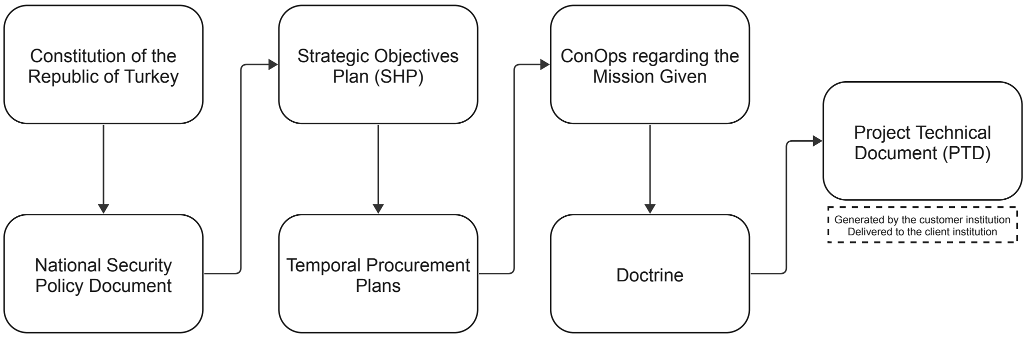

Figure 4.1: Workflow of the Customer Institution from Authorization to Order

Following that top-down approach, it was expected to have an idea of what the requirements of a vehicle are. However, the execution of these steps are hard, citing C1's own words:

> "After compiling these [steps], it starts to take shape what, how many, how, from where, with what specifications you will procure it. Well, that is the hard part." (C1.1)

These formal steps in deciding the need for a vehicle should also cover the future needs, as C1 refers to Armstrong's critique of the US Marine Corps after the Second

[2] It refers to ConOps. It was mentioned as *the concept* by C1.

World War [266]: “Do not focus on perfecting the techniques of the last war, instead of looking to the next war.”[3] In addition to the direct missions given to the operational unit, there are also implied tasks of which the customer should consider.

Workflow process of the client company was described by S1. S1 simply defined the definition of the work done as converting Project Technical Document (PTD) into SPS. This conversion is done through meetings with the customer and understanding what they want. Experience from previous projects play an important role in requirement identification. The personal experiences of the personnel inside the client institution was also said to be helpful; since, there were people who previously had been employed by the customer institution. S1 also stated that a document called Request for Proposal (RFP; Teklife Çağrı Dosyası, TÇD in Turkish) was also sent to the contractor company. In addition, M5 expressed that there was another formal communication between the client institution and the contractor company in the form of an RFI (Request for Information). RFI gathers preliminary information from the contractor company, before the client institution generates RFP. The workflow inside the client company can be schematized as in Figure 4.2.

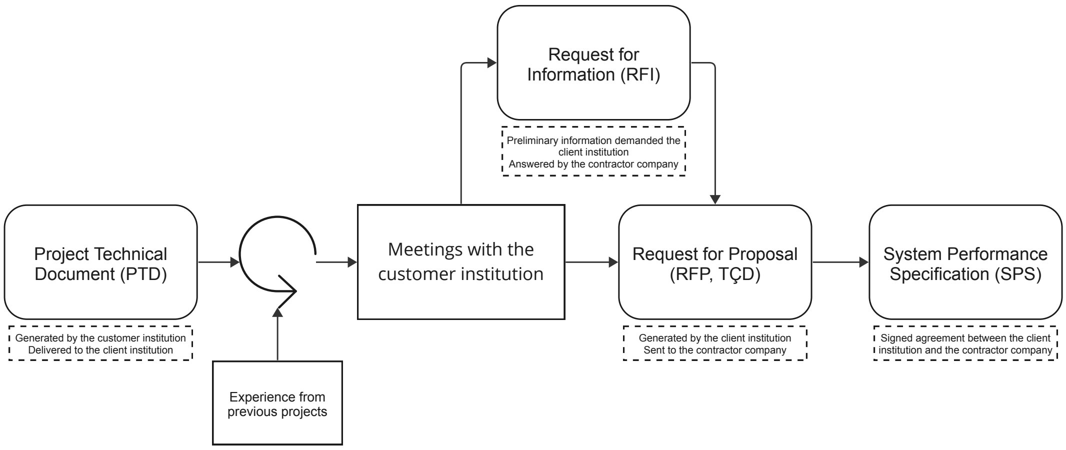

Figure 4.2: Workflow of the Client Institution from PTD to SPS

PTD is processed and evaluated by the client institution considering the applicability of the needs and the capability of the contractor, as S1 stated:

> "The customer comes with a document. They say: ‘I want this helicopter.’ Then, we, as the institution, examine this document. We first

[3] Quotation is directly in English.

> filter out how much is right or wrong. Then we say: 'Those needs you gave are applicable or not. The contractor has this capability or not. If not, we should bring this capability to them.'" (S1.1)

Applicability of the requirements are examined once again by the contractor company as M4 indicated. However, when the project comes to the contractor, it becomes apparent that the customer already had a requirement set in mind. The contractor company gives some advice considering several factors such as calendar and budget:

> "Normally, they already have an idea of how the helicopter will be, and it is usually an inspiration from other helicopters in the market, like 'Let's make the indigenous[4] version of it.'. Therefore the requirement set is already in the mind of the client. We are able to give advice regarding the factors of applicability, non-applicability, calendar, budget and so on." (M4.1)

The fact that the client already has a requirements set in mind is a direct example of the problem/solution bias [21]. It was also mentioned by R1 and R3. R1 further stated that during the requirement meetings, the customer directly referred to certain products in mind:

> "Sometimes there may be obstinateness from the customer institution like: 'If this is included in this helicopter, it should be in this one, too.' Because foreign helicopters have always been used." (R1.1)

Formal process of requirement development procedure in the contractor company was schematized in 2.21. M1 has expressed the same procedure that ends in the SRR phase. SRR is another decision gate that needs consensus of both the client[5] and the customer. The following phases after requirements identification are conceptual design phase, detailed design phase and production, according to M1. After that, verification and qualification processes are conducted at subsystems level, and finally at the product level. From requirements to the production phase, it is parallel to what was discussed as engineering design's consensus model. Following verification and qualification phases reflect the principles of the Vee model. Participant M3 defined the process of requirement identification simply as the analysis of the client's needs in

[4] The word *indigenous* is commonly used in official translations [267, 268, 269].
[5] Participant M1 called the client "the state side".

relation to what they affect, and the guidance of those needs into solutions. In comparison M5 defined a basic process model after the requirements phase, as preliminary design, critical design, and test/validation phases.

Participant R4 stated that direct communication with the customer was also used for clarifying some ambiguous parts of requirements. R4 further stated experience from previous projects was also examined, since the customer is the same. Participant R1 mentioned a meeting with the customer before the formal process starts in the contractor company:

> "Customer level requirements are elicited by direct meetings with the customer institution. A committee goes there [and asks]: 'What do you need?' or 'What [is] must-to-have for you in a helicopter?' In fact there is a measurement technique for this. It is called MOE [Measures of Effectiveness]. It is about how much the customer wants a technical feature. There is an order like 1-2-3-4-5[6]. It is a measurement technique used universally." (R1.2)

In the contractor company, MOEs are also used for requirement elicitation to decide the priority of the need stated by the customer. Acknowledging MOEs are success criteria for the execution of the mission, R5 described a sample MOE application in the form of a house of quality without the correlation matrix:

> "On the left, on the rows, there are mission scenarios. ... This is done essentially for the mission scenarios. You have the mission scenarios on the left, and design parameters on the columns. This side [meaning the rows] is decided by the forces as we say, the client institution, the customer institution and pilots. There are BCH [Basic Configuration] transport and air ambulance, for example. These are determined by the customer institution who will use it. There are importance [values] assigned to them. Some values are assigned. Then, after the engineers decide on the design parameters, test pilots assign those values at each cell. Let's say your mission is transport, then you need to have a wide loading flexibility or you really need a high payload value. ... The relations among them are determined by the test pilot.
>
> [Researcher: Do you quantify the importance?]
>
> Quantified. You get a numerical output. You multiply the relation with importance value, and you sum them up for every column, for every design parameter." (R5.1)

A sample MOE application matrix can be schematized as in Figure 4.3.

[6] It is a typical Likert-type scale.

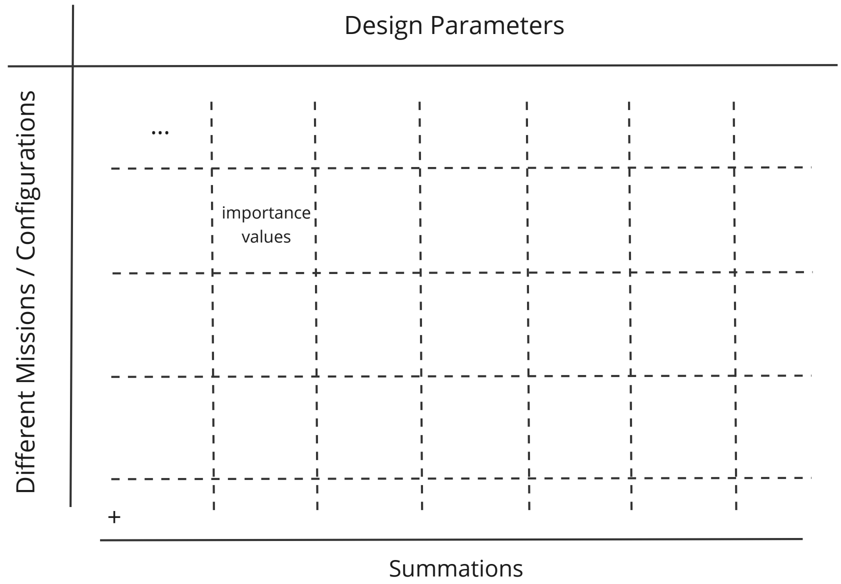

Figure 4.3: A Sample MOE Application Template (Based on the Description by R5)

R5 stated that processes involving MOE technique were not conducted successfully. R5 described the MOE process as defining the relations among performance parameters to certain missions. The parameters are decided by the engineering unit and their evaluation was done by test pilots, as R5 expressed. Nevertheless, R5 also criticized the impact of MOE study in the development process, because mostly the requirements were discussed with respect to sample projects.

R2 and R3 defined the requirement development process, simply as reviewing standards and making engineering judgements for the assessment of the operational needs given by the client. R6 defined their job as just to analyze the needs of the clients in terms of applicability. R3, further stated that this was the method used in defense industry projects, large-scale projects and “waterfall or Vee process” projects, as discussed in the literature. R4 did another description using an inverse relation to connect a function to a higher level requirement. Similar to the description R4, R6 stated the requirements were determined based on some fundamentals, and they were broken down from functions:

> "For example, I am saying this for the case of ECS [Environmental Control System], let’s say the client said: ‘I want ventilation in the cockpit of my aircraft.’ or ‘I want cooling.’ We determine a requirement ac-

> cording to it. That is, there needs to be cooling. There needs to be a cooling feature, under the ECS, environmental control system, title, under the related ATA [Air Transport Association] chapter[7]. ... Their needs are our baseline. They become the foundation. Then, we determine the requirements on that foundation, by breaking down downward from the functions." (R6.1)

The process of breaking down the requirements is conducted by the contractor company, as M5 mentioned. The client was said to determine the "high level requirements", and the design units were said to break those requirements. M5 further stated that the requirements concerning sub-systems and interfaces between systems were also formalized via SRD (System Requirement Definition) and SID (System Interface Definition) documents, respectively. High level and low level requirements were exemplified by M5:

> "For example, a high level [requirement] says 'The helicopter [rotor] shall have 5 blades.' and leaves the rest. Under that, we, as the design teams, break hundreds and thousands of requirements about how this rotor system should be. Or, it is said that the helicopter shall have a 4-axis auto-pilot system, but in the background, here, our auto-pilot team, software team and systems team break hundreds and thousands of requirements." (M5.1)

Requirements management may also start with the comparison of the demanded helicopter by any client with the current helicopters already being designed and manufactured by the contractor company, as R6 explained. In some cases, requirements engineers only study whether the existing products satisfy and comply with the needs delivered by potential customers.

Requirements identification method conducted in the contractor company was defined by M2 as spontaneous. M2 stated that there was no regulation about it at that moment. This situation is parallel to what Darlington and Culley [21] pointed out as the *ad hoc* methods being used in requirements development processes. According to M2, each design group conducts their own conceptual design process within the body of themselves. M4 expressed the lack of methods in requirements identification:

[7] This is a documentation system used in aviation, also known as ATA 100, for the standardization of the equipment classification for the ease of maintenance, piloting and manufacturing. Today, Air Transport Association of America (ATA) operates as Airlines for America (A4A). It is a trade association of several airlines operating in North America.

> "There is no such thing as 'Yes, the requirements are identified like this.'. More like inspiration, more like benchmarking..." (M4.2)

4.1.2 Criticisms Regarding the Methods in Practice and Idealized Methods

Participants were asked whether they have an ideal method that should be used in requirements identification. They have criticized the methods used in practice from their perspective.

Participant R1 acknowledged that the analysis of mission operation at the strategic level should be conducted in detail, in order to understand whether a helicopter is needed at the very beginning:

> "Firstly, the job or mission should be analyzed precisely. ... It should start with the question of 'Does Turkey really need such a helicopter?", and we should do this without fooling ourselves. ... If Turkey does not need a civil helicopter, should it be built just to build a helicopter?" (R1.3)

According to R1, after the detailed analysis of the mission at the strategic level, stakeholders should be defined in a wide manner including the test phases, and a good communication should be established at all phases:

> "Determining the right stakeholders, [including] whom we are going to sell it, and whom we are going to work with, is very important. Being communicated with them, their needs should be identified and the requirements should be identified by breaking down those needs. This is what is written in this job's book[8], at least." (R1.4)

C1 mentioned the vast amount of uncertainties which are specific to the defense industry, and called them risks. Technological and technical uncertainties are somehow solvable; however, conjunctural uncertainties in terms of administrative and political issues make this job hard. For instance, as M5 expressed, procurement of an engine might depend on the international relations among countries. In order to overcome the uncertainties as much as possible, the capabilities and needs should be recognized among all stakeholders within the framework of systems engineering. The interaction

[8] R1 referred to INCOSE's Systems Engineering Handbook [15]. Calling this book as "this job's book" is related to the institutionalization of knowledge as it was mentioned at Footnote 7 of Chapter 2.

between the customer and the client should be open in a way that the capabilities of the client are recognized by the customer. In addition to C1, R5 also acknowledged the importance of recognition in terms of capabilities of the contractor:

> "If they know exactly what they want, and if I know what I can give, then the process is managed flawlessly. However, the client is prone to demand, there is a problem like this. The client always demands. They will always demand to reach the highest speeds as possible, to carry the heaviest weights as possible. You need to show them its applicability in time." (R5.2)

Furthermore, R5 also allegorically implied some kind of agency issue regarding the effective role of requirements engineers in requirements identification, while talking about the potential use of the DDSS:

> "In fact, [the customer] will be able to see the limits of what they can do. This is a big plus for the customer. But I am not sure if this helps us who manages the requirements or the designers. Eventually, we manage the requirements process. We do not determine the requirement set. We are the people who manage their applicability of those requirements from the start of the identification process and after it. We are not the people who determine the requirements, not directly. ... We are in the process of requirements management, but not in the identification process. In my opinion, we are not." (R5.4)

Contract procedures of the US Army were taken as an example by C1. In those examples, the customer asks the procurement authority whether they are able to build that vehicle or not. C1 resembled a systems engineer to a maestro in an orchestra, who knows when the instruments play and when they wait in silence. Systems engineers were also said to be the most experienced people in companies operating worldwide; in contrast, in the contractor company, it is a job that fresh graduates do. Supporting the arguments of C1, R5 stated that they never experienced the requirement identification process from scratch, the requirements set were already ready. Current situation was pictured as far away from an orchestra, having made the resemblance C1 described the current picture in practice:

> "...[describing an orchestra] It does not happen much. Here is what happens: Everyone plays. Let the one who plays the best come out louder." (C1.2)

The criticism regarding the lack of interaction between the customer and the client in terms of the negotiations of the requirements is also related to the agency problem and authority struggle between them. This authority problem is more visible when the contractor gets involved. Direct demands from the client or the customer are considered non-negotiable orders. Over-demanding behavior of the client was described by R5:

> "Since they [the client] are not on the side of who determines the needs, they rather progress word to word. If they had this paper [showing a random piece of paper]: 'Yes, everything written in this paper has to be provided.' No stretching, no discussion. They are insisting." (R5.3)

Harmony among the institutions on a project was emphasized by C1, and the symphony metaphor was repeated many times. This harmony is required before the contract as well as it is needed afterwards. M5 stated that the guidance of both the client institution and the contractor company make the process more effective and faster. Applying the systems engineering principles, the Defence Industry Agency as the procurement authority should play the mediator role, and grant the support of the customer institution to the contractor company, after the contract is signed. S1 had also used the same terminology regarding conciliation and mediation while defining the work of the client institution. Moreover, the role of the test pilots was emphasized by C1, and it was stated that they may play the role of the interface between the contractor and the customer institution since they have experience in both sides. C1 prioritizes administrative issues over the technical issues:

> "A former NASA director who is also a test pilot once said: 'There are usually two types of problems in the project, technical problems and administrative problems. Technical problems are somehow solved. ... However, it was administrative problems that doomed the projects.' These administrative problems may be behaviors of the people, project model and project structure, organizational problems, it may be many things." (C1.3)

Cooperation and harmony is also needed among different units of one institution and that particular unit's relation with other institutions. M5 expressed that cooperation was needed between the aerodynamic performance unit and business development unit. M2 emphasized the importance of business development approach for an ideal method in requirement identification:

> "We can reveal the ideal process by setting the functions of conceptual design which progresses in parallel with the functions of business development, by prioritizing the external client's needs, by communicating with the clients one-to-one, and eliciting the requirements in a cooperation with the engineering units." (M2.2)

In parallel, M5 emphasized the importance of market analysis and saleability in the discussion of how an ideal process could be shaped:

> "Eventually, I will develop this [helicopter], and it needs to get into the market. That is, it needs to be saleable and acceptable in the domestic market, foreign market, international and national markets. Therefore, in this context, before starting a project, those market analyses, client analyses, and user feedback should be evaluated rigorously. Otherwise, there may be serious problems concerning saleability. Therefore the healthiest way to manage and identify requirements is [done by] setting the exact aims of the target market and target class with which helicopter." (M5.2)

Opposed to the direct communication emphasis of M2, participant S1 indicated that it may prevent the process to progress in a healthy manner, when they were asked about the ideal process:

> "We, as the client, are trying to create a requirements set that serves both the customer's and the contractor's interest. I do not know how to make this in an ideal way. Incorporating the contractor into every process may prevent the process from being managed in a healthy way." (S1.2)

From a methodical perspective, on the other hand, M2 stated that engineering work should start after the contract is signed by realizing the requirements stated in that contract. It should be noted that in the contractor company, the term engineering is mostly used to imply the organizational unit of engineering. There are also engineers employed in other units (and mostly engineers) such as conceptual design and business development; nevertheless, they are not referred to as being engineers or doing engineering work. The difference between the phases before and after the contract is the fact that the conceptual design before the contract is so flexible, according to M2:

> "Engineering, in my opinion, this is my personal opinion, steps in [the process] after the contract is signed. Then, it realizes the requirements coming from the client. However, before coming to the signing phase

> of the contract, we can think whatever we like, we can stretch, shorten, widen, shrink, enlarge, downsize the conceptual design. This is up to us. Because this is our imaginary world. This is the topic of business development and marketing, anyway. This is what differentiates us from them [engineering unit]. It has to be [this way]." (M2.3)

On the other hand, C1 stated that those administrative issues were in progress, and it was because this industry in Turkey is still young, considering the competitors had gone through these issues in 1940s and 50s. M4 repeated the same reason in the discussion of why the methods used in requirements identification are not mature enough, comparing 20 years of experience of the contractor company compared to companies of 100-year-old.

Having cited the institutionalized design process approaches from several institutions, M1 referred to those methodical approaches as the ideal ones in requirements identification. The issue here, according to M1, is the tailoring process of those approaches into aerospace industry, since they were written considering all industries:

> "[after referring to the Vee model's verification steps] This is the ideal requirement identification process. This is the process defined by INCOSE or some other documents like ARP[9] [Aerospace Recommended Practice]. ... We call this basic V&V [verification and validation] matrix management process. This is, in fact, an ideal process. However, in those documents, since they are written for all industries, it is not written like 'If you develop a helicopter platform, you will follow those steps.'. Therefore, there is a tailoring process for every standard." (M1.1)

M1, R2, R4 and R5 emphasized that there is a need for exactness about what the client wants. Supportive work including visual analytical support would speed this process up, according to M1. The most critical issue in the design process was said to be the change management. Similar to the exactness of needs, R1 stated that the procedure of breaking down the requirements is the core of systems engineering, and if it was done definitively, the process starts just right.

One of the most critical jobs that a systems engineer should conduct, according to C1, is to create baselines of a project and setting the phases of a project like in the development of Boeing AH-64 Apache helicopter [271]. C1 justifies the examples given

[9] M1 cited ARP4754A [270] guidelines by SAE International.

from the US with their experience in developing air platforms. M5 also stated that the varying needs of different customer institutions needed to be optimized, and packages for particular customers were managed easily after setting the baseline. There are also some uncertainties stemming from varying operational commands coming from the top management of the customer institution. This issue also leads to unlimited customer demands. Acknowledging the differences occur in the requirements of different helicopters operating at different conditions, C1 justifies this issue as preparing for the worst:

> “I acknowledge the customer to be right. If you do not give the task definitively, state the limitations clearly, if you do not give some kind of flexibility, a playground to the customer, they demand according to the worst [scenario]. We always demand, according to the worst. ... I may operate in the Aegean today, I may operate above Syria tomorrow, via the same helicopter.” (C1.4)

This issue of being over-demanding can be cured with the well-defined priorities of requirements; as C1 stated, there would be “must” requirements and “nice-to-have” requirements which could be treated as optional. This classification with a well-established communication with the contractor would prevent some demands that are impossible to satisfy. The customer should know that every feature on the helicopter has its own penalty. Besides, if the ConOps studies had been conducted accordingly inside the customer institution, performance criteria of the helicopter such as range and payload would already be ready. The importance of the usage scenario was also mentioned by R2 and M3. R4 did a description of what an ideal process would be, mostly based on a document referring to ConOps:

> "In my opinion, the most healthy method is that the user and the product owner prepare a document which [indicates] where they will use this product and how they will use it." (R4.1)

ConOps study was also found useful by R4 and C1, in order to determine the usage frequency of a certain equipment needed on the platform, since they also increase the cost of the product. R4 exemplified this issue as follows:

> "The customer sometimes wants equipment that will be used for 5% to 10% of the product’s life. However, we may conclude that it would not

> be that much beneficial, looking from a wider perspective. This way, the weight effect and cost effect increases. Do you attach equipment in your car that you would not use?
>
> [Researcher: No.]
>
> Me neither. You would, in fact, increase the cost with the equipment you would not use." (R4.2)

Participant M4 mentioned that consequences of the demanding behavior of the customer may result in additional design iterations for the contractor. According to M4, these additional maneuvers of going back could be prevented in the requirements phase:

> "They have an idea about the platform. We give advice and say: 'It will be too heavy. You cannot proceed like this.' They say: 'I want this.' Then we actually build a prototype, it becomes heavy, and we go back. If only they had listened to us, during the requirements phase, we would have concluded this job much quickly." (M4.3)

4.2 Issues Faced in Requirements Engineering Processes

Requirements engineering processes gather multiple stakeholders together to identify, elicitate and negotiate the requirements for a particular product to be designed and built. There are some issues that are natural in the execution of those processes such as problem/solution bias, agency of the stakeholders, and prescriptiveness of the design brief. On the other hand, there are specific issues faced during the meetings of the requirements development process. Those issues are mostly explored during the interviews conducted by the requirements engineers, the client and the customer. Those participants were also asked how they overcame those issues. They are reported in the related subsections.

