COLLABORATION BETWEEN ENGINEERS AND INDUSTRIAL DESIGNERS IN MEETING PACKAGING CONSTRAINTS: A CASE FROM DEFENSE INDUSTRY

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ABSTRACT

COLLABORATION BETWEEN ENGINEERS AND INDUSTRIAL DESIGNERS IN MEETING PACKAGING CONSTRAINTS: A CASE FROM DEFENSE INDUSTRY

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This study investigates how packaging constraints are met in the defense industry and the role of industrial designers in the project process. In this thesis, *packaging constraints* will be used for the geometric limitations, and its scope includes length, diameter, distance, clearance, location, and space for a design. They are among the essential requirements sets of a system project. Additionally, the term system will refer to a set of things working together as parts of a mechanism or an interconnecting network; a complex whole in this study. Packaging constraints may directly affect the performance, cost, design, and many other outcomes. Nevertheless, they are considered some of the secondary requirements of a project and are usually treated as a natural iterative process by project management. Such attitudes may cause loss of time, energy, money, and other configurational problems for project management and team members. Therefore, interdisciplinary collaboration and communication between industrial designers and engineers should be well established starting from the early phases of the project for a better project management and less iterative processes.

Keywords: Packaging Constraints, Interdisciplinary Collaboration, Project Management, Meeting Constraints, Defense Industry

ÖZ

PAKETLEME KISITLARININ KARŞILANMASINDA MÜHENDİSLER İLE ENDÜSTRİYEL TASARIMCILAR ARASINDAKİ İŞBİRLİĞİ: SAVUNMA SANAYİİNDEN BİR ÖRNEK

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Bu çalışma, savunma sanayisinde paketleme kısıtlarının nasıl karşılandığını ve endüstriyel tasarımcıların proje sürecindeki rolünü araştırmaktadır. Bu tezde, paketleme kısıtları terimi bir tasarım için uzunluk, çap, mesafe, boşluk, konum ve hacim kısıtlarını içerir ve bir sistem projesinin temel gereksinim kümeleri arasındadır. Ek olarak, sistem terimi, bu çalışmada birbiriyle etkileşen veya ilişkili olan, bir bütün oluşturan cisimler bileşkesini ifade etmektedir. Dolayısıyla sistem, birden çok alt-sistem ürününün işbirliği içerisinde oluşan birleşkeye karşılık gelmektedir. Paketleme kısıtları, bir projenin en önemli gereksinim setlerinden biridir ve performansı, maliyeti, tasarımı ve diğer birçok sonucu doğrudan etkilerler. Yine de, proje yönetimleri genellikle paketleme kısıtlarına erken aşamalarda yeterince önem vermiyorlar, bir projenin ikincil gereksinimlerinden bazıları olarak görüyorlar. Bu tür tutumlar, proje yönetimi ve ekip üyeleri için zaman, enerji, para kaybına ve diğer yapılandırma sorunlarına neden olabilir. Bu nedenle, daha iyi bir proje yönetimi ve daha az yinelemeli süreçler için endüstriyel tasarımcılar ve mühendisler arasındaki alanlararası işbirliği ve iletişim, projenin başlangıcından itibaren iyi bir şekilde oluşturulmalıdır.

Anahtar Kelimeler: Paketleme Kısıtları, Alanlararası İşbirliği, Proje Yönetimi, Kısıtların Karşılanması, Savunma Sanayii

I would like to dedicate this thesis to the love of my life, Zeynep and our dog-children, Pera and Melek.

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CHAPTER 1

INTRODUCTION

1.1 Background

Engineering is a discipline involving a significant number of specialized areas, and many of the engineering areas focus on developing a system, piece of equipment, or procedure to meet specifications and standards while considering the resources at hand. Resources are turned into solutions through a mostly iterative and creative decision-making process based on the natural sciences and mathematics.

To produce a solution while meeting the given requirements, engineering design entails the concept of work, creating matured requirements, conducting simulations and analyses, and evaluating alternative solutions while considering the project's requirements. Examples of potential requirements and constraints might be manufacturability, functionality, standards, local regulations and policies, constructability, cost, sustainability, ergonomics, schedule, maintainability, and aesthetics.