4.2.1 Issues Related to the Nature of Requirements Engineering

Requirements engineering brings many stakeholders together, and tries to obtain a balance in terms of authority and agency among them. C1 stated that if this balance starts to get lost in favor of the customer, product development may focus on perfecting the last war, instead of looking to the next war. In practice, the customer is usually the demanding side, they may demand things regardlessly. In this balance, the client institution should play a critical role; since, they also know technology readiness levels and production readiness levels. Citing Armstrong's discussion regarding the Marine's three pillars of success [266], C1 emphasized what is needed in the defense industry; recognition, organization, and leadership. The capabilities should be recognized, an organization should be set accordingly, all of them should be led in terms of top management. The agency problem was also mentioned by M4 and R3. Participant M4 underlined the importance of working in coordination with the contractor. However, it was also acknowledged that the work in practice goes under the sole guidance of the customer side.

In the nature of requirements engineering, there are conflicting requirements that may come from the customer, the client or the existing conditions inside the contractor company. According to R5, there may even be inconsistencies between decisions made throughout the requirements development process. In order to prevent them coming from the customer institution, C1 emphasizes the importance of ConOps that should define the requirements in a consistent manner. C1 exemplifies a typical demand from the customer as a situation which should be avoided:

> "The customer should not say this: I may use this [helicopter] at sea level. I may use it at 12000 feet [altitude] above Mount Sümbül in Hakkari, too." (C1.5)

Assessing and evaluating the consistency of the requirements in terms of applicability is also in the work definition of the client institution. S1 stated that, in PTD there were "challenging" needs that are impossible to realize at the same time. The client institution makes them mild and "applicable". One of the reasons why some of the meetings end without an outcome was stated to be the over-demanding behavior of the customer. S1 remarked that it was sometimes done in order to protect the contractor company. On the other hand R5 and R6 stated that the client is also over-demanding. M2 referred to the client institution as the *employer* of the contractor company, and M4 defined the client institution as the *subcontractor* of the customer. According to M4, the customer did not want to deal with budgets, verification process, procurement procedure etc., and they only wanted to get notified when certain support is needed.

The prescriptiveness of the design brief of contract in terms of design requirements was criticized by R5 stating that there was a need for negotiation:

> "Those [design] limits should be a bit open for negotiation. You say you can reach that speed, but maybe you cannot. It surprises me that when these numbers are provided, we have to ensure those [numbers]. According to what, I have to ensure? ... How are you going to do it with this much weight? Because you may have to change your engine in the process. You may have to work with a less-powered engine. I wonder how they do it." (R5.5)

According to M1, the core principle of the requirements development process is to understand exactly what the client really wants. It is also the reason why product development processes take long in aerospace industry:

> "There needs to be an agreement on what the client wants. It is required so that the client would not say 'This is not what I wanted, it was something like this.', and the project would not start all over again. This may happen. If it does, the process may delay a bit. What I mean by delay is that the normal platform development process may take 5 years, 10 years, 15 years for airplanes and helicopters in the literature. This is one of the reasons why there are delays in these processes." (M1.2)

There are also industry-specific issues such as information confidentiality, as it was stated by M3, M5, R4 and R6. M3 stated the following when they were asked the issues they had faced:

> "Some specs of the helicopters are not accessible. In our work, confidentiality becomes more of an issue. This is valid for other companies, too. Therefore, accession to information may not be easy." (M3.1)

4.2.2 Issues Faced in Requirements Meetings

Issues regarding the meetings where the requirements are negotiated, identified and elicited are discussed in different themes. Darlington and Culley [21] and Bjarnason et al. [70] had mentioned the fact that complex products and large organizations cause several communication issues. Unclear vision of goal [70] and weak understanding of the other stakeholders' work [176] in the meetings are major issues. Stakeholder participation, stakeholder interaction and communication activities, as identified by Coughlan and Macredie [72], with some of their subdimensions were also identified from the outcomes of the interviews.

4.2.2.1 Complex Product and Large Organization

Communication issues not only happen between external stakeholders, but also among internal stakeholders in an organization. In a large organization, there are numerous units and a stratified management structure. Having defined the ideal process as the integration of business development approach in conceptual design and requirements identification processes in Quote M2.2, M2 mentioned the lack of cooperation among different units that originates from the weak understanding of the other internal stakeholders' work despite having a positive understanding from the everchanging management in the contractor company:

> Newcomer executives' perspectives are so positive at the beginning; however, we could not carry out this topic [integrating business development approach in conceptual design and requirement identification] due to the fact that engineering units did not endogenize it. (M2.4)

Issues stemming from invisible work and priority differences can even occur between engineers whose field of expertise is different. R5 stated that it occurred between design engineers and systems engineers. Unclear vision of goal is in relation with the weak understanding of other stakeholders' work. In large organizations, due to the large number of employees specializing in different disciplines and subdisciplines, these types of issues are faced. R1 mentioned perspective differences of certification experts and design engineers even though they are both engineers:

> "For example, if I talk to someone who is in the heart of design work, they may say to me: 'Jobs you do are nonsense!' Helicopter level systems engineering may be regarded as nonsense for sub-system level systems engineers." (R1.5)

An unclear vision of the goal can also cause meetings to stray from their purpose by discussing subsystem level requirements rather than helicopter level requirements, according to R3. This phenomenon is also related to the priority differences for stakeholders, as discussed by R4 and R5. R4 asserted that each stakeholders try to guide the decisions for their behalf:

> "Everyone sees their job as the prior one, but when we look at it from a wide perspective, there may be even more prior work. ... A system's output can be the input of another system. Therefore, one cannot start before the other one's work is done. ... Everyone naturally sees their own job 'a little more prior' than others. Eventually, they expect the outcome to be on their behalf." (R4.3)

According to M2, the cooperation among units should embody not only the engineering units, but program management, and operational units as they contribute with their experiences in different fields. Nevertheless, even the engineering unit lacks cooperation inside it, since systems engineering and aeronautical sciences units conduct the same assessments within themselves. (Both are under the engineering management.) M2 calls this behavior "conservative".

4.2.2.2 Stakeholder Selection and Stakeholder Participation

Stakeholders participating in the meetings from the customer side may vary depending on the project. C1 lists the participants in the case of Land Forces Command. The unit who represents the end-user is Army Aviation Command. Other participants are Operations Presidency, Logistics Presidency, General Plan and Principles Presidency within the body of Land Forces Command. Each unit sends both managerial delegates and hierarchically-lower, technical experts who assess and evaluate the situation from the perspectives of funding, applicability with the doctrine, logistics and operation. C1 also defines the Defence Industry Agency as the interface between the client and the contractor. From the client institution's side, according to S1, the participants were listed as project departments inside the institution, quality and certification departments (if needed). In the meetings where the client and the contractor meet, S1 stated that they were meeting with requirements management unit, project management unit and functional units that deal with specific technical issues. This participation in terms of technical expertise was done at the chief engineering level. R1 indicated that there may also be participants to those meetings from the subcontractors of the contractor company, and from the certification institution depending on the hierarchical level of the requirement. R4 added the Maintenance Unit and Logistics Unit as special engineering units to the list of internal stakeholders of the contractor company. R6 mentioned program management and business development units among the internal stakeholders. According to R1 and R5, in the lower level requirements meetings, delegates of the certification institute manage the meetings. The general criteria for the selection of the delegates is firstly their responsibility level, and secondly their titles. In comparison, R6 asserted that the title is the prior criterion. R2 listed the internal stakeholders of the contractor company as systems engineers and design units. Roles of those stakeholders may vary depending on the project phase. According to R2, during the contract phase, systems engineers deal with the concept and performance of the helicopter, and the evaluations regarding the client's expectations. During the delivery phase, systems engineers deal with verification and validation processes. Designers find design solutions for subsystems.

Deciding on the stakeholder participation at personal level was considered as one of the human factors in product development, by C1. C1 also asserts that participation of competent and skillful people from both the client and the customer side made things easy. Related to the *task knowledge* sub-dimension discussed by Coughlan et al. [162], it is fluctuating mandatorily on the customer side due to the appointment system. C1 mentions some issues while handing over the post, in terms of transferring know-how:

> "...you go to a whole different post, and you hand over that know-how and history to someone who is fresh and never dealt with that kind of thing before. Those handovers cannot be fully executed, unfortunately. Therefore, there is a sinusoidal curve. New staff member comes, learns and learns, then they get appointed. Another staff member comes and starts to learn again." (C1.6)

Similarly, there are changes of personnel on the contractor side, too. R5, as a newcomer, stated that involvement in the requirements development process is a disadvantage without prior knowledge of how those requirements were shaped and decided. This causes a gap in the continuity of the decision-making process [162].

Another participation issue that causes communication gaps is the fact that the customer's participants are selected depending on the availability of the personnel at the exact time of the meeting. C1 states that the participant attends the meeting without the past knowledge and issues that are specific to that project. Usually, the young members of staff are selected. R4 made a similar comment on the lack of participation of the key people. (Key decision makers are mostly managers and people who are hierarchically above the managers, according to R6.) C1 assesses this method both positively and negatively. It is positive concerning the fresh ideas that the young ones may evoke, and it is negative in terms of the lack of knowledge about the history of the project. Young members are also low-ranked. Therefore, they lack the authority to make decisions. As C1 expressed, the participant should explain the situation to their superiors, but they may lack the technical expertise.

4.2.2.3 Stakeholder Interaction

Stakeholder interaction is negatively affected when the meeting schedules are not set properly, having the key participants available. C1 told their experience of meeting the people who are not informed enough but sent by the key people whom they expect to see. This extends the overall duration of the requirement phase. The schedules regarding the meeting should also include the dictating duration of the meeting report, according to C1. It was also experienced that after 5-6 hours of meeting, people get tired and become ineffective when it is time to write a report. Moreover, the secretary who was appointed to write a report should also be informed about the context of the meeting beforehand, otherwise people may have to spend time correcting the errors inside the report.

Calendar management was also emphasized by R1 as one of the most critical jobs in project management. Communication scheduling problems were also mentioned by R2, R3 and R5, for the preparation phase of the meetings.

One of the subdimensions of stakeholder interaction is culture and politics as discussed by Coughlan et al. [162]. R6 stated that there were issues when it came to the moment of decision. There may be a lack of authority about who will take the final decision. The reason why it happens, according to R6, is that the contractor company is operating like a non-profit organization and it is a safety-critical business:

> "[Participant was asked about the reason why there is a lack of decision in the meetings.] The reason is, in my opinion, non-profit... Well, we seek for profit but someone has to put on airs. ... Based on my previous experience in [a manufacturer producing for domestic use]... Someone puts on airs. Someone does it in any case. If you cannot, you will find a man[10] who will, and you make this decision to be taken. ... These processes should not take long for a company that produces 15000 [a product for domestic use] per day. The decisions should be taken fast. But, this is not the case here. There is something called airworthiness. That is, there is flight safety. If this is the case, people have to approach things cautiously, inevitably. ... Sometimes speed [in decision making] may lead you to a mistake, and sometimes you can go back. You may diminish two [a product for domestic use] in the worst case, or you may design something wrong, build a prototype and build another prototype again. This would not harm you commercially or regarding the prestige. However, here, things do not work like that. Let's say you build a helicopter here and, god forbid, the helicopter crashes, there is an accident-incident, or you make a mistake different from what was required, and you realize at the end that you lost millions of dollars... Or you may lose prestige. Or that platform will be thrash, 15 years of work..." (R6.2)

4.2.2.4 Communication Activities

Communication gaps may arise from the communication activity itself. C1 stated that in some meetings representatives of the customer and contractor do not understand themselves. From the customer's perspective, it is sometimes surprising that the contractor does not understand what they mean. According to C1, it may originate from two possible sources; the requirements were not broken down properly, or the contractor side does not want to understand it deliberatively. There may be discrepancies between what is written in the contract and the capability of the contractor. This deliberative gap may originate from the gaps between technical mastery level of the contract experts and technical experts. This is coherent to the knowledge acquisition sub-dimension discussed by Couglan et al. [162]. This gap between the technical experts and contract experts may also result in issues in the other way around. Sometimes the technical experts thrill to the extra demands of the customer that was not in the contract. C1 also added that there were cases where the delegates of the customer had not read the contract before coming to the meeting, which deepens this issue of

[10] Participant R6 had used slang words while describing the decision-making. The gendered subjective was chosen by the participant.

communication. This issue was also mentioned by R1 that some stakeholders may have not followed the job closely, and they may ask irrational questions. During the meetings one side may sometimes get aggressive. Gaps between technical mastery was also mentioned by R5, stating that the client did not deal with design work compared to the contractor side. According to R1, one of the reasons why there is a gap between technical mastery was stated to be in relation with the stakeholder participation issues about titles:

> "One side is an engineer and the other is a customer. Then, there may be a conflict of knowledge. The reason may be that they do not know or they think they know." (R1.6)

Priority differences among stakeholders may harm the communication activity. One stakeholder may want to prioritize their work over the others, then the meeting may face both communication issues and agency problems. This was the case in the discussion of the involvement of the contractor in the requirements identification processes conducted between the customer and the client. S1 stated that the customer may act uncompromisingly, and the client institution tries to prevent that to happen:

> "The discussion should be about a requirement that was filtered out by the client. There is no need for the contractor to see the raw requirement. The direct interaction between the contractor and the customer deteriorates the process in some situations. We are trying to prevent that." (S1.3)

4.2.3 Possible Solutions for the Issues of Requirements Engineering Processes

The fluctuating task knowledge issue that the stakeholders and their particular delegates have is an issue valid for the state institutions and also valid for Turkish Aerospace, according to C1. As a structural solution, C1 proposed institutionalization in order to overcome this general issue. Institutionalization is also beneficial to prevent the problems occuring the dependent nature of each person and their characteristic traits. In order to overcome the fluctuating task knowledge issue in the customer institution, C1 proposes the retired personnel to be employed again by contracts like the cases in the US and NATO. This way, the knowledge gap and adaptation period were said to be minimized.

Participants in the meetings may lack the authority to make decisions. Those types of issues were solved through authority again, by incorporating superiors and making sharp definitions in terms of authority, as R1, R3, R4 and R5 expressed. C1 attached importance to the preparations for the meetings. If the meeting will be a decision making, a comprehensive meeting inside the customer institution should be held, and the right to take initiative should be given to the delegates. In order to speed up the decision-making process, and bring a structural solution, C1 proposed an integrated approach in organizational design of the three institutions taking part in the requirement development process. In those organizations, every person should be introduced to their counterpart in the other organization. This requires both a vertical and horizontal approach in organizational design. Moreover, terms of references[11] should be well-defined and known by the other stakeholders. C1 stated that well-defined terms of references would also prevent the issues stemming from the characteristics of each person. Characteristics of a person means the fact that some people may prefer centralized authoritarian management, and some other people may prefer decentralized management. Those variations specific to each key person, or information broker, results in another uncertainty in the project management. Such issues stemming from personal traits, especially that of key people were acknowledged by R5. R5 stated that they had a list of people to connect at each design group, just for the ease of communication.

The importance of the preparation phase before a meeting was emphasized numerous times by C1. Considering the complexity of the product and the strict calendar that the project teams must satisfy, C1 created a meal preparation metaphor:

> "Preparation is important, it is like [preparing] a meal. What do you do before cooking a meal? You choose ingredients of good quality. You know which meal you will cook. You know when it will be ready. It will be ready for *iftar*[12]. Otherwise you cannot break your fast. Then, when should I start preparing? Depending on the complexity of the meal… Do you have the ingredients? Check the fridge. Okay. Have I cooked this before? No, I haven't. Then, let me watch its video from YouTube, or let me ask the people who did this before if there are any. If there is a

[11] Terms of reference (ToR) was used to mean the framework of authority, it defines what a person is authorized to do.

[12] It is the name of the evening meal after a day of fasting in Islamic belief. The interview was conducted during Ramadan month which is a special month in Islamic calendar. During this month, it is a common type of worship that the followers fast.

> cooking book, let me read it. Then, someone should chop tomatoes and onions. I should buy good quality ingredients, because the meal should be delicious. My pan, pot, and cooker should be accordingly. Sometimes I should turn down the heater, sometimes turn up. It is the same. Then, I prepared the ingredients. Let's start. If you turn the heater up too much, it burns; if you don't, it doesn't get cooked. You should put the water in at the right time. That is, good ingredients do not necessarily mean a good meal. It cooked, good. Was it cooked before its time or after? If it was cooked before, it gets cold. If it is cooked after, you stay hungry." (C1.6)

As it was mentioned, one of the problems faced during the meetings happens during the dictation of the meeting report. Related to the technical expertise gap discussed in communication activities, this phenomenon is also interrelated with other sub-dimensions of communication gaps. C1 proposed the usage of artificial intelligence tools like ChatGPT [272] for the specific problem of dictation and for the general issues of requirements development processes in terms of administrative issues of meetings.

The issue related to the confidentiality in terms of competitor products in the market, M5 stated that examining those helicopters on-site was a solution, and it was often preferred.

Using software support was also mentioned by M1 as one of the possible solution areas in the issues in requirements development processes. According to M1, integrating the requirements management processes and design management into a PLM system would speed the requirement identification and requirement tracing processes up. M1 also mentioned the capability of PLM systems to trace and manage the change logs and after-sale service systems. This kind of meta-system would eventually lead to the discussions of Industry 4.0.

4.3 Supportive Tools Used in Requirement Identification

There are certain tools and supportive methods already used in requirement identification and requirements management. Participants were asked if they had used this kind of tool before, and they criticized these tools' pros and cons. After the criticisms of the existing tools, participants tested the DDSS and made comments while using it. Feedbacks gathered regarding the DDSS, and design requirements were captured from the analyses of the feedbacks.

4.3.1 Existing Methods and Tools in the Industry

One of the supportive methods is benchmarking used by every stakeholder involved in this study. C1 acknowledged that benchmarking can become a paradigm for the pilots who are the end-users of a helicopter. Those paradigms can be both beneficial in terms of reflecting an experience, and harmful as it may limit the development of a different product:

> “There are paradigms. Those paradigms can be both in the good side and the bad side. Let me give an example, if you had always executed counter-terrorism operations, and flew Sikorsky [S-70], and if you are happy with it, you would say: ’*I want a helicopter like Sikorsky helicopter.*’ It has a good side, because it comes from experience. It has a bad side, because you have closed yourself. You may have prevented something that is better and has different specifications, which would have prepared you for future wars.” (C1.8)

Benchmark studies are also conducted by the client institution. S1 stated that they get inspiration from competitor products, and they gather information from the competitor companies to create an information repository. M4 criticized the benchmarking studies conducted in Defence Industry Agency, stating that they were creating a “best-of” list of the technical specifications:

> "...SSB [Turkish abbreviation of Defence Industry Agency] prepares a ‘best-of’ from technical specifications as if the best helicopter is the one with the most challenging conditions of every platform. Nevertheless, it is not the case. The product may become much heavier and much more impractical." (M4.4)

The result of the benchmark study conducted by the client institution was mentioned by M4 as building “the indigenous version” of a certain helicopter that exists in the market. M4 finds benchmarking secure and quick; because, the base products are already verified products in terms of so many aspects. On the other hand, M4 found this method as creativity-limiting against genuine products.

Having listed the benchmarking method, M3 added Ishikawa diagram (fishbone diagram) and observations on how the user conducts their job as methods of requirement identification. Those methods were said to be helpful to develop solutions that fit the purpose. Observations also help to analyze the problem and its effects to subjects; because, there were cases where there were multiple stakeholders affected by the problem mentioned, or there were cases when people had reported issues wrong, knowingly or unknowingly, causing distortion in problem analysis.

According to C1, there was a decision support system prepared within the body of the customer institution. It was aimed to support the decisions regarding how many of the desired platforms should be procured. It processes the operational radius, endurance, ammunition payload, maintenance schedule, being active/inactive ratio etc., and gives the output of how many of this platform will be needed. It does not provide information about the range or endurance themselves.

In order to gather the requirements together and trace them, M1 had used DOORS (Dynamic Object Oriented Requirements System) [273] and Teamcenter's [274] requirements module. In those softwares, the requirements were assessed with respect to their dictation and rhetoric. It was also checked whether the requirement guides the design. M1 expressed that those tools' main advantage and the main reason why they are being used is the traceability they provide for the requirements management. In contrast, the connectivity among those tools and ERP (Enterprise Resource Planning) modules was found inadequate. For instance, if a problem occurs in the after-sale service, service support tries to solve it, then it goes to the design unit or from the production unit, and those processes are handled manually, causing the process to slow down. M5, R1, R5 and R6 had also used DOORS for its traceability features and management of the requirements development process. R1 criticized this software for its licensing price, which could be overcome by building an in-house tool. R6 criticized DOORS's user interface for not being user-friendly. Focusing on the identification of the requirements, M1 and R4 declared that there is no such tool being used, in an organization level.

Participant R6 also mentioned Jira [275] being used as a project management tool which allows agile project management. It was found more agile compared to Microsoft Project [276]. Shock meetings organized via Jira were found effective compared to longer meetings conducted face-to-face.

R2 and R5 asserted that analyses were conducted with related design disciplines that assess the compliance of the performance needs with desired configuration and weight such as payload needs. R2 found those analysis tools practical and fast enough to make updates on the design. R3 stated that they conduct research in academic literature, using Jane's All the World's Aircraft database, IEEE (Institute of Electrical and Electronics Engineers) and ScienceDirect databases. R3 described the following academic literature as advantageous because it is verifiable and observable. On the other hand, R3 also noted that there may be differences in application given the differences in ecosystem and geography, for example between Turkey and the US.

Participant M2 mentioned a decision support system prepared in-house inside the contractor company under systems engineering management, which shows the conceptual images of the product to be designed. It was found helpful for the communication with the client or the top management of the contractor company. It was also giving ideas about the cost and manufacturability of the product with not only the financial resources needed but also the human resources. M2 stated that it was hard to integrate the usage of it to the product development process, because each unit wanted to conduct this work within themselves.

4.3.2 Feedback Related to the DDSS

All participants were asked to use the DDSS that was explained in Section 3.1.1. Participants were also asked to make comments while using it. Depending on the course of the interview, this discussion was sometimes intertwined with the critics of the existing tools used in requirements development. This subsection categorizes the feedback gathered related to the DDSS. This feedback will contribute to the design requirements of the DDSS, which are discussed in the next section.

Participants gave feedback regarding the parameters presented to the user of the DDSS, and the limits of those parameters that build a design space. Comments and feedback included the perspective differences of the potential users of the system, delivery of the information, and the structure of the DDSS.

4.3.2.1 Parameter Selection and Limits of the Design Space

The DDSS was created focusing on the initial negotiations of requirements, especially before the contract. Therefore, the parameters present for manipulation and experimentation had to be the ones discussed during those meetings. Participants were asked what type of requirements are being discussed at the initial requirement meetings. C1 and R3 said that topics at macro level were being discussed most. Then, the systems were broken down. R2 stated that the major technical specifications were being discussed:

> "If we are in the beginning stage of the project, technical specifications in the contract are being discussed. Because it lays a foundation. Design will be shaped on top of this foundation." (R2.1)

Macro level, higher level or helicopter level requirements refer to major design decisions. R3 gave an example of helicopter level requirements being discussed at the initial phases of requirements identification:

> "Initially, helicopter level requirements are being discussed such as if the helicopter rotor will have 4 blades or 5 blades, rather than discussing details of whether there will be an IFF [Identification Friend or Foe] device under the navigation system." (R3.1)

Participant M2 having experience with direct communications with the client and the customer, had a direct idea of the order of the inputs. The DDSS should first ask whether the helicopter will be of civil usage or military usage, then whether it will be armed or utility. M2 stated:

> "This is the experience I gathered from my fair meetings and other pilots and designers. First, military or civil? Second, utility or attack helicopter? Right after, how many people will the product [carry]? Then we discussed other requirements activities." (M2.5)

Parameters provided to the user as inputs and outputs were explained in Section 3.1.1. C1 listed a few *sine qua non* specifications of a helicopter as HOGE performance, endurance, useful load and payload. M1 added speed values and power requirements to the list of important parameters. R6 emphasized range, cargo capacity, and gross weight as important parameters; on the other hand, they stated that the selection of parameters should be made primarily by design units. It should be noted that useful load and payload terms are being used interchangeably; however, they are slightly different from each other. Useful load is the summation of the payload and fuel weight. Those two items of weight inside the useful load can be traded. R1 worded that safety requirements were given priority; then, the mission performance requirements were discussed:

> "In fact, pilot usually prioritize themselves first, then requirements regarding the mission. They first think about themselves, then the mission. . . . Let me put it in order again: safety regarding the pilot's own safety and comfort, then mission requirements, then nonessential needs, things that make the job easier." (R1.7)

C1 also added survivability equipment and other equipment that affect the weight should be provided inside the parameter cloud of the system, which was repeated by S1:

> "It comes to my mind: How can military spec survivability etc. be added? How could we treat them? Maybe they can be added as weights."

Following the same approach, S1 added crashworthiness parameters that can be added to the DDSS, since they wanted to see the effects on the weight of the helicopter. It was exemplified by M1 using the case of ballistic requirements of cockpit glass:

> "Let's say [they] wanted ballistic glass. If ballistic glass adds approximately 2 tons, we can see its effect here directly. In this type of study, I think they [optional equipment that affects weight] are advantageous. We should see them." (M1.3)

Additionally, stealth was mentioned by R1 as it may be added to constrain the geometry of the fuselage. In contrast, there may be non-quantifiable requirements about which the DDSS would not be able to support. R6 stated, those type of requirements might be able to increase the requirements engineer's workload:

> "Additionally, we have compliance requirements of CS [Certification Specification, referring to that of EASA], requirements regarding legal procedures, and needs that are not mathematical. For example, how are we

going to add VFR[13] [Visual Flight Rules] here? ... These requirements are not mathematical data, as I said. Therefore, you can get 20-25-30 data from 3-5 or 10 mathematical data; but eventually, you have to check the needs that the client had sent you, again. Then maybe, it [usage of the DDSS] may increase the workload." (R6.3)

Referring to the abandonment of NH-90 and Eurocopter Tiger by several NATO countries [277], C1 pointed to the importance of maintenance and operation costs of a helicopter. Those costs should be estimated and provided as decision support inside the DDSS. Those costs should be estimated and provided as decision support inside the DDSS. In addition to the cost estimation, which was also repeated by M2, resources needed in terms of funding and human resources can also be included in the DDSS, since it was mentioned as one of the pros of the tools that was used before.

The sizes of the helicopter inside the design space may be needed to be limited when there is a requirement for strategic air transport. C1 gives the example of Airbus A400M Atlas which is also in the inventory of the Turkish Armed Forces. If the customer has an operation including a strategic air transport via an A400M, then the design space should be limited accordingly, since the helicopter has to fit inside this aircraft.

In addition to cargo weight, M2 found cargo volume as required among the inputs.

Regarding the limits of the design space; S1, M5, R3 and R6 felt that the altitude limit of 6000 feet was too low. S1, M5 and R3 stated that it should be at least 20000 feet. In contrast, S1 and R3 found the range limits too high, S1, M5, R3 and R6 found the number of passengers limit too high, S1 added cabin height limits to this list, wanting to see lower values. Fuel tank configurations were also mentioned as there should be more variants. Similar to fuel tank location configurations, landing gear configurations whether they are retractable or fixed were said to be included in the system, by S1.

M3 stated that the limits used in the DDSS should be explicitly to the user, providing some kind of transparency. Limiting the inputs in a way that the DDSS used in this

[13] Visual flight rules are the set of rules that the pilot is allowed to fly by seeing the flight conditions. In comparison, there are instrument flight rules (IFR) in which the flight can only be conducted with the assistance of the instruments.

study, may lead the user to think as if this is a law. M3 explained this issue:

> "The software works in a limited framework. This also limits the user. For example, we can load a maximum of 500 kg of cargo. A user may think as if this is the maximum amount that a helicopter can be loaded." (M3.2)

R1, S1 and C1 stated that the speed values should have been inputs rather than outputs. S1 specifically mentioned never exceed speed value to be an input for the DDSS.

4.3.2.2 Verifiability and Validity

One of the most repeated feedback of the DDSS is its verifiability and validity. This theme was mentioned by C1, R2, R3, R4, S1, M1, M2 and M5. R2 emphasized the potential conclusiveness issue if the validity lacks:

> "If a supportive tool is not qualified, then there may be problems about the trustworthiness of its outputs and its defense against the client." (R2.2)

If the validity is ensured, R2 found the usage of the DDSS advantageous in terms of speeding the process up, provisionally. Validity was also referred to as being correct or right. C1 emphasized the need for correctness of a model constructed in the background of such supportive systems:

> "Your model should be correct. The more correct it is, the better results you get. If you constructed your model wrong, the results will delude you. There is a saying: garbage in, garbage out." (C1.9)

The validation can be ensured by statistical methods or subject-mature experts, according to C1. Nevertheless, it was said to be really hard considering the lack of quantitative data collected by the customer institution. C1 stated that it would be beneficial especially while deciding on which equipment should be integrated to which platforms, investigating their utilization data whether there is an under-utilizitaion or there is an over-utilization. However, those type of data collection was found insufficient by C1, and it was stated to be hard to provide correct inputs for the model to be constructed.

The data given for the competitor products should also be exact and verifiable, according to M2. M2 had experienced the difficulties in comparing different versions of a certain helicopter. (There may be several variations of a helicopter, specializing for the mission it conducts.) Therefore, it is important to indicate which version of the helicopter is being compared:

> "I believe; if we are to compare Apache[14] [Boeing AH-64] with ATAK 2 [TAI T929], we should think beforehand which versions of ATAK 2 and Apache will be compared, and we should guide the client this way." (M2.6)

4.3.2.3 Transparency

Participants C1, R4, R5, R6, M1 and M5 had questioned the calculations done in the background. Participant R6 first gave inputs of the helicopter they were currently working on at the time of the interview, and observed the results if they were consistent with the real values or not. After convincing themselves, the participant started to experiment with new values.

M1 proposed a solution to prove the validity of the DDSS by providing the calculation methods and background processing steps if demanded. C1 proposed that the DDSS may check the inputs that are very close to an existing helicopter, with its encyclopedic information which is very close to the outputs, like a demonstration.

4.3.2.4 Operation-Oriented Approach

The customer was stated to have an operation-oriented approach, by C1 and M4. Then, they proposed a mission profile checker to be integrated into the DDSS, in order to increase its tangibility from the customer's perspective:

> "Something like a sample mission profile execution [can be integrated]. For example, you got 400 kg [cargo], 8 passengers, this much of fuel; [the helicopter] would fly at this altitude, you can execute this mission and return. [The customer] may want to see something like this. But

[14] There are numerous variants of AH-64, denoted with letters A to F. There are cross modifications of those variants, and licensed production variants such as AgustaWestland Apache AH1 which was developed from Boeing AH-64D Apache Longbow.

> it will be in our conditions, our country's conditions. It will be in our mission fields like you take off from Şırnak, go there and return... If they see something like this..." (M4.5)

According to M4, showing a design solution or design proposal for the customer and the client via a simulation would be more tangible than just pledges given verbally. Hence, it would be more conclusive for the client or the customer. M4 also expressed their observations on how the customer evaluates a design solution in an operation-oriented approach:

> "If we say something like 'you can execute this operation easily', then they may be convinced. Because they are operation [oriented] people. Yes, there are engineers working there but the people they have to convince at higher levels work as 1/0. They do not care about this data. HIGE, HOGE, VNE [never exceed velocity] are not that important for them. Will this job get done or not? Will I execute the operation or not?" (M4.6)

Based on a previous experience, M4 expressed that the customer did not want to get lost within details. During a cockpit design part of a project, they were talking about dimensions and measurements; nonetheless, the customer wanted to understand if they were able to reach and access certain parts.

4.3.2.5 Representation and Consistency

Different modes of representation such as providing CAD visuals of the design configuration was also stated as feedback by M1 and R4. According to M1, it would help to strengthen the message aimed to deliver. If the user wants a design near the extreme of the design space, unusual and non-conventional visuals would contribute to the message about the applicability of the design solution. R4 related this need to provide CAD visuals with its verifiability in terms of FPDA calculation done in the background. The feedback in Quote M4.5 about providing a mission profile checker is also related to the mode of representation.

The inputs of the DDSS were criticized for having a level of consistency and rationality within themselves. R6 pointed out that lower cabin height values should be consistent with cargo requirements like carrying a specific vehicle:

> "[An example of carrying a land vehicle was discussed.] ... it is not that consistent. Seeing that you can choose higher cabin height, then the cargo weight input can also be selected as high as the [object] aimed [to carry]. For example a car is about 1200 kg and a jeep is 1600 kg. I am making up right now. Then I may be able to select 1600 kg." (R6.4)

4.3.2.6 Responsiveness

Helicopter design has many trade-off studies during the requirements identification phase. C1 stated that the system should warn the user about various topics. For instance, if the user tries to design a very big helicopter in terms of size, it should warn the user about the radar cross-section area which would affect the detectability of the aircraft negatively in warfare. If the user tries to design something very close to the limits of the technical availability, the DDSS should warn them with technology readiness levels and production readiness levels.

Indicating the unreal outputs with red color was recognized by R1, M1, M4 and M5. This choice was found to be appropriate about delivering its message that the design solution is not applicable. It was also acknowledged as a requirement by M3.

Participant R1 had repeated the issues of impossible requirements demanded by the client and the customer. Those demands can be answered by clear and technical responses from the DDSS. According to R1, the level of technical information in that feedback should be at an adequate level so that there would be no extra discussion about it. R6 stated the usage of the DDSS with appropriate responsiveness, could speed up the requirements identification process by guiding the client:

> "During the contract phase, we go to meetings with the client. They have a little data, we may insert these data [into the DDSS], and we say: 'Our range can be this much, endurance can be 4 hours, maximum speed can be this much. Hence, your needs satisfy these [parameters]. We cannot go further than that.' Then, they may change the inputs they gave. The process can speed up there." (R6.5)

Certification compliance can be a type of response that a requirements engineer seeks to check. R6 mentioned measures of compliance and proof of compliance being discussed as quantified checkpoints in terms of certification.

4.3.2.7 Interpretability for Different Perspectives

Usage of the DDSS was found advantageous by M1, if it is provided to the client, too. According to M1, it is important that the client should also be able to experiment with the design space and observe its consequences.

Different stakeholders have different perspectives on the discussion and negotiation of the requirements of a helicopter. Representatives of the customer institution were said to be more operation-oriented by participants C1 and M4. C1 described the DDSS that they tested as “too technical”, and the customer would not understand it. M4 described the outputs given in the comparison chart as “too detailed”. The outputs and feedback should be more interpretable in terms of the execution of the operation, rather than giving purely numerical outputs. Those numerical and “technical” outputs can be meaningful for the designers and pilots, as M2 and M4 stated. On the other hand, there may be differences between the mindset of pilots and engineers, as R5 mentioned while discussing a requirements meeting involving pilots:

> "Pilot said: ‘I am a regular human. I am an operator. I cannot think complicatedly, like an engineer.’" (R5.6)

Different modes of representation were acknowledged to be beneficial, especially for the customer side. C1 and M4 proposed putting a map to help the user from the customer side to help them visualize the operational range means. M4 asserted that a high-ranking officer from the customer institution would not interpret the numerical outputs, and would ask operational questions:

> "What would a high-ranking officer say looking at this [chart]? They would say: ‘alright’ meaning ‘alright’. ... They would ask: ‘I took off from Şırnak, but can I from İzmir?’ You would know if it can take off from İzmir or not." (M4.7)

Moreover, M4 stated that the interpretations from the customer were said to need more tangibility. M4 defined a practicality for the customer by referring to some kind of tangibility:

> "...the customer is rather operational as far as I have seen. They focus on the practicality, meaning they become happy from the things they can touch, they can see and they can understand at once." (M4.8)

From a managerial perspective, M2 interpreted the outputs of the DDSS as showing the strengths and weaknesses of the product. Therefore, there can be emphasized outputs according to the strengths and weaknesses compared to the competitors inside the market.

There are also differences in perspective between design engineers and systems engineers, as R6 noted that parameter selection may differ from the conceptual design approach to the requirements management approach. The perspective of the engineering side in general may treat some parameters as if they were the same. For instance, R1 treated both the number of passengers and the weight of cargo as payload:

> "The requirements of how many passengers I am going to carry and how much cargo I am to carry are so similar. Besides, more or less the same things occur when I change it." (R1.8)

4.3.2.8 Inexactness

The presentation of the outputs as if they are exact values and exact decisions were criticized by S1. The impression of an exact refusal of a requirement found harmful for the process. It would be used during SRR phase, much after the contract:

> "It needs to be pondered for a while, whatever the requirement is. It may be inappropriate to show it [to the customer] during the contract phase." (S1.5)

Similar comment to that of S1 made by R4. R4 was skeptical about the use of any software to assist in requirement identification if it would automate the process. Because, the compliance of the requirement should always be evaluated, according to R4.

Participant M1 had expressed a criteria for a requirement as it should not guide the design and it should let the design free. Similar argument about not limiting creativity was also mentioned by R1.

4.3.2.9 Traceability

Requirements development is a process in which the requirements are being negotiated. Through these negotiations, the requirements are being detailed and broken down into subsystems level. Among the pros of the existing requirements management tools, traceability was mentioned by M1, M5 and R6. It was also stated by M1 that the change management was critical in design processes that deal with complex products. This management should be integrated into the supportive tools, and the ideal tool, according to M1, should provide traceability from end to end.

R1 had also mentioned traceability ensured in DOORS as links can be created between requirements:

> "...links can be established. Using those links you may find the answer of that question: 'Where did that system requirements come from?' This provides good [level of] traceability." (R1.9)

4.3.2.10 Connectivity and Security

There are existing tools that are used for the lawfulness and traceability of the requirements such as requirement management tools, and CAD management tools inside PLM systems. It was mentioned by M1, as an issue that those tools have connectivity issues. M1 described the ideal connectivity level in such a way that all the management from conceptual design to after-sale services could be managed from one single tool's interface:

> "... a tool that I have written the requirements on it, tracing of those requirements, tracing of the design on top of it, production, [after-sale] service, if there is a single tool doing these, if an issue during the after-sale service would give me a feedback about the conceptual design, I could trace them from the same system, momentarily." (M1.4)

R4 stated that the user must be ensured for the *up-to-dateness* of the product, if one of its parts had been updated. Therefore, connectivity to the PLM systems can be said to be essential in order to ensure it:

> "It should be ensured that the parameters are the current design data. For example, maybe a mechanical part had been lightened. It needs to be updated. Otherwise, it [the helicopter] would be heavy." (R4.4)

On the opposite side of connectivity, there are information security issues that are critical in the defense industry. R1 mentioned that the involvement of the information technologies unit would be required in order to ensure the safety of that information.

4.3.2.11 Multilayeredness and Deeper Information

C1 stated that the DDSS may serve for different levels of requirements, and not just the macro level requirements like performance specifications. It may have different layers that provide information about subsystems at deeper levels. For instance, fuel weight was provided as an input to allow the user to evaluate its proportion in the gross weight; on the other hand, M1 stated that they could calculate the fuel consumption from there. Fuel consumption was not mentioned by any other interviewee. This type of extra information can be provided in deeper levels. This type of various expectation was also mentioned by M3:

> "Expectation on the [level of] detail may also vary. This should also be taken into consideration." (M3.3)

It should also be taken into consideration that providing numerous parameters at the same time would also be confusing for the user, according to R6:

> "You gather all the outputs from all angles. There will be 50 outputs at the same time. Then, it will be hard to interpret those outputs for you." (R6.6)

4.3.2.12 Clarity

The terms in the DDSS were used as they are being used at helicopter level design. For instance, range means the range of the helicopter; however, it is only written as “range”. This needed clarification for those who mostly deal with sub-systems. R1 asked for clarification for range, and power differences between HIGE and HOGE.

Cabin height parameter was found ambiguous whether it indicates the height measured from inside or outside of the cabin. M3 and R3 needed clarification, especially for the abbreviations used in the DDSS.

4.4 Discussion

Requirement identification process and the development of the design brief or contract were emphasized as separate stages in some of the design-focused procedural models (i.e. Pahl & Beitz's model, VDI models, Pugh's model and Ullman's model. See Section 2.1.2.4.2.1), project-focused procedural models (Section 2.1.2.4.2.2) and systems engineering life cycle approaches (Section 2.1.3.1). It can be said that the conceptualization of the requirements development is closely tied with the design process model applied. Although the requirement identification process method in practice was described mostly in parallel to the systems engineering's life cycle models, the identification of the need from the customer's side had unique characteristics with its relation to war strategy and organization type. The customer's leading role in the industry was mostly observed in agency issues happening among the institutions; between the customer and the client, between the client and the contractor, finally between the customer and the contractor. The agency was observed mostly in favor of the customer.

Criticisms regarding the method in practice included the lack of the cooperation among institutions and internal cooperation issues specific to each institution, mostly in the customer institution and the contractor company. Horizontal organizational design that aims to improve cooperation among different institutions on a personal scale is also related to the ideal method explained by M2. The lack of interaction among institutions also affects the method applied in practice. Organizational design, and design process model and methods are in a reciprocal relationship.

The lack of cooperation may also stem from the fact that the organizational structure of the industry and the product itself have a considerable amount of complexity. Therefore, it can be said that the complexities in organization and product may also deepen the issue of unclear vision of common goals among stakeholders and several communication gaps among the stakeholders. Continuity issues regarding the stakeholder participation were another key issue combined with relatively longer product development duration due to the nature of being a safety-critical industry. Another key issue was the lack of CSCW support during the requirement identification. At this stage, benchmarking applications were widely mentioned, and the client institution was criticized for its inadequacy for being the mediator, as in Quote M4.4 describing the client's work as preparing a "best-of" of the specifications. The contractor company developed some methodical approaches in requirement identification such as the application of MOEs.

R1 and R5 mentioned the usage of MOEs in the requirement identification process. In fact, MOEs are defined in an INCOSE workshop report [278] as follows: "The *operational* measures of success that are closely related to the achievement of the mission or operational objective being evaluated, in the intended operational environment under a specified set of conditions; i.e., how well the solution achieves the intended purpose." It can be said that the usage of MOEs may vary depending on the current design phase. In the same report [278], it was stated that MOEs are used to compare operational alternatives and evaluate their operational performance and serve as a standard of acceptance. It can be said that the definition and aim of MOEs are extended in such a way that they are not only used in determining success criteria of a design solution, but also assess and evaluate relative importance of the requirements.

Combining the communication gaps during the requirements negotiation meetings, complexity in the institutional structure with agency issues, and the lack of supportive methods specialized for requirement identification, it was acknowledged that the demands of the customer may become inappropriate for business plans, technical capability, and even for the operational goals of the customer itself. Those demands are reflected into the requirements, inelastically, such as leaving little room for negotiation as stated in Quote R5.3. Having ill-defined problems was mentioned to be in the nature of the design brief development process (see Section 2.2.1). Nevertheless, the participants from the contractor company criticized the customer or the client's need as not being "exact enough", mostly referring to the changing and conflicting needs of the customer and the client. Although the need for an exactness in identifying the requirements from the client's needs, as M1 mentioned, its potential issues were also discussed for the prescriptiveness of a design brief like limiting the freedom of the designer.

General structure of the major issues observed, and their relations can be seen in Figure 4.4. The arrows point in the resulting direction, and some arrows are double headed meaning that the relation is reciprocal.

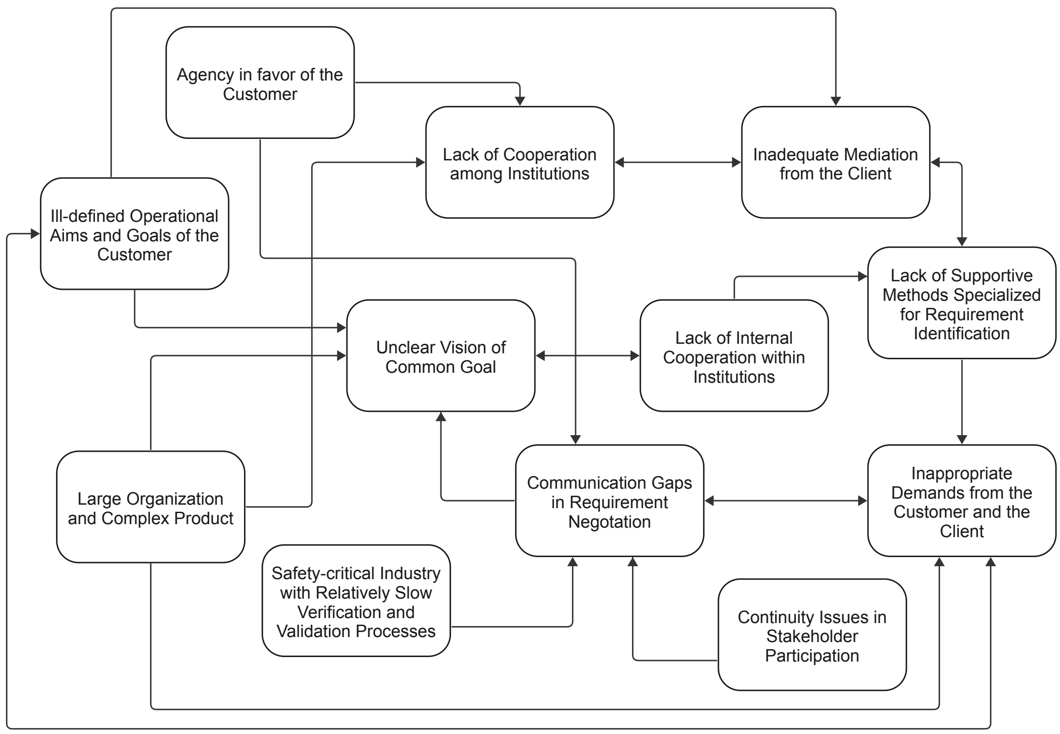

Figure 4.4: General Structure of the Issues Faced in Requirement Identification Process

Major issues whose relations were shown in Figure 4.4, can also be categorized in terms of their theme and domain. There are industry-specific issues that exist in the nature of the industry being a safety-critical industry, and dealing with complex products via large organizations. Lack of cooperation among and within institutions can be categorized as organizational problems. There is also a context-specific problem domain regarding the problems around the customer and client institutions. On top of these domains, there are cross-relational problems such as the lack of supportive methods and continuity issues being in the cross-sectional region of the nature of the industry and organizational problems. Communication gaps and unclear vision of common goals can be said to be in relation to both the context-specific problems and organizational problems. Inappropriate demands can be placed in between these cross-sections. It is related to all domains. The categories of the problem domain can be seen in Figure 4.5.