Packaging constraints (PC) are the geometric limitations of a design. Some companies use alternative terms such as “envelope” or “hacim yönetimi” in Turkish. Packaging constraints are essential because they can directly affect design processes and outcomes. Better packaging constraints management may decrease the products’ required volumetric space and lead to some advantages in the market compared to its competitors; iPod is a good example. The engineers claimed that it was impossible to make iPod any smaller and that they had to recreate the project in order to accomplish it. Steve Jobs, the co-founder, chairman, and CEO of Apple, remained silent for a while. Then he stood up and threw the prototype into the aquarium. Then air bubbles started to come out of the iPod, and he said: "Those are air bubbles. That means there is space in there. Make it smaller." (Tweedie, 2014). At the end of that meeting, Apple engineers had to restart their work because they had digressed from the proposed design and packaging constraints in the first prototype phase. They redesigned the product with better packaging management and completed it to the launch of the first iPod, which achieved a design triumph (Tweedie, 2014).

Currently, we are living in a world of extremes. With the enhancements in technology, products are gradually becoming more complex. So, they require the involvement of multiple individuals specialized in their disciplines in harmony. The challenge of packaging constraints comes from the performance, cost, weight, and other possible requirements along with geometric constraints. Optimizing packaging constraints requires detailed analyses and calculations made by system engineers and a high level of collaboration with all project team members. Packaging constraints are at the intersection of engineers and industrial designers. Understanding of the industrial designers' role is inadequate among engineers. As it will be explained in more detail in section 4.2.10, the recognition of industrial designers in defense industry companies is recently taking place.

On the other hand, a collaboration between industrial designers and engineers is crucial to establish system constraints properly. Otherwise, ill-defined constraints may cause problems at the more advanced phases of a project, which may lead to loss of time, energy, and money. Therefore, collaboration practices between engineers and industrial designers should be established in the early phases of a project, which may lead to a more reliable project process.

As a mechatronics design engineer at Roketsan Inc., I have always been working under packaging constraints, or as they say at Roketsan, "Hacim Yönetimi" (in Turkish). Our work is highly dependent on the constraints of the project. In the beginning, the concept phase of a project, the whole team gathers and discusses the preliminary details of the project. After the preliminary calculations, analysis, and design, the concept phase closes with the initial design requirements. After that, the systems engineer of the project assigns the packaging, performance, weight, and other requirements to the related sub-systems engineers. Therefore, as someone in the industry, I wanted to understand the ways in which packaging constraints are generated, their impact on the design process, and the role of industrial designers in the project process.

1.2 Aim and Scope of the Study

Packaging constraints are crucial in project management, as they directly affect the design processes, project management, and project outcomes. As a person working in a defense industry company has made me willing to understand the currently adopted practices in the defense industry. Therefore, this study explores how packaging constraints are met in the Turkish defense industry.

The research aims to uncover how packaging constraints are dealt with within the defense industry project process and the collaboration between engineers and industrial designers in meeting these constraints. However, there is a wide variety of products in the defense industry; therefore, this study will focus on systems with human users during operation.

1.3 Research Questions

Research questions are the building blocks of research, essentially. They will guide researchers to the desired answers with smooth gradients if generated wisely. Otherwise, they may cause more problems, direct the researcher in the wrong direction, and not sufficiently answer the research's main questions. Therefore, the following main question and sub-questions have been generated to get satisfactory findings for this study.

This study mainly examines the procedure and details of how project teams meet packaging constraints. Therefore, the main research question of this thesis is as follows:

- (Meeting PC) How do project teams meet packaging constraints in the defense industry?

However, to answer this question, we need to ask several sub-questions whose individual answers will construct a greater result, the answer to the main research question. Their thematic codes are specified within the parenthesis, packaging constraints will be denoted as PC for thematic codes.

On the other hand, sub-questions are more channeled questions. They are critical because they create the structural basis for the conclusion of the main question. They will help us focus on the research by breaking the complexity into manageable sections. Then, researchers will build the knowledge gathered from the sub-questions to address the main research question. Hence, the following seven sub-questions were created for this purpose:

- (PC's Scope) What is the scope of "packaging constraints" in the defense industry?
- (Generation of PC) How are these constraints generated? Through which processes and by whom?
- (Project Phases) What are the project phases, activities, methods, and tools involved in meeting packaging constraints?
- (Role of Team Members) What are the roles of project team members in meeting packaging constraints in various phases of the project process?
- (Role of Team Members) What is the involvement of industrial designers as project team members in meeting packaging constraints in the project process?
- (Challenges) What are the major challenges in the project process towards meeting packaging constraints?
- (Areas of Improvement) What are the potential areas for improvement in the project process towards meeting packaging constraints?

1.4 Significance of the Study

Packaging constraints are one of the design requirements in any project. In the case of defense industry systems, packaging constraints are especially significant due to the systems' volumetric limits, relevant military standards, and customer requirements. They control the dimensional geometric constraints of the system or sub-system. The designer must meet packaging constraints and other documented requirements in the system or sub-systems. In defense industry projects, systems engineers are responsible for the generation of the constraints and requirements. The design challenge usually comes with a combination of needs, not a specific requirement, solemnly. Therefore, well-set constraints by systems engineers are the accelerating factors in project processes.

However, systems engineers are not specialized in any discipline; rather, they are the subject-matter-expert of overall systems. They are knowledgeable of multiple disciplines to some extent, so they can understand complex and interdisciplinary issues more efficiently. Thus, the collaboration between project team members is effectively critical for better-defined requirements and constraints. Understanding how packaging constraints are being generated in projects could play an indispensable role in project management improvements. Therefore, the research and findings of this study may be used by any project team, whether in a defense industry, corporate company or a small project group, to enhance their collaboration and improve the systems' constraint sets.

1.5 Structure of the Thesis

This study is constructed from five chapters. They detail the research from the literature research to the conclusions and further studies. Each chapter is briefly explained below.

Introduction: In this chapter, initial and more fundamental information is presented. The information is formed by the background, aim and scope, research questions, the significance of the study, and lastly -here- the structure of the thesis. Moreover, the motivation of the study is also mentioned in the introduction.

Literature Review: This chapter is significant since preliminary ideas, related previous studies, and concepts in the literature are comprehensively provided under the literature review. Directly searching for packaging constraints was not very efficient; thus, searching for requirements management, ergonomy standards, constraints, and defense industry project management led to better results.

Methodology: This chapter presents the field study and how it was designed. The investigations are carried out in two steps, an exploratory study consisting of unstructured interviews and a case study. The chapter mentions the justifications for the design of the unstructured interviews, how participants were found, and the case study in detail. It continues with the participants of the case study and their backgrounds.

Findings: The qualitative analyses' findings from the field studies are presented to discover the perspectives of project team members in meeting packaging constraints and cooperating with other disciplines in an interdisciplinary project environment. Collected data from the exploratory and case studies and their related findings will be presented separately under two main subtitles.

Conclusion: This chapter presents the conclusions and provides answers to the research questions. Conclusions are constructed based on the literature review and field study findings. Lastly, the study's limitations and potential future research suggestions are discussed.

CHAPTER 2

LITERATURE REVIEW

The literature review of the study will cover project development phases, project team members, cross-functional teams, collaboration among team members, work packages with breakdown structures, requirements, constraints, and requirements management, some of the used standards in the defense industry, and followed by use of virtual reality and human models while designing.

Initially, understanding the general project phases are essential for this study. They are in close contact with the generation and accomplishment of system requirements. Then, the project team's structure in the defense industry is reviewed in the literature to grasp the involved actors with their roles and contributions to the project phases. For the focus of this thesis, only systems engineers and industrial designers are reviewed because they were more significant members considering the packaging constraints. Afterward, cross-functional teams are presented because defense industry projects are complex and require contributions from various disciplines. Moreover, systems engineering is interdisciplinary; therefore, assessing cross-functional teams and their structures may be beneficial for the integrity of the study.

After the cross-functional teams are introduced, their possible collaboration methods and practices are researched. Then, project management work packages and their breakdown structures are introduced to support the generation of requirements and one of the responsibilities of systems engineers. Then, requirements, constraints, and requirements management literature are reviewed as they are one of the crucial aspects of this study. Standards can also be a critical aspect in defense industry projects; therefore, standards are also researched. Finally, virtual reality and virtual human models in design practices are emerging and promising technology for projects. Hence, their literature review is also included in this chapter.

At the of this chapter, a summary underlines the gap in the research topic in the literature while emphasizing the importance of ongoing research.

2.1 Project Development Phases

Projects are usually segmented into time periods in order to improve management, workload, and deliverables. The segmentation is established by the project phases. Although there could be differences depending on the projects and their aims, the general project development life cycle can be readily found in the literature (Paton & Andrew, 2019)

Additionally, Dennehy's work (2009) presents a study and visualization of a traditional project development life cycle in defense industry projects, given in the Figure 1. The demonstrated figure will be supported with the information from MIL-STD-881E in order to generate brief yet comprehensive explanations of the project phases.