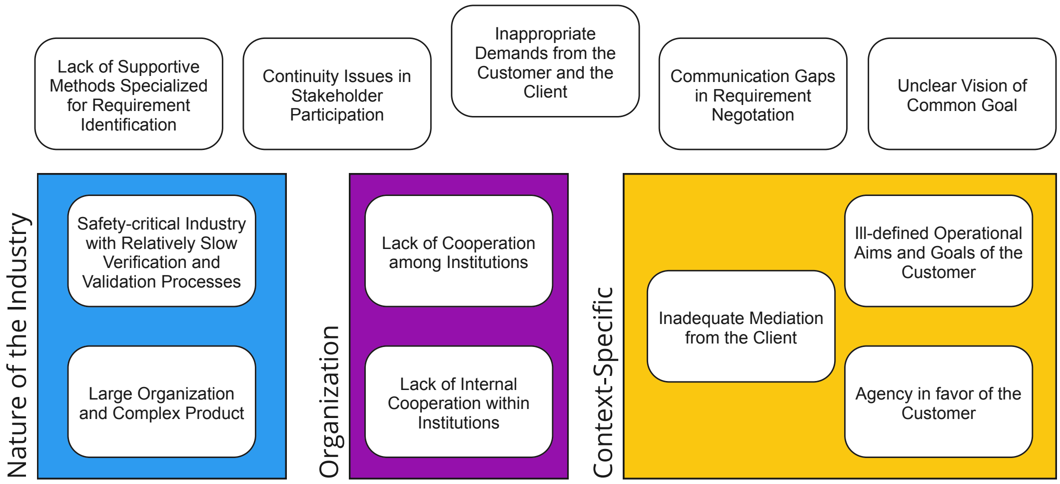

Figure 4.5: Categories of the Problems Faced in Requirement Identification

4.4.1 Requirements of the DDSS

Considering the feedback given for the DDSS, issues analyzed regarding the practice, and the evaluations of the existing tools used, requirements for the design of a DDSS to be used in the helicopter industry were determined. Those requirements have interrelations among them. Those relations can be seen in Figure 4.6.The arrows point in the contributing direction. Dashed arrow means conflict. Dashed boxes are provisionally defined requirements in Töre-Yargın and Crilly [228].

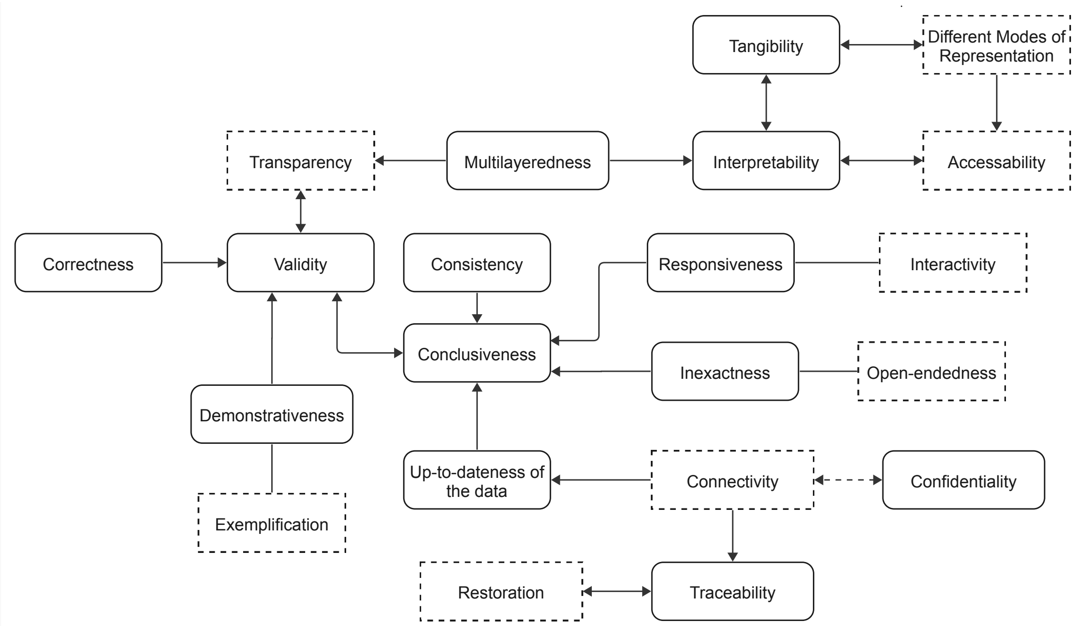

Figure 4.6: Relation Map of the Design Requirements Defined for the DDSS

Considering the inappropriate needs of the customer and the over-demanding behavior of both the customer and the client, the feedback regarding the DDSS was mostly focused on its conclusiveness for the customer in relation with its validity and responsiveness. Participants focused on the responses and feedback given by the DDSS that provides a checking system for the conflicting requirements, such as challenging technology with respect to its readiness level or limiting parameters. The DDSS needs to be verified for several reasons. Firstly, according to the safety-critical nature the stakeholders want to ensure that the system operates correctly without any doubt. Secondly, it contributes to its conclusiveness. Thirdly, it allows some kind of transparency.

Transparency was also examined as an interaction quality provided by a design support system as discussed by Töre-Yargın and Crilly [228]. It was observed in this study that the user convinces themselves first, regarding the principles of the system working in the background. It was apparent during the interview that was conducted with R6. Exemplification can also contribute to the validity requirement. If the user gives inputs of an existing product, the DDSS may show that it is very close to that particular helicopter with its encyclopedic information which is very close to the outputs, like a demonstration. As C1 stated, it would contribute to the self-persuasion of the user.

Conclusiveness of the information provided by the DDSS as a design solution alternative was also mentioned as its up-to-dateness regarding the current design data. Up-to-dateness can be ensured with adequate connectivity with several applications like PLM solutions that are already in use. Therefore, these two requirements are also connected to each other. Connectivity is also a threat for information security. As an industrial-specific issue, confidentiality and information security were mentioned by M3, M5, R4 and R6. Confidentiality and connectivity should be taken into consideration as conflicting requirements.

Perspective differences with respect to different stakeholders should be taken into consideration while designing a DDSS. It should be accessible for different types of users. In order to ensure the interpretability and accessibility for the customer, the tangibility of the inputs and outputs was emphasized such as mission profiles and operational instances. Tangibility is different from exemplification, it mostly refers to the information quality being easily understood by the operation-oriented users.

Providing different modes of representation was already found to be supporting the accessibility [228]. Tangibility requirement in this study can be related to providing different modes of representation to some extent, and there are differences between tangibility and exemplification. Tangibility does not necessarily mean giving practical examples. For instance, an existing design without any examples existing in the market can be represented via simulations. As M4 expressed, this would be tangible for the user.

Providing the inputs as exact solutions was found problematic in two different aspects. Firstly, it was mentioned by R1 as limiting the designer's freedom. Secondly, it was expressed by S1 that it may misguide the user that the design solution is directly appropriate or inappropriate, conflicting with conclusiveness. Therefore, another requirement of the DDSS is open-endedness ensuring an inexactness to the outputs provided as design solution alternatives.

Participants evaluated the existing tools used in the industry. Traceability of the requirements in an hierarchical breakdown system and in the process of requirements development was mentioned as a major advantage. Therefore, the DDSS should also provide traceability of the requirements, like a history log of the previous decisions. This is also related to the restoration requirement [228] which emphasizes restoring the last instance of the system and allowing the user to return back.

The level of detail provided by the DDSS was found dependent on the role of the stakeholder. Providing too much information at the same time may conflict with the interpretability of the DDSS as it was mentioned in Quote R6.6. Therefore, a multi-layered structure can be built for the information provided by the DDSS. Multilayered presentation of the information would be beneficial for the users who want to examine certain types of information in detail. For instance, R4 asked for the details of FPDA calculation and which version of master geometry[15] was used in the calculations. R6 wanted to compare the numerical values which were proportioned in the comparison chart. This type of information can be provided in deeper layers.

It should also be noted that some of the requirements are organically related in a superset-subset relationship. Responsiveness, demonstrativeness, and inexactness are specialized requirements that can be viewed as subsets of interactivity, exemplification, and open-endedness, respectively. These relationships are shown without arrows, indicating that the relationship is direct and organic.

There are direct and indirect relations between some of the problems faced in practice, and some of the requirements of the DDSS. Since, some problems refer to multiple requirements of the DDSS that are interrelated, some requirements are grouped. The relation chart can be seen in Figure 4.7.

Validity, demonstrativeness and conclusiveness are a group having dense relations within each other. Safety-critical industries require a detailed verification and validation process having demonstration procedures for some of the verification processes. Therefore, this group of requirements can serve this industry-specific problem. Lack of supportive methods problem is also related to this group, as industry needs validated tools to ensure the validity of the tool for other stakeholders and for themselves. Moreover, the usage of the DDSS is directly a solution domain for this problem.

[15] Master geometry can be defined as the outer surface definition which is one of the most essential factors calculating the FPDA value.

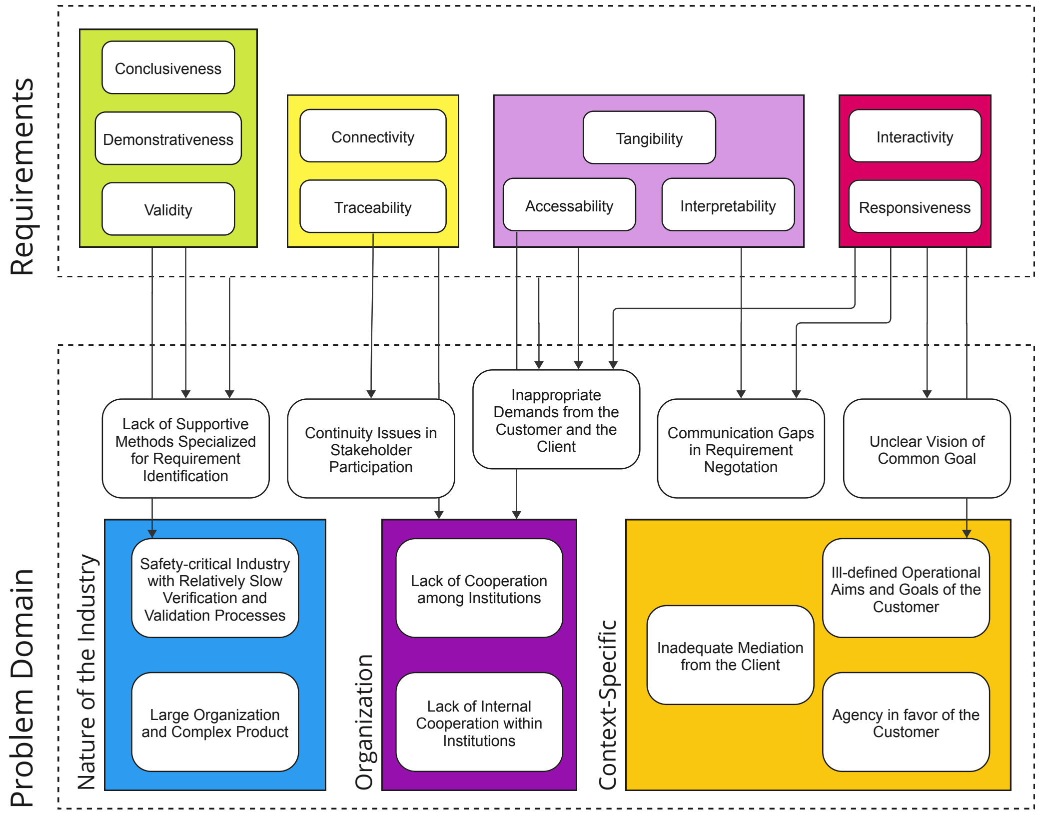

Figure 4.7: Relation Map of the Design Requirements of the DDSS and Problems Faced in Practice

Continuity issues are directly related with traceability requirements, since it allows the users to trace the history of a requirement. Traceability and connectivity are grouped, as they are similar. This group also allows external stakeholders to keep familiar with the reasoning of the requirements. Moreover, it may support the coordination within an institution since the connectivity to existing tools allows the internal stakeholders to get familiar with the information provided by the DDSS, in relation to the information that they are already familiar with.

Tangibility, accessibility and interpretability are grouped together as they mostly serve the perspective differences of different stakeholders. As a group, they are related to the communication gaps originating from those perspective differences. Inappropriate demands problem is in relation with the lack of understanding these perspective differences. Moreover, it requires that multiple stakeholders should be able to access the DDSS. Therefore, this problem is directly related to accessibility. A solution for this problem also requires an interpretable platform with tangible information; therefore, it is also related to the accessibility-interpretability-tangibility group. The usage of the DDSS itself is also in relation with this problem.

Responsiveness and interactivity are grouped together, since they are closely connected. As a group, they mostly serve the purpose of showing the complex relations among requirements to the user. Therefore, they are in relation with the inappropriate demands problem, communication gaps, unclear vision of common goal, and ill-defined operational aims. Being able to show the relations among requirements would warn the users to consider their demands iteratively. It would also allow the user to understand the effects of someone else's requirements, and result in an enhanced understanding leading to create a common vision.

CHAPTER 5

CONCLUSION

Requirement identification process in helicopter design is the main context in this thesis. This process is in relation to several factors such as the social and technical relationship structure among stakeholders, and the design process itself. Considering the specific conditions of the helicopter industry in Turkey, especially the social and technical structure among the stakeholders has its own complexities. Those factors in requirement identification creates particular issues and problems that are faced in practice. This thesis explores those issues and problems via an experimental DDSS, and develops design guidelines for such a system.

In order to explore the structural factors that lie behind the issues of requirement identification, a literature review (Chapter 2) was conducted. The literature review followed a top-down approach, and it can be said to have two major parts. The first part examined methodical approaches in product design and development with different philosophies depending on how the product or the business was taken into consideration. Different design process models conceptualized requirements identification and requirements development in different ways. Then, a similar investigation was conducted within the scope of systems engineering which is the disciplinary approach applied in the practice of the helicopter industry. It was possible to see similar patterns concerning how the requirement identification was conceptualized between the consensus model in engineering design and process models in systems engineering approach, and they were discussed in the discussion of the literature review. After the investigation regarding the methods discussed in literature, the focus was narrowed to the formal agreement of the design brief and product design specifications as the "legal" end-product of requirement identification process. For the briefing process, requirements engineering as a systems engineering approach was investigated, since it is the disciplinary approach applied in practice. Social and technical relations among different stakeholders were the focus in this investigation as communication gaps faced in requirements engineering processes. Then, CSCW studies in design and development context, especially in industries where there are multiple stakeholders were examined as a potential solution domain. Finally, design support systems and design-decision support systems with their design requirements were examined at the most specific instance of the literature review.

A qualitative research was designed (Chapter 3) that aims to explore the issues faced in the practice, possible solutions, and feedback regarding the experimental DDSS, in the light of the findings from the literature review. The findings and results (Chapter 4) were reported following a similar pattern in the literature review. This chapter can also be said to have two major parts, the issues and problems faced in practice, and the feedback regarding the DDSS. The application of the design process models discussed in literature was reported within the context of the helicopter industry in Turkey. The participants who are professionals in the industry gave insights and criticisms regarding the methods in practice. Then, specific issues faced in requirements meetings were reported that revealed the social and technical structures in these processes. The second major part of the findings was the feedback about the DDSS. The participants used the system and gave feedback regarding its usage, qualities, structure and information qualities. Those comments and feedback were transformed into design requirements in the discussion of the findings and results chapter.

In this chapter, key findings are summarized as the research questions listed in Chapter 1 are being answered. Moreover, limitations of the study and recommendations for further research are discussed in related sections.

5.1 Revisiting the Research Questions

In this section, key insights and findings are underlined and summarized as the research questions are answered.

How can the requirements identification processes dealing with higher level require-

ments in helicopter design be supported by a design-decision support system?

Requirement identification is a complex and dynamic process that cannot be overemphasized regarding its effects on the final product and its impact on the business and market dynamics. There is a stakeholder structure mainly consisting of the customer, the client and the contractor. Workflow regarding the requirement identification flows from the customer to the client, and from client to the contractor with inadequate cooperation among them. Stakeholder structure in the industry operates in favor of the customer institution, hence the requirement identification process is mainly under the influence of the customer's needs and demands reflecting onto the work of the client and the contractor, as it was discussed in Section 4.1. The design process, on the other hand, is handled in a sequential manner where the conceptual design studies with feasibility trade-off are conducted after the requirements are formalized and legalized with a contract.

Problems related to the design process model used in practice have structural roots to the evolution of the engineering design's consensus model. Different taxonomy models throughout the literature were reviewed in Section 2.1.2. The categorization regarding conceptualizing the design phases as activities and stages can also be examined as defining distinct boundaries of design stages. This process is an example of territorialization in which the design *stages* are placed and conceptualized separately preventing the interactive and highly iterative nature of creative design *activities* to take place. Requirement identification is a complex design activity which has strong relations to conceptual design, market analysis, and stakeholder relations with social and technical dimensions. The territorialization of design stages became so apparent in procedural design process models that the evolution of those models from design-focused to project-focused tried to integrate the interactions between stages and influences of external factors other than purely technical requirements in requirement identification or problem analysis. In addition to these structural problems, the investigation of the practice in the helicopter industry yielded that the design process model is also strongly related with the organization structure of the organizations. Hence, it can be said that the dynamic nature of the requirement identification should be acknowledged in a design process, considering its implementation in a design organization management in relation with multiple stakeholders.

Even though the dynamic nature of requirements identification is acknowledged in systems engineering literature (Section 2.2.2) and in practice, the facilitator role of the systems engineering in these processes were found inadequate. Requirement identification process should be considered as part of the product design process, and the prescriptiveness of a contract should increase incrementally as the design space is being explored through conceptual design studies. The facilitator should be aware of the fact that the design space is bounded by the capabilities of the contractor, business plans of the client, and strategic aims of the customer. These boundaries and the concerns of the stakeholders can be represented in a DDSS as a boundary object, aiming to increase the coordination among them. The answers of the following questions will also contribute to this main question.

What are the issues and problems faced in these processes?

The issues explored throughout the research are in parallel to the communication gaps discussed in the literature on requirements engineering (Section 2.2.2.2). In addition to the communication gaps, other factors affecting requirements identification and requirements development were explored (Section 4.2), and it was found that those issues are in relation with each other (Section 4.4). Communication gaps also result in the unclear vision of common goal. The external and internal stakeholders do not completely share the vision of a success criteria regarding the final product. The conflicting nature of the interests in a narrow scale is also in a reciprocal relation with the lack of cooperation. The communication gaps observed among the stakeholders also stem from the safety-critical nature of the helicopter industry. These type of industries prioritizes safety, and foster verification and validation process in spite of slower progression through the project realization processes. This relatively-slow progression also results in longer product development process which results in continuity issues in stakeholder participation from every stakeholder.

The lack of cooperation between institutions and within the units of the same organization was one of the key problems that led to and reproduced several other problems. Lack of cooperation is produced by the nature of the complex product and large organizations. In a context-specific perspective, the agency in favor of the customer institution also prevented the coordination to improve in an autonomous manner. The customer institution's needs have a significant priority in the requirement identification process over the needs of the client and the technical and financial capability of the contractor. Within these conditions, the client institution who was supposed to ensure the mediation among institutions seemed lacking to coordinate the workflow and balance the agency/power relations. In addition the imbalanced agency among the stakeholders, these problems were found to be deepened with the lack of supportive methods in practice with ill-defined operational and strategic aims of the customer that result in inappropriate, order-like demands in terms of feasibility, producibility and saleability to the contractor. Consequently, the lack of cooperation and the ill-defined operational aims are in a reciprocal relation; they reproduce each other.

What are the design requirements for a design-decision support system which aims to assist the requirements identification?

Main design requirements for a DDSS were found as validity, traceability, interpretability, accessibility, responsiveness, demonstrativeness, connectivity, tangibility, interactivity and conclusiveness. Other requirements are transparency, multilayeredness, confidentiality, open-endedness, inexactness and consistency. There are also relations among them, as it was discussed in Section 4.4.1.

One of the main factors questioned regarding the qualities of the DDSS was the conclusiveness of the information provided by the system. In order to ensure the adequate level of conclusiveness, validity of the DDSS was found important (Section 4.3.2.2). Validity of the system can be strengthened by demonstrativeness in relation with exemplification and transparency (Section 4.3.2.3) in terms of the match between how the system works in the mind of the user and how it really works. Connectivity (Section 4.3.2.10) ensuring the up-to-dateness of the data used, open-endedness providing the inexactness of the design solution alternative (Section 4.3.2.8), and responsiveness with adequate levels of interactivity (Section 4.3.2.6) were found to be the other design requirements which also contribute to the conclusiveness of the system.

What are the dimensions that the stakeholders (customers, users, clients, contractor managers and requirements engineers) consider about such a system?

Perspective differences on the requirements of the DDSS varied depending on the role of the user in the design and development. The customer side was found to be operation-oriented, as it was discussed in Section 4.3.2.4. They prioritize the needs of the operation they need to execute. The customer can be said to seek for mission profile compliance rather than numerical data of the performance specifications. They prefer tangible representation of the design outcomes. The users (pilots) were said to have both the mindset of the institutional perspective of the customer in an operation-oriented way, and the technical mindset of the engineers and designers in the contractor company (Section 4.3.2.7). The client's perspective was focused on the social factors of requirements engineering between them and the customer. Exactness of the design solution provided by the system was found conflicting with the conclusiveness of it. They also value the technical capability of the contractor with its strategic value for the industry. It can be said that the client's perspective is business-driven, as the strategic and non-productive outputs for the state are also considered. Contractor managers prioritize the company's technical capability, and profit-based business in terms of saleability. Therefore, financial design parameters and feasibility trade-off studies were also found important as well as the conclusiveness of the system in terms of delivering the technical appropriateness of the design output provided by the system. Requirement engineers focus on both the technical factors and social factors involved in the requirements identification processes. The validity of the system was emphasized by the requirements engineers considering the safety-critical nature of the industry. Their requirements consisted of the need for deeper information which can easily be found as over-technical by other stakeholders. Traceability of the requirements was also found critical from the requirements engineers perspective (Section 4.3.2.9), since one of the major jobs of them is not only to participate in the requirements identification but also to manage the requirements throughout the whole life cycle of the product.

How can those requirements be satisfied?

Transparency of the system can be ensured by providing more information and demonstrations regarding the consistency and correctness of the inputs given to the system. On the other hand, providing more and deeper information conflicts with the interpretability and accessibility. Therefore, a multilayered structure can ensure transparency by providing stratified information depending on the needs of the user, as well as preventing the lack of interpretability that comes from excessive information (Section 4.3.2.11). Up-to-dateness of the data and traceability can be ensured by connectivity with other systems such as PLM softwares and requirements management tools, while minding the confidentiality needed specifically in the helicopter industry which is closely tied to the defense industry (Section 4.3.2.10). Responsiveness can be provided by presenting feedback mostly about operational needs and technology readiness levels that indicate the technical appropriateness of the design solution.

Having answered the sub-questions of the main research question, it can be said that the usage of a properly designed DDSS can support the requirement identification process in response to the problems faced in practice. There are also relations between these problems and design requirements of the DDSS, as it was schematized in Figure 4.7. The usage of the DDSS will also have impact on the design process model to be schematized and used in practice. The potential use of the DDSS should be integrated into the creative process of requirement identification in interaction with the initial design activities such as conceptual design studies and market analysis or competitor analysis studies. Those design phases should be considered as an integrated, complex design activity rather than defining as bounded design stages with limited interaction. This complex activity of requirement identification brings multiple stakeholders with differing interests, and the DDSS has the potential to be a boundary object among the stakeholders. The following phases in the design process may require its own DDSS support with specially tailored DDSS applications. This study focused on the high level requirements during the initiation of a helicopter design project.

5.2 Implications of the Study

This study determines the design requirements of a DDSS to be used in the requirement identification of a helicopter. It explores the problems faced in practice and relates them with the requirements of the DDSS, in a qualitative way. The findings and results of this study have several theoretical and practical implications.

Findings of the study firstly contribute to the literature on design support systems and their qualities (Section 2.3.1.1). Secondly, the usage of the DDSS is related to improving the cooperation among different external and internal stakeholders in the helicopter industry. Therefore, the study contributes to the literature on CSCW (Section 2.3), from a perspective from the helicopter industry. The finding about the problems faced in requirements engineering with insights from the helicopter industry contributes to the literature on the factors in requirements development process (Section 2.2.2.1).

Additionally, the outcomes of this study can be a guide for not only the practitioners in the helicopter industry who are to design a DDSS focusing to support the requirement identification process, but also the other stakeholders involved in this process. The findings also reflect several perspective differences between stakeholders, and their differing priorities. Designers and design managers can use this insight to improve collaboration within and across organizations.

5.3 Limitations of the Study and Recommendations for Further Research

Major limitations are about the sample group of participants in the study. The possible number of participants are inherently limited considering the size of the helicopter industry in Turkey. Within this limited size of the industry, the number of people involved in the requirement identification process is also limited. Even though the sample group of requirements engineers represent a significant portion currently working in the industry, it poses a limitation for the study. Number of participants from managerial people is another limitation. Moreover, this study focused on a case in an organization. Further research may include more companies and institutions to get a wider picture of the industry.

There were differences between the audio taped interviews and other interviews that the participant did not permit voice recording, in terms of the level of detail of information captured on-the-record. This lack of detail in the interviews conducted without voice recording is another limitation. Possible participants both hesitated to participate in the study and to permit voice recording, considering the confidentiality issues and sensitivity of the information related to the state and the army.

Another major limitation was the lack of participants from the client and the customer institutions. Those institutions are closer to the confidential and sensitive information. On top of the hesitations stemming from these factors, their work schedules are heavy. (Ironically, this was one of the issues resulting in communication gaps discussed in this thesis.) Therefore, the perspective difference of those stakeholders may not be reflected enough onto the findings of this study. Further research in this field may focus more on the customer's and the client's sides. The insights captured in this study were expressed by former members of staff of those institutions. Further research may compare the current issues faced with deeper insights gained from more participants from those institutions. The client institution has shares in other companies operating in the defense industry which collaborate with the major contractor company in the helicopter industry. Those collaborations can be examined regarding their impact on the requirements identification.

The prototype DDSS used in this study was presented as a sample and fictional case, and it was not implemented in a real case. Further study may include a DDSS which is designed following the requirements presented in this study, and it may investigate its implication on a real design case. Those insights can deepen the findings presented in this thesis.

There are other stakeholders in the requirement identification process such as certification authorities and airworthiness institutions. These were not investigated in detail in this study. Their presence was mentioned indirectly by other stakeholders. Although their contribution is limited compared to the ones involved in the study, further research may include the perspectives of those stakeholders.

Helicopter industry is also in relation with other industries considering the spillover effect. Therefore, those relations in the industry and the bureaucracy can also be examined for their impact on design. Comparative studies can be conducted in other countries to reveal cultural differences and political influences on design depending on how the military-industrial-congressional complex has evolved in different socio-cultural and material conditions.

Qualitative nature of this research can be enhanced by quantitative data with enough participants, regarding the frequency and the priority of the themes explored as design requirements of the DDSS.

REFERENCES

[1] D. Wynn and J. Clarkson, "Models of designing," in *Design Process Improvement: A review of current practice* (J. Clarkson and C. Eckert, eds.), ch. 1, pp. 34–59, London: Springer, 2005.

[2] A. D. Hall, "Three-dimensional morphology of systems engineering," *IEEE Transactions on Systems Science and Cybernetics*, vol. 5, no. 2, pp. 156–160, 1969.

[3] R. J. McCrory, "The design method — a scientific approach to valid design," in *Contributions to a Philosophy of Technology: Studies in the Structure of Thinking in the Technological Sciences* (F. Rapp, ed.), pp. 158–173, Dordrecht: Springer Netherlands, 1974.

[4] N. F. M. Roozenburg and J. Eekels, *Product Design: Fundamentals and Methods*. John Wiley & Sons, 1995.

[5] G. Pahl, W. Beitz, J. Feldhusen, and K. H. Grote, *Engineering Design: A Systematic Approach*. London: Springer-Verlag, 2007.

[6] VDI-Fachbereich Produktentwicklung und Mechatronik, "VDI-Richtlinie 2222 Blatt 1: Konzipieren technischer Produkte. Düsseldorf: VDI-Verlag 1977. – Überarbeitete Fassung (Entwurf): Methodisches Entwickeln von Lösungsprinzipien," *Düsseldorf: VDI-EKV*, 1996.

[7] VDI-Fachbereich Produktentwicklung und Mechatronik, "VDI 2221: Methodik zum Entwickeln und Konstruieren Technischer Systeme und Produkte," *Düsseldorf: VDI-GPP*, 1993.

[8] J. Jänsch and H. Birkhofer, "The development of the guideline VDI 2221-the change of direction," in *DS 36: Proceedings DESIGN 2006, the 9th International Design Conference, Dubrovnik, Croatia*, pp. 45–52, 2006.

[9] S. Pugh, "Design activity models: worldwide emergence and convergence," *Design Studies*, vol. 7, no. 3, pp. 167–173, 1986.

[10] C. Hales and S. Gooch, *Managing engineering design*. London: Springer, 2004.

[11] N. I. of Standards and Technology, "Integration definition for function modeling (IDEF0)," standard, U.S. Department of Commerce, Technology Administration, Gaithersburg, MD, Dec. 1993.

[12] D. Steward, "The design structure matrix: A method for managing the design of complex systems," *IEEE Transactions on Engineering Management*, vol. 28, no. 1981, p. pp, 1981.

[13] A. Kusiak and J. Wang, "Efficient organizing of design activities," *The International Journal Of Production Research*, vol. 31, no. 4, pp. 753–769, 1993.

[14] K. Forsberg, H. Mooz, and H. Cotterman, *Visualizing Project Management: Models and Frameworks for Mastering Complex Systems*. John Wiley & Sons, 2005.

[15] D. D. Walden, G. J. Roedler, K. J. Forsberg, R. D. Hamelin, and T. M. Shortell, *INCOSE Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities*. Hoboken, NJ: John Wiley & Sons, 2015.

[16] W. W. Royce, "Managing the development of large software systems," in *Proceedings IEEE WESCON*, pp. 328–338, The Institute of Electrical and Electronics Engineers, 1970.

[17] FDA Centre for Devices and Radiological Health, *CDRH strategic plan*. Rockville, MD: US Food and Drug Administration, 2001.

[18] B. O'Donovan, C. Eckert, J. Clarkson, and T. R. Browning, "Design planning and modelling," in *Design Process Improvement: A review of current practice* (J. Clarkson and C. Eckert, eds.), ch. 2, pp. 60–87, London: Springer, 2005.

[19] B. W. Boehm, "A spiral model of software development and enhancement," *Computer*, vol. 21, no. 5, pp. 61–72, 1988.

[20] D. G. Ullman, *The Mechanical Design Process*. New York, NY: McGraw-Hill, 2010.

[21] M. Darlington and S. Culley, "A model of factors influencing the design requirement," *Design Studies*, vol. 25, no. 4, pp. 329–350, 2004.

[22] C. Earl, C. Eckert, and J. Johnson, "Complexity models in design," in *DS 32: Proceedings of DESIGN 2004, the 8th International Design Conference, Dubrovnik, Croatia* (D. Marjanovic, ed.), pp. 163–168, The Design Society, 2004.

[23] N. Cross and N. Roozenburg, "Modelling the design process in engineering and in architecture," *Journal of Engineering design*, vol. 3, no. 4, pp. 325–337, 1992.

[24] D. G. Ullman, T. G. Dietterich, and L. A. Stauffer, "A model of the mechanical design process based on empirical data," *Ai Edam*, vol. 2, no. 1, pp. 33–52, 1988.

[25] S. Nidamarthi, A. Chakrabarti, and T. Bligh, "The significance of co-evolving requirements and solutions in the design process," *Schriftenreihe WDK*, pp. 227–230, 1997.

[26] A. Chakrabarti, S. Morgenstern, and H. Knaab, "Identification and application of requirements and their impact on the design process: a protocol study," *Research in engineering design*, vol. 15, pp. 22–39, 2004.

[27] NASA, *Systems Engineering Handbook*. Washington, D.C.: National Aeronautics and Space Administration, 2007.

[28] Defense Acquisition University, *System Engineering Fundamentals*. Fort Belvoir, VA: Defense Acquisition University Press, 2001.

[29] M. Glinz, "On non-functional requirements," in *15th IEEE international requirements engineering conference (RE 2007)*, pp. 21–26, IEEE, 2007.

[30] O. L. De Weck, A. M. Ross, and D. H. Rhodes, "Investigating relationships and semantic sets amongst system lifecycle properties (ilities)," 2012.

[31] KHK/696, "Olağanüstü hal kapsamında bazı düzenlemeler yapılması hakkında kanun hükmünde kararname," *Resmi Gazete*, no. 30280, Dec. 24, 2017.

[32] Cumhurbaşkanlığı Kararnameleri, "Cumhurbaşkanlığı Teşkilatı Hakkında Cumhurbaşkanlığı Kararnamesi (Kararname Numarası: 1)," *Resmi Gazete*, no. 30474, Jul. 10, 2018.

[33] Turkish Aerospace, "About us." [Online]. Available: `https://www.tusas.com/en/corporate/about-us`, [Accessed: Oct. 6, 2022].

[34] Law No: 3388, "Türk Silahlı Kuvvetlerini Güçlendirme Vakfı Kanunu," *Resmi Gazete*, no. 19498, Jun. 25, 1987.

[35] Turkish Armed Forces Foundation, "Administration." [Online]. Available: `https://www.tskgv.org.tr/en/about-us/administration`, [Accessed: Oct. 14, 2022].

[36] A. Hall, "Patron-client relations," *The Journal of Peasant Studies*, vol. 1, no. 4, pp. 506–509, 1974.

[37] L. Ennser-Jedenastik, "Political control and managerial survival in state-owned enterprises," *Governance*, vol. 27, no. 1, pp. 135–161, 2014.

[38] A. Shleifer and R. W. Vishny, "Politicians and firms," *The quarterly journal of economics*, vol. 109, no. 4, pp. 995–1025, 1994.

[39] S. K. Pandey and B. E. Wright, "Connecting the dots in public management: Political environment, organizational goal ambiguity, and the public manager's role ambiguity," *Journal of Public Administration Research and Theory*, vol. 16, no. 4, pp. 511–532, 2006.

[40] E. C. Stazyk and H. T. Goerdel, "The benefits of bureaucracy: Public managers' perceptions of political support, goal ambiguity, and organizational effectiveness," *Journal of Public Administration Research and Theory*, vol. 21, no. 4, pp. 645–672, 2011.

[41] J. Malay and M. R. Fairholm, "How ideological divides serve to limit bureaucratic autonomy: A case study of the blm," *The American Review of Public Administration*, vol. 50, no. 4-5, pp. 375–386, 2020.

[42] J. Morales, "State-owned enterprises as a political tool: The case of a venezuelan oil company," *Problems and Perspectives in Management*, vol. 20, no. 1, pp. 473–487, 2022.

[43] J. D. Sinsay, "Re-imagining rotorcraft advanced design," *The Aeronautical Journal*, vol. 122, no. 1256, pp. 1497–1521, 2018.

[44] T. Sahin, "Turkish Aerospace inks deal with Ukrainian firm to buy helicopter engines: TAI to procure 14 engines from Ukraine's Motor Sich for heavy class attack helicopter." [Online]. Available: `https://www.aa.com.tr/en/economy/turkish-aerospace-inks-deal-with-ukrainian-firm-to-buy-helicopter-engines/2288815#`, Jun. 29, 2021 [Accessed: Mar. 5, 2023].

[45] A. Mevlutoglu, "Turkish-Ukrainian Defense Cooperation: Drones, Engines, and More: The Russia-Ukraine War was a stark reminder for Turkey that complex aerospace and defense programs are important assets in foreign relations.." [Online]. Available: `https://politicstoday.org/turkish-ukrainian-defense-cooperation-drones-engines-and-more/`, Dec. 22, 2022 [Accessed: Mar. 5, 2023].

[46] L. Bullen, "Russia Destroys Motor Sich Engine Plant In Zaporizhzhia: Russian troops fire missiles into the air and reportedly destroy the Motor Sich engine plant in south-eastern Ukraine.." [Online]. Available: `https://www.zenger.news/2022/05/27/russia-destroys-motor-sich-engine-plant-in-zaporizhzhia/`, May. 27, 2022 [Accessed: Mar. 5, 2023].

[47] J. Kankaanpää, L. Oulasvirta, and J. Wacker, "Steering and monitoring model of state-owned enterprises," *International Journal of Public Administration*, vol. 37, no. 7, pp. 409–423, 2014.

[48] OECD, *Corporate Governance of State-Owned Enterprises: A Survey of OECD Countries*. Paris: Organisation for Economic Co-operation and Development, 2005.

[49] B. Spector, *Implementing organizational change: Theory and practice*. Upper Saddle, NJ: Prentice Hall, 2012.

[50] A. M. Pettigrew, "Decision-making as a political process," in *The politics of organizational decision-making*, ch. 2, pp. 16–31, Routledge, 1973.

[51] G. Frawley, *The International Directory of Military Aircraft 2002/03*. Motorbooks Intl, 2003.

[52] G. Frawley, *The International Directory of Civil Aircraft 2003-2004*. Zenith Imprint, 2003.

[53] J. M. DiNuccio, "A case study of requirements in the helicopter industry," M.S. thesis, Massachusetts Institute of Technology, Boston, MA, USA, 1999.

[54] P. Suciu, "Italy's Flying Mongoose: Meet the Agusta A129 Mangusta." [Online]. Available: `https://nationalinterest.org/blog/reboot/italys-flying-mongoose-meet-agusta-a129-mangusta-184467`, May 5, 2021 [Accessed: Mar. 1, 2023].

[55] IndraStra Global, "TAI T625 Özgün - Turkey's "Home-grown" Multi-role Helicopter." [Online]. Available: `https://www.indrastra.com/2018/09/Turkish-T625-004-09-2018--037.html`, Sep. 21, 2018 [Accessed: Mar. 1, 2023].

[56] D. Donald, "Turkish Aerospace Flies T625 Utility Helicopter." [Online]. Available: `https://www.ainonline.com/aviation-news/defense/2018-09-07/turkish-aerospace-flies-t625-utility-helicopter`, Sep. 7, 2018 [Accessed: Mar. 1, 2023].

[57] K. Ramani, D. Ramanujan, W. Z. Bernstein, F. Zhao, J. Sutherland, C. Handwerker, J.-K. Choi, H. Kim, and D. Thurston, "Integrated Sustainable Life Cycle Design: A Review," *Journal of Mechanical Design*, vol. 132, no. 9, 2010.

[58] W. J. Fabrycky and B. S. Blanchard, *Life-Cycle Cost and Economic Analysis*. Englewood Cliffs, NJ: Prentice-Hall, 1991.

[59] V. Walsh, R. Roy, M. Bruce, and P. Stephen, "From design brief to manufactured product," in *Winning by Design: Technology, Product Design and International Competitiveness*, ch. 7, pp. 191–228, Oxford: Blackwell, 1992.

[60] A. Blyth, "Briefing: strategy & tactics for change," in *OH Seminar, Norges Byggforsknings-Institutt*, 2000.

[61] J. Yen and W. A. Tiao, "A systematic tradeoff analysis for conflicting imprecise requirements," in *Proceedings of ISRE'97: 3rd IEEE International Symposium on Requirements Engineering*, pp. 87–96, IEEE, 1997.

[62] T. Viana, A. Zisman, and A. K. Bandara, "Identifying conflicting requirements in systems of systems," in *2017 IEEE 25th International Requirements Engineering Conference (RE)*, pp. 436–441, IEEE, 2017.

[63] P. Eden, *The encyclopedia of modern military aircraft*. Amber Books Limited, 2004.

[64] CNN, "Army cancels Comanche helicopter." [Online]. Available: `https://edition.cnn.com/2004/US/02/23/helicopter.cancel/`, Feb. 24, 2004 [Accessed: Mar. 2, 2023].

[65] N. Ryd, "The design brief as carrier of client information during the construction process," *Design studies*, vol. 25, no. 3, pp. 231–249, 2004.

[66] F. Yang and G. Renda, "The design briefing process matters: a case study on telehealthcare device providers in the UK*," *Disability and Rehabilitation: Assistive Technology*, vol. 14, no. 1, pp. 91–98, 2019.

[67] Y. Meron, "What's the brief?: Building a discourse around the graphic design brief," *M/C Journal*, vol. 24, no. 4, 2021.

[68] R. Stevens, P. Brrok, K. Jackson, and S. Arnold, *Systems engineering: coping with complexity*. London: Prentice Hall Europe, 1998.

[69] D. Norman, *The design of everyday things: Revised and expanded edition*. Basic books, 2013.

[70] E. Bjarnason, K. Wnuk, and B. Regnell, "Requirements are slipping through the gaps—a case study on causes & effects of communication gaps in large-scale software development," in *2011 IEEE 19th international requirements engineering conference*, pp. 37–46, IEEE, 2011.

[71] A. Al-Rawas and S. Easterbrook, “Communication problems in requirements engineering: a field study,” in *Proceedings of the first Westminster Conference on Professional Awareness in Software engineering*, (London), pp. 47–60, 1996.

[72] J. Coughlan and R. D. Macredie, “Effective communication in requirements elicitation: a comparison of methodologies,” *Requirements Engineering*, vol. 7, no. 2, pp. 47–60, 2002.

[73] W. Zeiler, P. Savanovic, and E. Quanjel, “Design decision support for the conceptual phase of the design process,” in *Proceedings of the International Association of societies of design research : Emerging trends in design research Conference 2007 (IASDR 2007) 12/15 November 2007, Hong Kong* (S. Poggenpohl, ed.), pp. 1–15, School of Design, The Hong Kong Polytechnic University, 2007.

[74] J. Bernsen, “The design before the design,” *Danish Design Centre Magazine*, no. 2, 1996.

[75] A. Collier, “The design brief: Are you listening?,” in *Design and Designing: A Critical Introduction* (S. Garner and C. Evans, eds.), ch. 14, pp. 210–223, New York, NY: Berg Publishers, 2012.

[76] M. Lier, A. Krenik, P. Kunze, D. Kohlgrüber, D. Schwinn, and M. Lützenberger, “A toolbox for rotorcraft preliminary design,” in *AHS 71st Annual Forum*, May 2015.

[77] H. Ibacoglu, A. E. Coskun, and T. Kayabasi, “Rotorcraft conceptual design methodology by using fully parametric CAD model with embedded empirical formulations,” in *78th Annual Vertical Flight Society Forum and Technology Display (FORUM 78): The Future of Vertical Flight*, vol. 2, pp. 803–812, Fairfax, VA: Vertical Flight Society, 2022.

[78] H. Ibacoglu, A. E. Coskun, and T. Kayabasi, “Conceptual level sizing, evaluation and design space exploration tool,” in *Multi-Fidelity Methods for Military Vehicle Design (Méthodes multifidélités pour la conception de véhicules militaires)*, pp. 13.1–13.16, STO/NATO, 2023.

[79] M. Luchs and K. S. Swan, “Perspective: The emergence of product design as a field of marketing inquiry,” *Journal of Product Innovation Management*, vol. 28, no. 3, pp. 327–345, 2011.

[80] N. Roozenburg and N. Cross, “Models of the design process: Integrating across the disciplines,” *Design Studies*, vol. 12, no. 4, pp. 215–220, 1991.

[81] W. Holmes, M. Azam, and P. Hills, “A preliminary study of the relationship between industrial design and engineering design,” in *Proceedings of the 1st conference on Designing interactive systems: processes, practices, methods, & techniques*, pp. 105–114, 1995.

[82] M. Black, *The Black Papers on Design*. Pergamon Press, 1983.

[83] B. R. Lawson, “Cognitive strategies in architectural design,” in *Developments in Design Methodology* (N. Cross, ed.), pp. 209–220, Chichester: Wiley, 1984.

[84] C. Alexander, *Notes on the Synthesis of Form*. Cambridge, MA: Harvard University Press, 1964.

[85] C. Alexander, “A city is not a tree,” *Design*, vol. 206, pp. 46–55, 1966.

[86] N. P. Suh, *Axiomatic Design : Advances and Applications*. New York: Oxford University Press, 2001.

[87] N. P. Suh, *The Principles of Design*. New York: Oxford University Press, 1990.

[88] H. W. J. Rittel and M. M. Webber, “Dilemmas in a general theory of planning,” in *Developments in Design Methodology* (N. Cross, ed.), pp. 135–144, Chichester: Wiley, 1984.

[89] D. M. Buede, “Introduction to systems engineering,” in *The Engineering Design of Systems: Models and Methods*, ch. 1, pp. 3–48, New Jersey: John Wiley & Sons, 2009.

[90] V. Walsh, R. Roy, M. Bruce, and P. Stephen, “Organizing design and innovation,” in *Winning by Design: Technology, Product Design and International Competitiveness*, ch. 5, pp. 138–166, Oxford: Blackwell, 1992.

[91] C. Lorenz, "Scrum and scrabble: the Japanese style," *Financial Times*, 19 June 1987.

[92] D. Winstanley and A. Francis, "Designing for competitiveness: A review of engineering design practices in Britain," *Engineering Designer*, vol. 14, pp. 18–19, 1988.

[93] G. E. Box and N. R. Draper, *Empirical model-building and response surfaces.* John Wiley & Sons, 1987.

[94] R. von der Weth, "Design instinct?—the development of individual strategies," *Design Studies*, vol. 20, no. 5, pp. 453–463, 1999.

[95] G. Fricke, *Konstruieren als flexibler Problemlöseprozeß — empirische Untersuchung über erfolgreiche Strategien und methodische Vorgehensweisen beim Konstruieren*. Düsseldorf: VDI-Verlag, 1993.

[96] L. Blessing, *A process-based approach to computer supported engineering design*. PhD thesis, University of Twente, May 1994.

[97] A. D. Hall, *A methodology for systems engineering*. Princeton, NJ: van Nostrand, 1962.

[98] M. Asimow, *Introduction to design*. Englewood Cliffs, NJ: Prentice-Hall, 1962.

[99] J. Darke, "The primary generator and the design process," *Design studies*, vol. 1, no. 1, pp. 36–44, 1979.

[100] L. March, "The logic of design," in *Developments in Design Methodology* (N. Cross, ed.), Chichester: Wiley, 1984.

[101] J. C. Jones, "A method of systematic design," in *Conference on design methods*, pp. 9–31, Pergamon Press Ltd., 1963.

[102] N. Cross, *Engineering Design Methods: Strategies for Product Design*. John Wiley & Sons, 2008.

[103] S. Finger and J. R. Dixon, "A review of research in mechanical engineering design. part i: Descriptive, prescriptive, and computer-based models of design processes," *Research in engineering design*, vol. 1, no. 1, pp. 51–67, 1989.

[104] J. H. Evans, “Basic design concepts,” *Journal of the American Society for Naval Engineers*, vol. 71, no. 4, pp. 671–678, 1959.

[105] M. J. French, *Conceptual Design for Engineers*. London: Springer, 1999.

[106] A. D. d. Groot, *Methodology : Foundations of Inference and Eesearch in the Behavioral Sciences*. Psychological studies ; 6, The Hague: Mouton, 1969.

[107] V. Hubka, *Principles of Engineering Design*. Butterworth & Co Ltd, 1982.

[108] C. L. Dym, P. Little, and E. J. Orwin, *Engineering Design: A Project-Based Introduction*. John Wiley & Sons, 2013.

[109] S. Pugh, *Total design: integrated methods for successful product engineering*. Addison-Wesley, 1991.

[110] British Standard BS 7000, *Guide to Managing Product Design*. London: British Standards Institute, 1989.

[111] P. Buckle and J. Clarkson, “Systems engineering,” in *Design Process Improvement: A review of current practice* (J. Clarkson and C. Eckert, eds.), ch. 3, pp. 88–113, London: Springer, 2005.

[112] M. M. Andreasen and L. Hein, *Integrated Product Development*. IFS/Springer, 1987.

[113] L. B. Archer, *Technological innovation: A methodology*. PhD thesis, Royal College of Art, 1970.

[114] R. G. Cooper, “Third generation new product processes,” *Journal of Product Innovation Management*, no. 11, pp. 3–14, 1994.

[115] ISO 9000:1987, “Quality management and quality assurance standards — Guidelines for selection and use,” standard, International Organization for Standardization, Geneva, CH, Mar. 1987.

[116] PMI Standards Committee, *A project management body of knowledge (PMBOK)*. Project Management Institute, 2000.

[117] T. R. Browning, “Applying the design structure matrix to system decomposition and integration problems: a review and new directions,” *IEEE Transactions on Engineering management*, vol. 48, no. 3, pp. 292–306, 2001.

[118] P. J. Clarkson and J. R. Hamilton, “‘signposting’, a parameter-driven task-based model of the design process,” *Research in Engineering Design*, vol. 12, no. 1, pp. 18–38, 2000.

[119] Leonardo S.p.A., “History.” [Online]. Available: `https://www.leonardo.com/en/about/history`, [Accessed: Dec. 9, 2022].

[120] Leonardo S.p.A., “Turkey: a longstanding commercial and industrial presence.” [Online]. Available: `https://www.leonardo.com/en/global/turkey`, [Accessed: Dec. 9, 2022].

[121] P. J. Clarkson, A. Melo, and C. Eckert, “Visualization of routes in design process planning,” in *2000 IEEE Conference on Information Visualization. An International Conference on Computer Visualization and Graphics*, pp. 155–164, IEEE, 2000.

[122] G. Booch, *Object-oriented analysis and design with applications*. Addison-Wesley, 1993.

[123] I. Jacobson, M. Christerson, P. Jonsson, and G. Overgaard, *Object-oriented software engineering: A use case driven approach*. Addison-Wesley, 1992.

[124] G. Gladden, “Stop the life-cycle, i want to get off,” *ACM SIGSOFT Software Engineering Notes*, vol. 7, no. 2, pp. 35–39, 1982.

[125] H. Li and K. Womer, “Optimizing the supply chain configuration for make-to-order manufacturing,” *European Journal of Operational Research*, vol. 221, no. 1, pp. 118–128, 2012.

[126] C. Eckert and J. Clarkson, “The reality of design,” in *Design Process Improvement: A review of current practice* (J. Clarkson and C. Eckert, eds.), pp. 1–29, London: Springer, 2005.

[127] M. Foucault, *The Archeology of Knowledge*. London: Routledge, 1972.

[128] INCOSE, "Systems engineering definition." [Online]. Available: https://www.incose.org/about-systems-engineering/system-and-se-definition/systems-engineering-definition, [Accessed: Dec. 9, 2022].

[129] ISO 15288:2015, "Systems and software engineering — System life cycle processes," standard, International Organization for Standardization, Geneva, CH, May 2015.

[130] ISO 24748-1:2018, "Systems and software engineering — Life cycle management — Part 1: Guidelines for life cycle management," standard, International Organization for Standardization, Geneva, CH, Nov. 2018.

[131] DoDI 5000.2, *Acquisition Management*. Washington, DC: US Department of Defense, 2004.

[132] NASA GPG 7120.5, *System Engineering*. Greenbelt, MD: NASA GSFC, 2004.

[133] NASA NPG 7120.5C, *Program and Project Management Processes and Requirements*. Washington, DC: NASA HQ, 2005.

[134] J. Achenbach, "NASA's Mars mission has some seeing red." [Online]. Available: https://www.nbcnews.com/id/wbna29134295, Feb. 11, 2009. [Accessed: Jan. 15, 2023].

[135] FDA Centre for Devices and Radiological Health, *Program and Project Management Processes and Requirements*. Rockville, MD: US Food and Drug Administration, 1997.

[136] K. Forsberg and H. Mooz, "The relationship of system engineering to the project cycle," in *INCOSE international symposium*, vol. 1, pp. 57–65, Wiley Online Library, 1991.

[137] S. Dennehy, "Agile requirements – irritation or opportunity?," in *INCOSE South Africa Systems Engineering Conference*, 09 2009.

[138] MIL-STD-973, *Military Standard: Configuration Management*. Washington, DC: US Department of Defense, 1992.

[139] ISO 24765:2017, "Systems and software engineering — Vocabulary," standard, International Organization for Standardization, Geneva, CH, Sept. 2017.

[140] M. A. Cusumano and R. W. Selby, *Microsoft secrets: how the world's most powerful software company creates technology, shapes markets, and manages people*. Simon and Schuster, 1998.

[141] B. Boehm, J. A. Lane, S. Koolmanojwong, and R. Turner, *The incremental commitment spiral model: Principles and practices for successful systems and software*. Addison-Wesley Professional, 2014.

[142] N. Cross, "The design brief," in *T211 Design and Designing Block 2: User Requirements and the Design Brief*, ch. 9, pp. 94–98, Milton Keynes: Open University, 2006.

[143] A. Blyth and J. Worthington, *Managing the brief for better design*. Taylor & Francis, 2010.

[144] A. M. Maier, C. M. Eckert, and P. J. Clarkson, "Identifying requirements for communication support: A maturity grid-inspired approach," *Expert Systems with Applications*, vol. 31, no. 4, pp. 663–672, 2006.

[145] P. Badke-Schaub, A. Neumann, K. Lauche, and S. Mohammed, "Mental models in design teams: a valid approach to performance in design collaboration?," *CoDesign*, vol. 3, no. 1, pp. 5–20, 2007.

[146] S. Pugh, "Design techniques and methods," in *Creating Innovative Products Using Total Design* (D. Clausing and R. Andrade, eds.), ch. 3, pp. 137–204, Reading, MA: Addison-Wesley, 1996.

[147] N. Cross, "Product design specification," in *T211 Design and Designing Block 2: User Requirements and the Design Brief*, ch. 10, pp. 99–108, Milton Keynes: Open University, 2006.

[148] N. Cross, "Consumer choice," in *T211 Design and Designing Block 2: User Requirements and the Design Brief*, ch. 7, pp. 75–84, Milton Keynes: Open University, 2006.

[149] R. Roy, D. Walker, and N. Cross, *Design for the Market*. Watford: Engineering Industry Training Board Publications, 1987.

[150] G. Fischer and J. Ostwald, "Knowledge communication in design communities," in *Barriers and Biases in Computer-Mediated Knowledge Communication: And How They May Be Overcome* (R. Bromme, F. W. Hesse, and H. Spada, eds.), pp. 213–242, Boston, MA: Springer US, 2005.

[151] M. Bruce, S. Potter, and R. Roy, "The risks and rewards of design investment," *Journal of Marketing Management*, vol. 11, no. 5, pp. 403–417, 1995.

[152] J. Kolko, *Exposing the Magic of Design: A Practitioner's Guide to the Methods and Theory of Synthesis*. New York, NY: Oxford University Press, 2011.

[153] R. Rambow and R. Bromme, "Was schöns 'reflective practitioner' durch die kommunikation mit laien lernen könnte," in *Wissen - Können - Reflexion: Ausgewählte Verhältnisbestimmungen* (G. H. Neuweg, ed.), pp. 245–263, Innsbruck: Studienverlag, 2000.

[154] M. Oakley, *Managing product design*. John Wiley & Sons, 1984.

[155] NEDO, *Product Design, a report by K. G. Corfield*. London: National Economics Development Office, 1979.

[156] IEEE 830:1984, "IEEE Guide for Software Requirements Specifications," standard, Institute of Electrical and Electronics Engineers, New York, NY, Feb. 1984.

[157] ISO 29148:2011, "Systems and software engineering — Life cycle processes — Requirements engineering," standard, International Organization for Standardization, Geneva, CH, Dec. 2011.

[158] B. W. Boehm, "Software engineering economics," *IEEE transactions on Software Engineering*, no. 1, pp. 4–21, 1984.

[159] K. Pohl, "The three dimensions of requirements engineering," in *Advanced Information Systems Engineering: 5th International Conference, CAiSE'93 Paris, France, June 8–11, 1993 Proceedings 5*, pp. 275–292, Springer, 1993.

[160] P. Loucopoulos, "Requirements engineering," in *Design Process Improvement: A review of current practice* (J. Clarkson and C. Eckert, eds.), ch. 4, pp. 116–139, London: Springer, 2005.

[161] D. M. Berry, K. Czarnecki, M. Antkiewicz, and M. AbdElRazik, "Requirements determination is unstoppable: an experience report," in *2010 18th IEEE International Requirements Engineering Conference*, pp. 311–316, IEEE, 2010.

[162] J. Coughlan, M. Lycett, and R. D. Macredie, "Communication issues in requirements elicitation: a content analysis of stakeholder experiences," *Information and Software Technology*, vol. 45, no. 8, pp. 525–537, 2003.

[163] P. Loucopoulos and E. Kavakli, "Enterprise modelling and the teleological approach to requirements engineering," *International Journal of Cooperative Information Systems*, vol. 4, no. 01, pp. 45–79, 1995.

[164] E. S. Yu, "Towards modelling and reasoning support for early-phase requirements engineering," in *Proceedings of ISRE'97: 3rd IEEE International Symposium on Requirements Engineering*, pp. 226–235, IEEE, 1997.

[165] A. I. Antón, W. M. McCracken, and C. Potts, "Goal decomposition and scenario analysis in business process reengineering," in *Advanced Information Systems Engineering: 6th International Conference, CAiSE'94 Utrecht, The Netherlands, June 6–10, 1994 Proceedings 6*, pp. 94–104, Springer, 1994.

[166] W. R. Flemming, "Requirements communication," in *International Automatic Testing Conference AUTOTESTCON'78.*, pp. 228–229, IEEE, 1978.

[167] J. A. Bubenko, "Challenges in requirements engineering," in *Proceedings of 1995 IEEE International Symposium on Requirements Engineering (RE'95)*, pp. 160–162, IEEE, 1995.

[168] P. Loucopoulos and V. Kavakli, "Enterprise knowledge management and conceptual modelling," in *Conceptual Modeling: Current Issues and Future Directions*, pp. 123–143, Springer, 1999.

[169] A. Shaw, D. Aitchison, J. Raine, and K. Whybrew, "Rapid product development for world class manufacturing," tech. rep., Technical Report 58, University of Canterbury, New Zealand, 2001.

[170] R. Frost, "Why does industry ignore design science?," *Journal of Engineering Design*, vol. 10, no. 4, pp. 301–304, 1999.

[171] K. T. Ulrich and S. D. Eppinger, *Product Design and Development*. New York, NY: McGraw-Hill, 2012.

[172] Luqi and F. Kordon, "Advances in requirements engineering: Bridging the gap between stakeholders' needs and formal designs," in *Innovations for Requirement Analysis. From Stakeholders' Needs to Formal Designs* (B. Paech and C. Martell, eds.), (Berlin, Heidelberg), pp. 15–24, Springer, 2008.

[173] A. Wootton, R. Cooper, and M. Bruce, *A Generic Guide to Requirements Capture*. Manchester: University of Salford, 1998.

[174] S. Marczak, D. Damian, U. Stege, and A. Schröter, "Information brokers in requirement-dependency social networks," in *2008 16th IEEE international requirements engineering conference*, pp. 53–62, IEEE, 2008.

[175] S. Marczak, I. Kwan, and D. Damian, "Investigating collaboration driven by requirements in cross-functional software teams," in *2009 Collaboration and Intercultural Issues on Requirements: Communication, Understanding and Softskills*, pp. 15–22, IEEE, 2009.

[176] G. Sabaliauskaite, A. Loconsole, E. Engström, M. Unterkalmsteiner, B. Regnell, P. Runeson, T. Gorschek, and R. Feldt, "Challenges in aligning requirements engineering and verification in a large-scale industrial context," in *Requirements Engineering: Foundation for Software Quality: 16th International Working Conference, REFSQ 2010, Essen, Germany, June 30–July 2, 2010. Proceedings 16*, pp. 128–142, Springer, 2010.

[177] B. Curtis, H. Krasner, and N. Iscoe, "A field study of the software design process for large systems," *Communications of the ACM*, vol. 31, no. 11, pp. 1268–1287, 1988.

[178] R. E. Quinn and M. R. McGrath, "The transformation of organizational cultures: a competing values perspective," in *Organizational Culture* (P. Frost, L. Moore, M. Louis, C. Lundberg, and J. Martin, eds.), pp. 315–334, Newbury Park, CA: Sage, 1985.

[179] J. Hartwick and H. Barki, "Communication as a dimension of user participation," *IEEE transactions on professional communication*, vol. 44, no. 1, pp. 21–36, 2001.

[180] C. A. Ellis, S. J. Gibbs, and G. Rein, "Groupware: some issues and experiences," *Communications of the ACM*, vol. 34, no. 1, pp. 39–58, 1991.

[181] C. A. Ellis, "Workflow technology," *Computer Supported Cooperative Work, Trends in Software Series*, vol. 7, pp. 29–54, 1999.

[182] A. M. Palermo and S. C. McCready, "Workflow software: A primer," in *Proceedings of the Conference GROUPWARE'92*, (London), pp. 155–159, 1992.

[183] S. Nurcan and J. Trolliet, "Une méthode d'analyse et de conception pour les applications workflow," in *Informatique des Organisations et Systèmes d'Information et de Décision*, pp. 453–472, 1995.

[184] S. Nurcan and C. Rolland, "A meta-model for goal-driven cooperative work processes," in *Workshop on the many facets of Process Engineering (MEPE'97), Gammarth, Tunis*, 1997.

[185] S. Nurcan and J.-L. Chirac, "Quels modèles choisir pour les applications coopératives mettant en œuvre les technologies de workflow et de groupware?," in *Proceedings of the AFCET 95 congress*, (Toulouse), pp. 593–602, 1995.

[186] S. Nurcan, "A method for cooperative information systems analysis and design: Cisad," in *Proceedings of the Second International Conference on the Design of Cooperative Systems (COOP'96)*, (Juan-Les-Pins), pp. 681–700, 1996.

[187] V. M. R. Penichet, I. Marin, J. A. Gallud, M. D. Lozano, and R. Tesoriero, "A classification method for cscw systems," *Electronic Notes in Theoretical Computer Science*, vol. 168, pp. 237–247, 2007.

[188] S. M. S. da Cruz, M. L. M. Campos, and M. Mattoso, "Towards a taxonomy of provenance in scientific workflow management systems," in *2009 Congress on Services-I*, pp. 259–266, IEEE, 2009.

[189] D. Poola, M. A. Salehi, K. Ramamohanarao, and R. Buyya, "A taxonomy and survey of fault-tolerant workflow management systems in cloud and distributed computing environments," *Software architecture for big data and the cloud*, pp. 285–320, 2017.

[190] T. Fahringer, R. Prodan, R. Duan, J. Hofer, F. Nadeem, F. Nerieri, S. Podlipnig, J. Qin, M. Siddiqui, H.-L. Truong, *et al.*, "Askalon: A development and grid computing environment for scientific workflows," *Workflows for e-Science: Scientific Workflows for Grids*, pp. 450–471, 2007.

[191] D. R. McCarthy and S. K. Sarin, "Workflow and transactions in inconcert," *IEEE Data Eng. Bull.*, vol. 16, no. 2, pp. 53–56, 1993.

[192] I. Taylor, M. Shields, I. Wang, and A. Harrison, "The triana workflow environment: Architecture and applications," *Workflows for e-science: Scientific workflows for grids*, pp. 320–339, 2007.

[193] J. Zhao, C. Goble, R. Stevens, and D. Turi, "Mining taverna's semantic web of provenance," *Concurrency and Computation: Practice and Experience*, vol. 20, no. 5, pp. 463–472, 2008.

[194] J. Lee and K.-Y. Lai, "What's in design rationale?," *Human–Computer Interaction*, vol. 6, no. 3-4, pp. 251–280, 1991.

[195] A. Streit, P. Bala, A. Beck-Ratzka, K. Benedyczak, S. Bergmann, R. Breu, J. M. Daivandy, B. Demuth, A. Eifer, A. Giesler, *et al.*, "Unicore 6—recent and future advancements," *Annals of Telecommunications-annales des Télécommunications*, vol. 65, pp. 757–762, 2010.

[196] W. van der Aalst and A. ter Hofstede, "Yawl: yet another workflow language," *Information Systems*, vol. 30, no. 4, pp. 245–275, 2005.

[197] G. Urobuchi (Writer) and N. Shiotani (Director), *Psycho-Pass*. [TV series] Tokyo: Fuji TV, 2012.

[198] A. Rozinat, M. T. Wynn, W. M. van der Aalst, A. H. ter Hofstede, and C. J. Fidge, "Workflow simulation for operational decision support," *Data & Knowledge Engineering*, vol. 68, no. 9, pp. 834–850, 2009.

[199] H. R. Siller, A. Estruch, C. Vila, J. V. Abellan, and F. Romero, "Modeling workflow activities for collaborative process planning with product lifecycle management tools," *Journal of Intelligent Manufacturing*, vol. 19, pp. 689–700, 2008.

[200] M. Contero and C. Vila, "Collaborative engineering," in *Advances in Electronic Business* (E. Y. Li and T. C. Du, eds.), vol. 1, ch. 4, pp. 87–122, Hershey, PA: Idea Group Publishing, 2004.

[201] PTC, *PTC Windchill*. Boston, MA: PTC Inc., 1998.

[202] D. T. Liu and X. W. Xu, "A review of web-based product data management systems," *Computers in industry*, vol. 44, no. 3, pp. 251–262, 2001.

[203] X. G. Ming, J. Q. Yan, W. F. Lu, and D. Ma, "Technology solutions for collaborative product lifecycle management–status review and future trend," *Concurrent Engineering*, vol. 13, no. 4, pp. 311–319, 2005.

[204] E. Subrahmanian, S. Rachuri, S. J. Fenves, S. Foufou, and R. D. Sriram, "Product lifecycle management support: a challenge in supporting product design and manufacturing in a networked economy," *International Journal of Product Lifecycle Management*, vol. 1, no. 1, pp. 4–25, 2005.

[205] E. Subrahmanian, C. Lee, H. Granger, and N-Dim Group, "Managing and supporting product life cycle through engineering change management for a complex product," *Research in Engineering Design*, vol. 26, pp. 189–217, 2015.

[206] N. Matta and G. Ducellier, "Traceability and structuring of decision-making," in *Daily Knowledge Valuation in Organizations: Traceability and Capitalization* (N. Matta, H. Atifi, and G. Ducellier, eds.), ch. 3, pp. 35–72, John Wiley & Sons, Ltd, 2016.

[207] E. Subrahmanian, I. Monarch, S. Konda, H. Granger, R. Milliken, A. Westerberg, and N-Dim Group, "Boundary objects and prototypes at the interfaces of

engineering design," *Computer Supported Cooperative Work (CSCW)*, vol. 12, pp. 185–203, 2003.

[208] L. L. Bucciarelli, *Designing Engineers*. Cambridge, MA: The MIT Press, 1994.

[209] S. L. Star and J. R. Griesemer, "Institutional ecology, 'translations' and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39," *Social Studies of Science*, vol. 19, no. 3, pp. 387–420, 1989.

[210] E. Wenger, "Communities of practice and social learning systems," *Organization*, vol. 7, no. 2, pp. 225–246, 2000.

[211] G. Fischer, "External and shareable artifacts as opportunities for social creativity in communities of interest," in *5th International Conference on Computational and Cognitive Models of Creative Design* (J. S. Gero and M. L. Maher, eds.), (Heron Island, Australia), pp. 67–89, 2001.

[212] M. Fominykh, E. Prasolova-Førland, M. Divitini, and S. A. Petersen, "Boundary objects in collaborative work and learning," *Information Systems Frontiers*, vol. 18, pp. 85–102, 2016.

[213] T. Tharchen, R. Garud, and R. L. Henn, "Design as an interactive boundary object," *Journal of Organization Design*, vol. 9, pp. 1–34, 2020.

[214] H. J. Timmermans, *Design and Decision Support Systems in Architecture*. Dordrecht: Kluwer Academic Publishers, 1993.

[215] Y. J. Grobman, A. Yezioro, and I. G. Capeluto, "Non-linear architectural design process," *International Journal of Architectural Computing*, vol. 8, no. 1, pp. 41–53, 2010.

[216] Y. Sagdic and H. Demirkan, "A design decision support system model for the wet space renovation of elderly people's residences," *Architectural Science Review*, vol. 43, no. 3, pp. 125–132, 2000.

[217] H. ku Lee, Y. sun Lee, and J. jun Kim, "A cost-based interior design decision support system for large-scale housing projects," in *Convergence and Hy-*

brid Information Technologies (M. Crisan, ed.), pp. 149–164, Vukovar: Intech, 2010.

[218] M. Zanni, T. Sharpe, P. Lammers, L. Arnold, and J. Pickard, "Developing a methodology for integration of whole life costs into BIM processes to assist design decision making," *Buildings*, vol. 9, no. 5, p. 114, 2019.

[219] The Boeing Company, "About Boeing defense, space & security." [Online]. Available: `https://www.boeing.com/company/about-bds/`, [Accessed: Apr. 5, 2023].

[220] R. Beggs, J. Sawaya, C. Ciric, and J. Etzl, "Automated design decision support system," in *[1992] Proceedings 29th ACM/IEEE Design Automation Conference*, pp. 506–511, 1992.

[221] H. Jack, "Universal design topics," in *Engineering Design, Planning, and Management*, ch. 9, pp. 323–380, Boston: Academic Press, 2013.

[222] L. Xu, Z. Li, S. Li, and F. Tang, "A decision support system for product design in concurrent engineering," *Decision support systems*, vol. 42, no. 4, pp. 2029–2042, 2007.

[223] H. Zhao, Y. Zhang, Z. Wang, S.-f. Lee, and W.-c. Kwong, "Research on group decision support system for concurrent product development process," *Journal of Materials Processing Technology*, vol. 139, no. 1-3, pp. 619–623, 2003.

[224] D. C. Rose, C. Parker, J. Fodery, C. Park, W. J. Sutherland, and L. V. Dicks, "Involving stakeholders in agricultural decision support systems: Improving user-centred design," *International Journal of Agricultural Management*, vol. 6, no. 1029-2019-924, pp. 80–89, 2018.

[225] G. Töre-Yargın and Ç. Erbuğ, "Information system for visualizing user research to lead innovation," in *Leading Innovation Through Design: Proceedings of the DMI 2012 International Design Management Research Conference* (E. Bohemia, J. Liedtka, and A. Rieple, eds.), pp. 71–85, Boston, MA: Design Management Institute, 2012.

[226] G. Abraham and M. E. Atwood, "Patterns or claims: Do they help in communicating design advice?," in *Proceedings of the 21st Annual Conference of*

the Australian Computer-Human Interaction Special Interest Group: Design: Open 24/7, pp. 25–32, 2009.

[227] M. Nørgaard and K. Hornbæk, "Exploring the value of usability feedback formats," *Intl. Journal of Human–Computer Interaction*, vol. 25, no. 1, pp. 49–74, 2009.

[228] G. Töre-Yargın and N. Crilly, "Information and interaction requirements for software tools supporting analogical design," *AI EDAM*, vol. 29, no. 2, pp. 203–214, 2015.

[229] G. Töre-Yargın, *Developing a model for effective communication of user research findings to the design process*. PhD thesis, Graduate School of Natural and Applied Sciences, Middle East Technical University, Ankara, 2013.

[230] T. Diggins and P. Tolmie, "Theadequate'design of ethnographic outputs for practice: some explorations of the characteristics of design resources," *Personal and Ubiquitous computing*, vol. 7, pp. 147–158, 2003.

[231] J. Blomberg and M. Burrel, "An ethnographic approach to design," in *The Human-Computer Interaction Handbook* (A. Sears and J. A. Jacko, eds.), pp. 965–988, New York, NY: Taylor & Francis, 2008.

[232] C. Cardoso and P. Badke-Schaub, "Fixation or inspiration: Creative problem solving in design," *The Journal of Creative Behavior*, vol. 45, no. 2, pp. 77–82, 2011.

[233] G. Goldschmidt, "Avoiding design fixation: transformation and abstraction in mapping from source to target," *The Journal of creative behavior*, vol. 45, no. 2, pp. 92–100, 2011.

[234] N. Bonnardel, "Towards understanding and supporting creativity in design: analogies in a constrained cognitive environment," *Knowledge-Based Systems*, vol. 13, no. 7-8, pp. 505–513, 2000.

[235] L. J. Ball, T. C. Ormerod, and N. J. Morley, "Spontaneous analogising in engineering design: a comparative analysis of experts and novices," *Design studies*, vol. 25, no. 5, pp. 495–508, 2004.

[236] M. Avital and D. Te'Eni, "From generative fit to generative capacity: exploring an emerging dimension of information systems design and task performance," *Information Systems Journal*, vol. 19, no. 4, pp. 345–367, 2009.

[237] G. Töre-Yargın, R. M. Firth, and N. Crilly, "User requirements for analogical design support tools: Learning from practitioners of bio-inspired design," *Design Studies*, vol. 58, pp. 1–35, 2018.

[238] M. Resnick, B. Myers, K. Nakakoji, B. Shneiderman, R. Pausch, T. Selker, and M. Eisenberg, "Design principles for tools to support creative thinking," in *NSF Workshop Report on Creativity Support Tools* (B. Shneiderman, G. Fischer, and T. Hewett, eds.), pp. 25–36, Washington, DC: NSF, 2005.

[239] E. A. Edmonds, A. Weakley, L. Candy, M. Fell, R. Knott, and S. Pauletto, "The studio as laboratory: Combining creative practice and digital technology research," *International Journal of Human-Computer Studies*, vol. 63, no. 4-5, pp. 452–481, 2005.

[240] R. Martin, "Design and business: why can't we be friends?," *Journal of Business Strategy*, vol. 28, no. 4, pp. 6–12, 2007.

[241] G. Töre-Yargın and Ç. Erbuğ, "Inspiration, guidance and justification: An interactive information system to assist design decisions with user research data," *METU Journal of the Faculty of Architecture*, vol. 34, no. 2, 2017.

[242] J. Hughes, J. O'Brien, T. Rodden, M. Rouncefield, and S. Viller, "Patterns of home life: informing design for domestic environments," *Personal technologies*, vol. 4, pp. 25–38, 2000.

[243] B. Shneiderman, "Creating creativity: user interfaces for supporting innovation," *ACM Transactions on Computer-Human Interaction (TOCHI)*, vol. 7, no. 1, pp. 114–138, 2000.

[244] M. Stacey and C. Eckert, "Against ambiguity," *Computer Supported Cooperative Work (CSCW)*, vol. 12, pp. 153–183, 2003.

[245] C. Alexander, "A city is not a tree," *Architectural Forum*, vol. 122, no. 1, pp. 58–62, 1965.

[246] A. Chakrabarti and T. P. Bligh, “A scheme for functional reasoning in conceptual design,” *Design Studies*, vol. 22, no. 6, pp. 493–517, 2001.

[247] L. Fiorineschi, F. Rotini, and P. Rissone, “A new conceptual design approach for overcoming the flaws of functional decomposition and morphology,” *Journal of Engineering Design*, vol. 27, no. 7, pp. 438–468, 2016.

[248] P. Sarkar and A. Chakrabarti, “Assessing design creativity,” *Design Studies*, vol. 32, no. 4, pp. 348–383, 2011.

[249] G. S. Altshuller and P. B. Shapiro, “On the psychology of inventive creation (in Russian),” *Vopr. Psikhologii Questions Psicol.*, vol. 6, pp. 37–39, 1956.

[250] R. Jana, “The world according to TRIZ: Blue-chip American companies are embracing a 60-year-old innovation theory pioneered by a Russian inventor.” [Online]. Available: `https://www.bloomberg.com/news/articles/2006-05-30/the-world-according-to-triz`, May. 31, 2006. [Accessed: May. 13, 2023].

[251] L. Fiorineschi, F. S. Frillici, and F. Rotini, “Enhancing functional decomposition and morphology with triz: Literature review,” *Computers in Industry*, vol. 94, pp. 1–15, 2018.

[252] R. B. Frost, “A converging model of the design process: analysis and creativity, the ingredients of synthesis,” *Journal of Engineering Design*, vol. 3, no. 2, pp. 117–126, 1992.

[253] W. E. Eder, “Design modeling-a design science approach (and why does industry not use it?),” *Journal of Engineering Design*, vol. 9, no. 4, pp. 355–371, 1998.

[254] PR Newswire, “Lockheed Martin completes acquisition Of Sikorsky Aircraft: Corporation welcomes Sikorsky, a Lockheed Martin Company.” [Online]. Available: `https://news.lockheedmartin.com/2015-11-06-Lockheed-Martin-Completes-Acquisition-of-Sikorsky-Aircraft`, Nov. 6, 2015. [Accessed: Apr. 20 2023].

[255] Microsoft, *Microsoft Excel*. Redmond, WA: Microsoft Corporation, 1987.

[256] Lockheed Martin, “BLACK HAWK: Best-in-Class Multi-Mission Performer.” [Online]. Available: https://www.lockheedmartin.com/en-us/products/sikorsky-black-hawk-helicopter.html, [Accessed: Apr. 23 2023].

[257] EASA, *Certification Specifications, Acceptable Means of Compliance and Guidance Material for Large Rotorcraft (CS-29)*. Cologne: European Union Aviation Safety Agency, 2023.

[258] M. B. Miles, A. M. Huberman, and J. Saldaña, *Qualitative Data Analysis: A Methods Sourcebook*. Thousand Oaks, CA: SAGE Publications, 2014.

[259] A. J. Kuzel, “Sampling in qualitative inquiry.,” in *Doing Qualitative Research* (B. F. Crabtree and W. L. Miller, eds.), pp. 31–44, Newbury Park, CA: Sage Publications, 1992.

[260] J. M. Morse, *Qualitative nursing research: A contemporary dialogue*. Newbury Park, CA: Sage Publications, 1989.

[261] L. A. Palinkas, S. M. Horwitz, C. A. Green, J. P. Wisdom, N. Duan, and K. Hoagwood, “Purposeful sampling for qualitative data collection and analysis in mixed method implementation research,” *Administration and policy in mental health and mental health services research*, vol. 42, pp. 533–544, 2015.

[262] VERBI, *MAXQDA*. Berlin: VERBI GmbH, 1995.

[263] J. Saldaña, *The coding manual for qualitative researchers*. London: Sage, 2013.

[264] E. Goodman, M. Kuniavsky, and A. Moed, *Observing the user experience: A practitioner’s guide to user research*. Waltham, MA: Elsevier, 2012.

[265] C. von Clausewitz, *On War*. London: Penguin Books, 1982.

[266] B. Armstrong, “Reaching translational lift: The history of the helicopter and lessons for 21st century technology,” *Chronicles Online Journal*, 2008.

[267] Anadolu Agency, “Turkey’s indigenous helicopter makes maiden flight: Mass production expected after 2021.” [Online]. Available: https://www.aa

.com.tr/en/economy/turkeys-indigenous-helicopter-makes-maiden-flight/1247643#, Jul. 09, 2018 [Accessed: May. 1, 2023].

[268] Anadolu Agency, "Turkey's indigenous helicopter achieves important milestone: Turkish companies produced 14 sub-systems for T625 helicopters." [Online]. Available: https://www.aa.com.tr/en/economy/turkeys-indigenous-helicopter-achieves-important-milestone/1252248, Sep. 12, 2018 [Accessed: May. 1, 2023].

[269] E. Yasar, "Turkey successfully tests 2nd prototype of indigenous helicopter engine: Prototype of Turkey's 1st indigenous helicopter engine passes ignition test, says manufacturing company." [Online]. Available: https://www.aa.com.tr/en/turkey/turkey-successfully-tests-2nd-prototype-of-indigenous-helicopter-engine/2107887, Jan. 13, 2021 [Accessed: May. 1, 2023].

[270] ARP4754A, "Guidelines for development of civil aircraft and systems," standard, SAE International, Warrendale, PA, Dec. 2010.

[271] E. W. Ference, "Case study of the development of the Apache attack helicopter (AH-64)," Master's thesis, Naval Postgraduate School, Monterey, CA, 2002.

[272] OpenAI, *ChatGPT*. San Francisco, CA: OpenAI, Inc., 2022.

[273] IBM, *IBM Engineering Requirements Management DOORS*. Armonk, NY: International Business Machines Corporation, 1993.

[274] Siemens Digital Industries Software, *Teamcenter*. Plano, TX: Siemens AG, 2007.

[275] Atlassian, *Jira Software*. Sydney: Atlassian Corporation, 2002.

[276] Microsoft, *Microsoft Project*. Redmond, WA: Microsoft Corporation, 1984.

[277] J. M. Olsen, "Norway ends contract for NH90 helicopters, wants full refund." [Online]. Available: https://www.defensenews.com/industry/2022/06/10/norway-ends-contract-for-nh90-helicopters-wants-full-refund/, Jun. 10, 2022. [Accessed: May. 19, 2023].

[278] G. J. Roedler and C. Jones, “Technical measurement: A collaborative project of psm, incose, and industry,” technical report, INCOSE, Dec. 2005.

APPENDIX A

CONSENT FORM (TURKISH)

ARAŞTIRMAYA GÖNÜLLÜ KATILIM FORMU

Bu çalışma, Orta Doğu Teknik Üniversitesi Endüstriyel Tasarım Bölümünde yüksek lisans öğrenimine devam etmekte olan Abdullah Enes Coşkun tarafından Dr. Öğr. Üyesi Gülşen Töre Yargın danışmanlığında gerçekleşmektedir. Bu form sizi araştırma koşulları hakkında bilgilendirmek için hazırlanmıştır.

Çalışmanın Amacı Nedir?

Araştırmanın amacı, helikopter endüstrisi özelinde gereksinim tanımlama süreçlerinin çeşitli paydaşlar çerçevesinden incelenmesi ve bir tasarım karar destek sisteminin bu süreçlerde kullanımının ne gibi etkileri olabileceğini anlamaktır.

Bize Nasıl Yardımcı Olmanızı İsteyeceğiz?

Araştırmaya katılmayı kabul ederseniz, sizden beklenen, yarı yapılandırılmış mülakat sorularına cevap vermeniz ve bir bilgisayar yazılımını kullanmanızdır. Bu çalışmaya katılım ortalama olarak 45 dakika sürmektedir.

Sizden Topladığımız Bilgileri Nasıl Kullanacağız?

Araştırmaya katılımınız tamamen gönüllülük temelinde olmalıdır. Mülakatta sizden kimlik veya kurum belirleyici hiçbir bilgi istenmemektedir. Cevaplarınız tamamıyla gizli tutulacak, sadece araştırmacılar tarafından değerlendirilecektir. Katılımcılardan elde edilecek bilgiler toplu halde değerlendirilecek ve bilimsel yayımlarda kullanılacaktır. Sağladığınız veriler gönüllü katılım formlarında toplanan kimlik bilgileri ile eşleştirilmeyecektir.

Katılımınızla ilgili bilmeniz gerekenler:

Mülakat, genel olarak kişisel rahatsızlık verecek sorular içermemektedir. Ancak, katılım sırasında sorulardan ya da herhangi başka bir nedenden ötürü kendinizi rahatsız hissederseniz mülakatı yarıda bırakıp çalışmadan ayrılabilirsiniz. Böyle bir durumda mülakatı uygulayan kişiye, çalışmadan çıkmak istediğinizi söylemek yeterli olacaktır.

Araştırmayla ilgili daha fazla bilgi almak isterseniz:

Bu çalışmaya katıldığınız için şimdiden teşekkür ederiz. Çalışma hakkında daha fazla bilgi almak için ODTÜ Endüstriyel Tasarım yüksek lisans öğrencisi Abdullah Enes Coşkun (E-posta: enes.coskun@metu.edu.tr) ile iletişim kurabilirsiniz.

Yukarıdaki bilgileri okudum ve bu çalışmaya tamamen gönüllü olarak katılıyorum.

Ad Soyad	Tarih	İmza
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Yukarıda belirtilen gizlilik koşullarına uyacağım.

Abdullah Enes Coşkun	Tarih	İmza
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APPENDIX B

INTERVIEW QUESTIONS (TURKISH)

A. Giriş ve tanıma

1. Şirketteki unvanınız nedir?
2. Ne kadar zamandır bu şirkettesiniz ve ne kadar zamandır bu işi yapıyorsunuz?
3. Yaptığınız işin kısa bir tanımını yapabilir misiniz?

B. Paydaşları tanıma

1. Gereksinimle alakalı toplantılarınızda hangi paydaşlar yer alır? Toplantılardaki görevleri nelerdir?
2. Toplantılara katılan kişiler hangi kriterlere göre belirlenir? (Konuda tecrübesi olması, eğitimi, pozisyonu vs.)

C. Toplantı süreçleri

6. Gereksinim saptama faaliyetlerinde izlenen belirli bir yöntem var mı? Neden böyle bir yöntem izleniyor?
7. Bize bir toplantı sürecini anlatır mısınız?
   i. Toplantı öncesinde neler oluyor, bir hazırlık yapılıyor mu? (Kendisi ve başkaları ne tür hazırlıklar yapıyor?)
      - Hazırlık sürecinde yaşadığınız sıkıntılar neler? (İletişim pratikleri)
      - Bu zorlukları nasıl yönetiyorsunuz? Başarılı yönettiğiniz durumlara yönelik örnek verebilir misiniz?
   ii. Bir toplantı genel hatlarıyla nasıl ilerliyor, başlangıcından sonuna kadar anlatır mısınız?
      - Bu süreçte yaşadığınız sıkıntılar neler? (İletişim pratikleri)
      - Bu zorlukları nasıl yönetiyorsunuz? Başarılı yönettiğiniz durumlara yönelik örnek verebilir misiniz?
      - Hangi tip gereksinimler daha çok tartışılıyor? Sizce neden?
   iii. Toplantı sonrasında neler oluyor?
      - Bu süreçte yaşadığınız sıkıntılar neler? (İletişim pratikleri)
      - Bu zorlukları nasıl yönetiyorsunuz? Başarılı yönettiğiniz durumlara yönelik örnek verebilir misiniz?
8. Sizce ideal bir gereksinim belirleme süreci nasıl olurdu? Biraz açıklar mısınız? Böyle bir süreci destekleyici unsurlar neler olabilir?

D. Gereksinim saptama

9. Gereksinimleri saptamada yardımcı yöntemler (yazılım vs.) kullandınız mı?
   i. Bunların olumlu yanları neler? Olumsuz yanları neler? Neden?

(Tasarım karar destek sistemi kullandırılır.)

10. Kullanırken yorumlarınızı belirtir misiniz?
11. Bunun gibi bir sistem kullanmanın avantajları/dezavantajları neler olurdu?

APPENDIX C

ORIGINAL QUOTATIONS IN TURKISH

C1.1 "...bunları oluşturduktan sonra zaten senin neyi, ne kadar, nasıl, nereden, hangi özelliklerle tedarik edeceğin şekillenmeye başlar. İşte işin zor tarafı da budur."

C1.2 "Bu çok olmuyor. Burada ne oluyor: Herkes çalsın, en iyi çalanın sesi çok daha fazla çıksın."

C1.3 "Eski bir NASA direktörünün, aynı zamanda kendisi test pilotu, bir lafı var: 'Projelerde 2 türlü problem vardır genelde; bir teknik problemler vardır, bir de idari problemler vardır. Teknik problemler eninde sonunda çözülür. ... Fakat projelerin sonunu getiren daha çok idari problemlerdir.' Bu idari problemleri tabii açabilirsin, insan davranış şekilleri olabilir, projenin modeli olabilir, projenin yapısı olabilir, organizasyonel problemler olabilir, bir sürü şey olabilir."

C1.4 "Kullanıcıya da ben hak veriyorum. Sen kullanıcıya da yukarıdan o görevi çok net vermezsen, oradaki kısıtları düzgün ortaya koymazsan, adama bir oyun sahası bir esneklik bırakmazsan, adam en kötüye göre ister. Biz hep en kötüye göre isteriz. ... Bugün ben Ege'de harekât yapabilirim, yarın ben Suriye'de harekât yapabilirim. Aynı helikopterle!"

C1.5 "Kullanıcı şunu dememeli: 'Ben bunu deniz kenarında da kullanabilirim. Hakkari'nin 12000 feet Sümbül Dağı'nda da kullanabilirim.'"

C1.6 "...bambaşka bir göreve gidiyorsun. Ve oradaki biriktirdiğin o know-how ve geçmişi yepyeni gelen ve onunla ilgili hiç uğraşmamış olan birisine devretmek zorunda kalıyorsun. Bu devir-teslimler de maalesef tam olamıyor. Dolayısıyla orada sinüzoidal bir eğri oluyor. Yani personel geliyor, öğreniyor öğreniyor, ondan sonra tayini çıkıyor, yeni bir personel tekrar öğrenmeye başlıyor."

C1.6 "Hazırlık önemli. Yani yemek gibi bir şey. Yemeği yapmadan önce ne yapıyorsun? İyi malzeme seçiyorsun. Ne yapacağını, hangi yemeği yapacağını biliyorsun. O yemek ne zaman hazır olacak biliyorsun. İftara hazır olacak o yemek. Yemek hazır olmazsa iftarını açamazsın. O zaman, ne zaman başlamam lazım benim buna? Yemeğin kompleks olma durumuna bağlı olarak... Malzemen var mı? Bak bakalım, buzdolabına? Var. Ben bunu daha önce hiç yaptım mı? Yapmadım. O zaman YouTube'dan bir videosunu seyredeyim. Yapanlar varsa yapanlara sorayım. Bir yemek kitabı varsa, yemek kitabını bir okuyayım. Ondan sonra birisinin domatesi doğraması lazım, soğanı doğraması lazım. İyi soğan alayım, çünkü yemek lezzetli olsun. Tavam, tencerem, ateşim ona göre olsun. Ateşi bazen kısayım, bazen açayım. Aynısı. Sonra tamam hazırladım malzememi. Hadi başlayayım. Ateşi çok açarsan yanar, ateşi az açarsan pişmez. Suyu zamanında koyman lazım. Yani malzemen çok iyi olduğu zaman bir yemek çıkmıyor yani. E pişti. E güzel... Zamanından önce mi pişti zamanından sonra mı pişti? Zamanından önce pişerse soğur, sonra pişerse olmaz aç kalırsın."

C1.8 "Paradigmalar vardır. Bu paradigmalar iyi tarafta da olabilir, kötü tarafta da olabilir. Şöyle bir örnek vereyim: Siz hep terörle mücadele harekâtı yapıp da sadece Sikorsky helikopterle uçtuysanız ve ondan memnunsanız, dersiniz ki: 'Ben Sikorsky helikopteri gibi bir helikopter istiyorum.' Bunun iyi tarafı vardır, çünkü bu bir yaşanmışlıktan gelen bir şeydir. Kötü tarafı vardır, kendini kapatmışsındır. Belki ondan daha iyi ve daha farklı özelliklerde, gelecek savaşlara seni hazırlayacak bir şeyin önünü kapatıyor olabilirsin."

C1.9 "Modelinin doğru olması lazım. Modelin ne kadar doğruysa o kadar iyi sonuç alırsın. Modelini yanlış kurduysan aldığın sonuçlar seni yanıltır. Bir söylem vardır: garbage in, garbage out."

M1.1 "Bu ideal bir gereksinim belirleme süreci. Bu, işte INCOSE gibi veya başka ARP dokümanları gibi bazı ürün geliştirme standartları tarafından belirlenmiş ideal bir gereksinim yönetimi süreci. ... Temel bir V&V matrix yönetim süreci dediğimiz bir süreç. Bu ideal bir süreç aslında. Ama bu sürecin nasıl yapılandırılması gerektiği tam ideal olarak bütün dokümanlarda, bu dokümanlar genel olarak bütün sektörlere göre yazıldığı için, bu net olarak havacılıktaki platform, ‘bir helikopter platformu geliştirecekseniz şu adımları takip edeceksiniz’ diye yazılmıyor. Dolayısıyla burada bir tailoring süreci var, her standart için."

M1.2 "Müşterinin ne istediğinin tam olarak üzerinde anlaşılması gerekiyor. Anlaşılması gerekiyor ki proje ileri safhalarında müşteri birden bire ’Bu değildi benim istediğim, şöyle bir şeydi.’ deyip proje kurgusu baştan başlatılmasın. Böyle olabiliyor. Böyle olursa, süreçler biraz gecikebiliyor. Yani gecikmeden kastım, normal platform geliştirme süreçleri 5 sene 10 sene 15 sene görebiliyoruz, literatürdeki helikopterlerde uçaklarda. Bu süreçlerin aslında biraz geç olmasının biraz da sebeplerinden biri bu."

M1.3 "Atıyorum balistik korumalı bir cam istedi, balistik korumalı camın işte helikoptere aşağı yukarı 2 ton ise bu 2 tonun direkt şu anda burada karşılığını görebiliriz. Böyle bir çalışma böyle bir şey yaptığımızda onlar bence avantajlı. Onları görmemiz lazım."

M1.4 "... bir araç, üzerine gereksinimleri yazmışım, bu gereksinimin takibi, üzerine tasarımın takibi, üzerine üretim, üzerine servisin takibini yaptığım tek bir araç olsa ben serviste oluşan bir sıkıntı eğer kavramsal tasarımda bana feedback verecek ise onu aynı sistem üzerinden anlık takip edebilirim."

M2.1 "Bizim ülkemizde ticari anlamda yapılacak olan faaliyetler, şirketimizde, devletimizin tedarik birimi olarak atadığı Savunma Sanayi Başkanlığı bünyesinde ilerlemekte. Projeler, oradan gelir. Tabii ki Savunma Sanayi Başkanlığının müşterileri de şu anki Milli Savunma Bakanlığı çatısı altındaki Türk Hava Kuvvetleri, Kara Kuvvetleri ve Deniz Kuvvetlerinden gelen isterlerdir. Bunlara paralel olarak şu anda İçişleri Bakanlığı altında Türk Jandarmamız ve Türk Polis Havacılık Dairelerinin bünyesinde havacılık icra edilmekte ve onların ihtiyacı olan hava araçlarını üretmekteyiz."

M2.2 "İş geliştirme fonksiyonuyla paralel hareket eden, öncelikle dış müşterinin ihtiyaçlarını ortaya koyan, müşterilerle birebir iletişim kuran ve o müşterilerden toplanan gereksinimleri mühendislik birimleriyle birlikte hareket ederek anlamlandıran ve daha sonra kavramsal tasarım fonksiyonlarını kullanarak ideal süreci ortaya çıkarabiliriz."

M2.3 "Mühendislik, benim fikrime göre, bu benim kendi kişisel görüşüm, imza sürecinden sonra devreye girer. Ondan sonra müşteriden gelen gereksinimi, yani programın kontratı imzalandıktan sonraki süreçte gereksinimleri hayata geçirtir. Ama biz, daha imzalanma aşamasına gelmeden önce, istediğimiz gibi düşünebiliriz, istediğimiz gibi kavramsal tasarımı uzatırız, kısaltırız, genişletiriz, büyütürüz, küçültürüz. O bizim kendi elimizde. Çünkü o bizim kendi hayal dünyamız. Zaten iş geliştirmenin, pazarlamanın konusu bu. Bu nedenle bizi oradan ayıran şey bu. Öyle olmalı."

M2.4 "Yeni gelen yöneticilerimizin bakış açıları çok olumlu, başta çok olumlu yaklaşıyorlar fakat mühendislik birimleri bunu içselleştirmedikleri için bir türlü konuyu, ne derler... Sonuca ulaştıramadık."

M2.5 "Benim fuar görüşmelerimde ve diğer pilot ve tasarımcılarla görüşmelerim sırasında edindiğim tecrübe hep bu oldu. Önce asker mi, sivil mi? Daha sonra genel maksat mı taarruz helikopteri mi? Ve hemen akabinde de o ürünün kaç kişi olması gerektiğini ilk olarak sordular. Daha sonra diğer gereksinim faaliyetlerini ele aldık."

M2.6 "Apache ile ATAK 2'yi karşılaştıracaksak yani ATAK 2'nin ürünüyle Apache'nin versiyonlarının hangisini karşılaştıracağımızı önceden düşünmemiz, müşteriyi de o şekilde yönlendirmemiz gerektiğine inanıyorum."

M3.1 "Aranan bazı helikopterlerin spec'lerine ulaşılamıyor olabilir. Çalıştığımız işlerde gizlilik önem arz ediyor. Bu diğer firmalar için de geçerli. Bu nedenle bilgiye erişim kolay olmayabiliyor."

M3.2 "Program kısıtlı bir çerçevede çalışıyor. Bu kullanıcıyı da kısıtlıyor. Örneğin, maksimum 500 kg kargo koyabiliyoruz. Bir kullanıcı, bir helikoptere en fazla bu kadar kargo koyulabileceğini düşünebilir."

M3.3 "Kullanıcının detay beklentisi değişkenlik gösterebilir. Bu da göz önünde bulundurulmalıdır."

M4.1 "Normal şartlarda bir helikopteri nasıl istediklerine dair bir fikirleri oluyor ve genellikle bu da, sektördeki diğer helikopterlerden esinlenerek olabiliyor. "Bunun yerlisini yapalım." şeklinde. Dolayısıyla gereksinim seti müşterinin aklında, aslında, en başında oluyor. Biz oradan olabilecekleri, olamayacakları, takvim, maliyet gibi etkenleri göz önüne alarak tavsiyelerde bulunabiliyoruz."

M4.2 "'Evet gereksinim böyle belirlenir.' dediğimiz bir şey yok. Biraz daha esinlenerek, benchmark yaparak. . . "

M4.3 "Platformla ilgili bir fikri var, biz tavsiyede bulunuyoruz, diyoruz ki: 'Çok ağır olur. Bu şekilde devam edemezsin.' Diyor ki: 'Ben bunu istiyorum.' Sonra hakikaten prototipini yapıyoruz, ağır oluyor, geriye dönüyoruz. Hâlbuki en baştan bizi dinlese gereksinim noktasında, çok daha hızlı sonuçlandıracağız işi."

M4.4 "SSB teknik şartnamelerden alıp bir 'best-of' hazırlıyor. En iyi helikopter sanki her platformun en zorlayıcı koşullarının alındığı helikoptermiş gibi düşünülerek... Hâlbuki öyle değil, çok daha ağır çok daha kullanışsız bir noktaya gidebilir ürün günün sonunda."

M4.5 "Bir örnek görev profili icrası gibi bir şey olabilir. Yüklüyor mesela işte aldın, 200 kilo aldın, işte 8 tane yolcu aldın, işte yakıtı şöyle aldın; böyle gider, bu irtifada uçar, bu görevi yapar gelirsin, gibi bir şeyi görmek ister. Ama bizim koşullarımızda, bizim ülke koşullarında. Bizim görev sahalarında bir şey mesela işte Şırnak'tan kalktın şuraya gider bunu yapar gelirsin gibi bir şeyi görürse..."

M4.6 "Sen bu operasyonu rahatlıkla yapabilirsin, gibi bir şey desek belki daha ikna olur. Çünkü şey istiyorlar, onlar operasyon insanı. Evet, mühendisler çalışıyor ama ikna edecekleri üst düzey insanlar sadece 1/0 çalışıyor aslında, yani, o bu veriyle ilgilenmiyor. HIGE HOGE işte VNE çok önemli değil onun için. O iş olacak mı, olmayacak mı? Operasyonu yapacak mıyım, yapmayacak mıyım?"

M4.7 "Buna bakan bir üst düzey subay ne diyecek? Diyecek ki: 'Peki.' Yani, 'peki' diyecek. ... Onlar şey diyecek: 'Ya Şırnak'tan kalktım da İzmir'den kalkıyor mu bu?' diyecek. Sen bileceksin İzmir'den kalkıp kalkmadığını."

M4.8 "...kullanıcı, daha ziyade, benim gördüğüm kadarıyla bu güne kadar, hep operasyoneldi. Kullanışlılığa odaklanıyor yani dokunabildiği, görebildiği, bir seferde anlayabildiği şeylerden mutlu oluyor."

M5.1 "Örneğin üst seviye, 'helikopter 5 palli olsun' der bırakır. Onun altında, o rotor sisteminin nasıl olması gerektiğine yönelik yüzlerce gereksinimi biz, tasarım ekipleri olarak kırarız. Ya da helikopterde '4-axis oto-pilot olsun' denir ama onun geri planında bizim buradaki oto-pilot ekibimiz, yazılım ekibimiz, sistem ekibimiz, yüzlerce binlerce gereksinimi kırarlar."

M5.2 "En nihayetinde ben bunu geliştiriyorum, ama belli bir pazara hitap etmesi gerekiyor bunun. Yani bu iç pazar dış pazar, uluslararası ve ulusal alanda bunun satılabilir kabul edilebilir olması gerekiyor. Şimdi bu kapsamda da bu pazar analizini, ondan sonra müşteri analizini, kullanıcı feedback'lerini çok dikkatli değerlendirmek gerekiyor bir projeye başlamadan. Aksi takdirde sonrasında ürün çıktıktan sonra satılabilirlikle ilgili ciddi problemler ortaya çıkartabilir. O yüzden en sağlıklı gereksinim yönetimi, gereksinim setinin belirlenmesi, yapacağınız geliştireceğiniz hava aracının hangi sınıfta hangi pazara hitap ettiğini bir kere kesinlikle hedef olarak koymanız gerekiyor."

R1.1 "Bazen [customer institution]'in, sonuçta hep yabancı helikopterler kullanıldığı için, 'bu helikopterde varsa bu helikopterde de olsun' falan şeklinde bazen inatçılık diyebileceğimiz şeyler oluyor."

R1.2 "Kullanıcı seviyesi gereksinimler ilk başta doğrudan [client institution] ile görüşülerek alınıyor. Oraya bir heyet gidiyor. 'Size ne lazım?' veya "bir helikopterde sizin için olmazsa olmaz"... Aslında bunun için bir ölçüm tekniği de var. MOE diye geçiyor. Bu, kullanıcının, hangi teknik özelliği ne kadar istediği... 1-2-3-4-5 diye bir sıralama var, bu bir ölçüm tekniği."

R1.3 "Önce iş veya görev çok doğru bir şekilde analiz edilmeli. ... "Türkiye'nin gerçekten de böyle bir helikoptere ihtiyacı var mı?" sorusuyla ve bunu, kendimizi kandırmadan başlamak lazım. ...eğer Türkiye'nin sivil bir helikoptere ihtiyacı yoksa, sadece bir helikopter yapmış olmak için helikopter yapılmalı mı acaba?"

R1.4 "Doğru paydaşların belirlenmesi, biz bunu kime satacağız, kimle beraber yapacağız, bunun doğru belirlenmesi çok önemli. Bunlarla iletişim halinde olarak, önce bunların ihtiyaçlarının sonra bu ihtiyaçlardan kırarak da gereksinimleri belirlemek lazım. En azından bu işin kitabında böyle yazıyor."

R1.5 "Mesela şahsen ben de bu tasarımın tam içinde olan bir adamla konuşsam belki şey diyebilir: 'Senin yaptığın işler ne kadar saçma!' diyebilir bana. Helikopter seviyesi sistem mühendisliği, alt sistemci için mantıksız gelebilir mesela."

R1.6 "Yani şimdi, bir taraf mühendis bir taraf kullanıcı olunca, o arada bir bilgi çatışması olabiliyor.

[Researcher: Kullanıcının çok mühendislik ya da teknik bir şeyi...]

[Completing the sentence] Bilmemesinden kaynaklı ya bildiğini sanmasından da belki kaynaklanıyor olabilir."

R1.7 "Aslında genelde pilot önceki kendini, sonra görevi düşüneceği gereksinimler çok önde tutuluyor. Önce kendini düşünüyor, sonra görevi düşünüyor. ... Tekrar sıralayayım: Safety, pilotun kendisiyle alakalı olan safety ve konfor isterleri; ondan sonra, görev isterleri; ondan sonra, görevle ilgili daha, çok da elzem olmayan, isterler. İş kolaylaştırıcı şeyler."

R1.8 "Ne kadar yolcu taşıyacağım ve ne kadar kargo yükü taşıyacağım gereksinimi birbirine çok benziyor. Kaldı ki bunu değiştirdiğim zaman da aşağı yukarı aynı şeyler oluyor."

R1.9 "...linkler kurulabiliyor. Linklerle de "ya bu sistem gereksinimleri nerden gelmiş" sorusunun cevabını o linkten bir önceki gereksinime atlayarak şey yapabiliyorsun. Bu iyi bir izlenebilirlik sağlıyor."

R2.1 "Eğer projenin başlangıç evresindeysek sözleşme teknik isterleri tartışılıyor. Çünkü orada temel atılıyor. Bu temelin üzerine tasarım şekillenecek."

R2.2 "Yardımcı bir tool'un kalifiye olmaması halinde çıktılarının güvenilirliği ve müşteriye karşı savunulması noktasında sıkıntılarla karşılaşılabilir."

R3.1 "İlk başta bir navigasyon sisteminin altındaki IFF cihazının detayındansa, işte helikopter 5 rotorlu mu 4 rotorlu mu olacak vs. bu tarz helikopter seviyesi gereksinimleri ilk başta tartışılıyor."

R4.1 "Bence, ürünü kullanacak kişinin ve ürün sahibinin, "Bu ürünü nerede kullanacak? Nasıl kullanacak?" şeklinde bir doküman hazırlaması bence en sağlıklı yöntem."

R4.2 "Bazen kullanıcı, belki o ürünün ömrünün %5'inde %10'unda kullanacağı bir ekipman takılmasını istiyordur. Ama baktığımızda "genel çerçeveye fazla bir faydası olmayabileceği" çıkıyor. Böyle olunca ağırlık etkisi, maliyet etkisi artıyor. Sen arabanda kullanmayacağın bir aksesuarı taktırıyor musun?

[Researcher: Hayır.]

Ben de. Kullanmayacağın ekipmanlarla maliyeti artırıyorsun aslında."

R4.3 "Herkes kendini işini hep öncelikli görüyor ama genel çerçevede baktığımızda daha öncelikli işler çıkabiliyor. ... Bir sistemin inputu bir başka sistemin outputu olabiliyor. Bu nedenle birisi bitirmeden diğeri başlayamıyor. ... Herkes tabii kendi sistemini "bir tık daha kritik" görüyor. Ona yönelik de çıktısının kendi lehine olacağı kararlar beklentisi içerisine giriyor."

R4.4 "Parametrelerin sürekli güncel tasarım verilerini yansıttığından emin olmak gerekiyor. Mesela bir mekanik parçada hafiflemeye gidilmiştir, bunun güncellenmesi gerekiyor. Aksi halde ağır çıkacaktır."

R5.1 "Bunun sol tarafı, yani row'ları görev senaryoları. ... Temelinde görev senaryoları için yapılmış. Görev senaryoların var sol tarafında, column'larında da dizayn parametrelerin var. Bu tarafı daha çok kuvvet diyoruz ama [client institution], [customer institution] ve pilotlarla beraber belirleniyor görev senaryolarının ne olduğu, BCH transport var mesela. Ya da air ambulance var. Bunları bu taraf belirliyor, [customer institution], kullanacak taraf belirliyor bu işi. Bunların bir importance'ları var. Bir değer veriyorsun bunlara. Daha sonra da dizayn parametrelerini belirleyen, işte mühendisler belirledikten sonra, bunlar arasındaki ilişkileri her cell'e uygulayan, yani her cell'e bunlar arasındaki ilişkiyi veren test pilotları oluyor. Atıyorum senin transport'sa görevin aslında senin loading flexibility'inin geniş olması lazım. Ya da taşınabilir yükünün hakikaten yüksek olması lazım. ... Bunların arasındaki ilişkiyi belirleyen kişi de test pilotu oluyor.

[Researcher: Bu önemleri sayısallaştırıyor musunuz?]

Sayısallaştırıyorsun. Bunun sayısal olarak bir dökümünü elde ediyorsun işte ilişkileri var importance'larıyla ilişkilerin değerlerini çarpıp, her sütun, her dizayn parametresi için bunu topluyorsun."

R5.2 "O ne istediğini çok iyi biliyor, ben de neyi verebileceğimi çok iyi biliyorsam tertemiz bir süreç yönetiliyor. Ama müşteri daima istemeye meyillidir, böyle de bir sıkıntı var. Müşteri hep ister. Ne kadar çok yüksek hızlara çıkabiliyorsa, ne kadar çok ağırlık taşıyabiliyorsa, bunları daima isteyecek. Sen de bunun olabilitesini aslında onlara zamanla gösterebilmen gerekiyor."

R5.3 "İsterleri belirleyen tarafta olmadıkları için daha küt, motamot hareket etmek istiyorlar. Yani ellerinde şu kâğıt varsa, 'Evet, bu kâğıttaki her şey verilmeli.' Esnetmek, tartışmak yok. Biraz diretme durumundalar."

R5.4 "Aslında yapabileceği şeyi, limitlerini, burada görebilecek. Bu bence büyük bir artı kullanıcı için. Ama bu daha çok bizim gibi gereksinim yöneten kişilerde mi olur ya da tasarımcıların mı işine yarar onu tam olarak anlayamadım. Sonuç olarak biz gereksinim sürecini yönetiyoruz. Gereksinim setini biz belirlemiyoruz. Biz set belirlendikten sonra ya da belirlenmeye başladığı süreçten sonuna kadar bunun olabilitesini yöneten kişileriz. Gereksinimi aslında belirleyen kişiler biz değiliz. Doğrudan değiliz. ... Gereksinim yönetilme sürecindeyiz, belirlenme sürecinde biz yokuz aslında. Bence yokuz."

R5.5 "Bu limitler pazarlığa bir tık da açık olabilmeli, yani sen şu hıza ulaşabilirim diyorsun ama belki ulaşamayacaksın. Şey kısmı beni birazcık şaşırtıyor mesela teknik isterlerde bu tarz rakamlar belirlendiğinde bunları bunları kesinlikle vermek zorundayız. Neye göre vermek zorundasın? ... Şu kütlede nasıl yapıyorsun bunu yani? Çünkü senin motorun değişmek zorunda kalabilir arada. Daha zayıf bir motorla çalışman gerekebilir. Bunu nasıl yaptıklarını merak ediyorum."

R5.6 "Pilot diyor ki, 'ben' diyor 'düz insanım, ben operatörüm' yani, 'Ben mühendis gibi oturup komplike düşünemem.'"

R6.1 "Mesela ECS bazında söylüyorum, mesela eğer müşteri dediyse ki 'Benim hava aracımın kokpitinde, ben havalandırma istiyorum.' ya da 'Cooling istiyorum.' dediyse biz ona göre bir gereksinim belirliyoruz. Yani cooling olması lazım, o zaman bizim ECS, environmental control system, o ATA chapter bazında bizim cooling özelliğinin olması gerekiyor. ... Onların isterleri, bize baz oluşturuyor. Temel oluşturuyor. Ondan sonra da biz o temelin üstüne gereksinimleri fonksiyonlardan aşağı doğru kırarak belirliyoruz."

R6.2 "Sebebi bence kar amacı gütmeyen yani biz kar amacı güdüyoruz ama yani birisinin racon kesmesi lazım. ... Mesela ben şimdi eski tecrübelerime dayanarak söylüyorum yani [a manufacturer producing for domestic use]'te... Racon kesilir, illa ki birisi keser. Sen kesemiyorsan kesecek olan adamı bulursun. O raconu kestirirsin. ... Günde 15 bin tane [a product for domestic use] üreten bir firma için süreçlerin çok uzun olmaması lazım. Çok hızlı kararlar alınması lazım. Ama burada öyle değil. Burada şöyle bir durum var: Airworthiness diye bir şey var. Yani uçuş emniyeti diye bir şey var. Şimdi öyle olunca ister istemez, insanlar bazı şeylere temkinli yaklaşmak zorundalar. ... Hız bazen seni yanlışa götürüyor ya yanlışa götürdüğü zaman geri dönebiliyorsun bazen. En fazla [a product for domestic use] şey olur, ne olur yani iki tane [a product for domestic use] fire verirsin. Ya da işte ne bileyim yaptığın bir tasarım yanlış olur, prototipini yaparsın, olmadı yeni bir prototip yaparsın. Yani bu sana büyük ticari zararlar vermez ya da büyük prestij zararları da vermez. Ama burada öyle değil. Burada şimdi bir helikopter yapsan ve o helikopter, Allah korusun, işte bir kazaya karışsa, bir kaza kırım olsa ya da işte ne bileyim olması gerekenden daha farklı bir yanlış yapsan ve sürecin sonunda fark etsen belki milyon dolarlar seviyesinde zararın olacak. Ya da işte ne bileyim prestij kaybın olacak."

R6.3 "Bir de bazen CS uyumluluklarla ilgili, işte yasal prosedürlerle ilgili, matematiksel olmayan isterlerimiz de oluyor. Şimdi mesela VFR, bunu nasıl burada yazacağız? ... Bu isterler dediğim gibi matematiksel veriler değil. O yüzden burada 3-5 tane 10 tane matematiksel veri koyup işte output olarak 20-25-30 tane neyse veriler çıkartabilirsin ama sonuçta nihayetinde tekrar dönüp müşterinin sana gönderdiği isterleri tekrar kontrol etmek zorundasın. Bu belki de iş yükünü de arttırabilir o zaman."

R6.4 "...yine tutarlı olmamış oluyor. Madem yüksekliği bu kadar yapıyorsun, bu sefer ağırlığı da cargo weight'i de o zaman ne taşıyacaksan, amacın neyse oraya kadar çıkartıyor olabilmen lazım. Yani bir arabanın ağırlığı 1200 kilo falan. Şimdi bir jipin ağırlığı da 1600 kilo olur. Sallıyorum şimdi. O zaman burayı da 1600 kilo seçiyor olabilmen lazım."

R6.5 "Müşteriyle biz görüşmelere gidiyoruz sözleşme esnasında. Onların birkaç tane verisi var ve biz bu verileri yazarız. Deriz ki, 'Bizim range'imiz şu kadar olabiliyor. Endurance'ımız 4 saat olabiliyor. Maksimum hızımız bu kadar olabiliyor. Yani sizin vermiş olduğunuz bu isterler bunları karşılayabiliyor. Bunların dışına çıkarmıyoruz.' diyebiliriz. O zaman belki adam dönüp verdiği inputlardan bazılarını değiştirebilir. Süreç orada hızlanabilir."

R6.6 "Her açıdan bakanların bütün outputlarını toplayacaksın, bir kerede 50 tane output çıkacak. O zaman da bu sefer bu outputları yorumlamak zor olacak senin için."

S1.1 "Kullanıcı bir dokümanla geliyor. "Ben bu helikopteri istiyorum." diyor. O dokümanı biz [client institution] olarak inceliyoruz. Ne kadar doğru ne kadar yanlış olduğu önce bizim süzgecimizden geçiyor. Sonra diyoruz ki: 'Bu verdiğin ister yapılabilir ya da değil. [contractor]'ın bu kabiliyeti var ya da yok. Yoksa da kazandırmalıyız.'"

S1.2 "Müşteri olarak hem kullanıcının hem yüklenicinin çıkarlarına hizmet eden bir gereksinim seti oluşturmaya çalışıyoruz. Bunun ideal olması yolu nasıl olur bilmiyorum. Her sürece yüklenicinin katılması, sürecin sağlıklı işletilmesini engelleyebilir."

S1.3 "İlk önce müşteri süzgecinden geçmiş bir gereksinimle tartışılması gerekiyor. Yüklenicinin ham gereksinimi görme ihtiyacı bulunmuyor. Yüklenicinin kullanıcıyla direkt görüşerek bazı durumlarda süreci kötüye götürmesi yaşanabilir. Bunu önlemeye çalışıyoruz."

S1.4 "Aklıma bir de "Military spec survivability vs. nasıl eklenebilir?" sorusu geliyor. Bunları nasıl alırdık acaba? Ağırlık olarak eklenebilir belki."

S1.5 "Gereksinim ne olursa olsun biraz çalışılması gerekir. Sözleşme aşamasında gösterilmesi uygun olmayabilir."