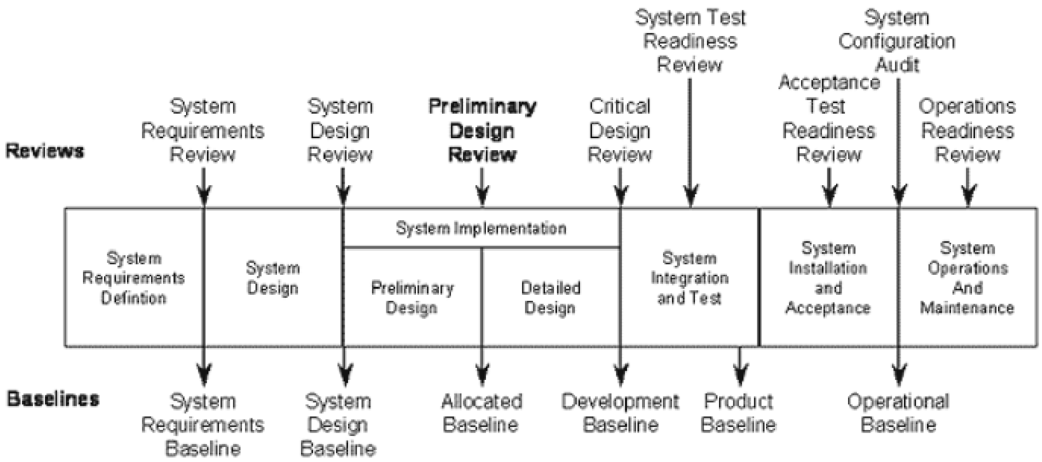

Figure 1 Traditional defense systems development life cycle (Dennehy, 2009)

Concept development phase. This phase is where the literature, market, and potential customers' research are made. Therefore, necessary market and literature research are also conducted in this phase. They may use a decision support system or analysis programs such as dynamics, weight, structural analysis, or Monte Carlo methods to determine the system's optimal parameters (*MIL-STD-881E*, 2020). Then, project team members start to work on the project to create the concept designs. In the Figure 1, the concept design phase corresponds to the combination of system requirements definition and system design.

Preliminary design phase. For the project configuration to determine system concepts, major sub-systems and all other related items can be defined. Additionally, project requirements and constraints can be improved, lower-level functions may be defined, and inputs for the detailed design phase can be generated (*MIL-STD-881E*, 2020).

Development phase. The development phase is the continuum of the preliminary design phase, where designers and all other project members finalize their works. Systems engineers will create a baseline for the system and sub-system requirements. Sub-systems engineers and designers will finalize their designs. During the development phase, requirements and designs may significantly change due to more detailed analysis or sub-system designs. Therefore, there is a loop within DP (Dennehy, 2009; *MIL-STD-881E*, 2020).

Testing and system integration phase. The testing phase can be designed in several steps. The first step is the sub-systems' qualification. Sub-systems must prove they are working properly as required and bug-free before being integrated into the system. After the validation of sub-systems, they can be integrated into the system so that system-level tests can be executed. At this phase, there will most likely be a loop generation due to the iterative testing and design refinement processes.

Closing phase. In order to close a project, system-level qualification tests must be executed, and they must fulfill every project requirement appropriately. After confirming that the system is well-working and approved by the customer, if there are any, then the project could be closed and delivered. In some cases, the project may be transferred to process engineering, where it is produced in mass quantities. Therefore, there will be no more design, but only mass production works taken care of.

2.2 Collaboration

One definition of collaboration states that "the process through which parties who see different aspects of a problem can constructively explore their differences and search for solutions that go beyond their limited vision of what is possible" (Salam et al., 2019, p. 762). According to Dykes et al. (2009), collaboration is common in modern design approaches. These qualities may indicate that the next generation of designers will require new talents to adapt to the ongoing dynamics. Central to Marshall's study (2008), the adoption of computer-based manufacturing and design technologies has promoted the fusion of these disciplines. Therefore, with the superpositioning of Salam et al. (2019), Dykes et al. (2009), and Marshall (2008), we can understand that collaboration practices are evolving, and CAD systems are promoting the fusion of disciplines, resulting in a multi- or interdisciplinary collaboration works.

Team Collaboration. The most efficient form of collaboration is team cooperation, which is also the oldest. It involves teamwork where everyone is aware of each other's skills and contributions to the current project. A team leader often motivates the group to work well together and leads the charge to keep the team in balance. There are due dates, and accomplishments may be fairly rewarded.

Cross-Functional Collaboration. When teams from different departments or industry sectors work together to achieve a common objective for the organization, this is known as cross-functional collaboration. This may occur more frequently than expected, and businesses that do it well frequently perform much better in innovation and implementing ideas that transform entire sectors of the economy. By providing all the tools necessary to make cross-functional cooperation successful, a digital workplace increases its potential.

Cloud Collaboration. Recently, the most effective collaboration paradigm could be invented thanks to modern technology, cloud-based collaborative era. Project teams may upload, access, collaborate on, and deliver their work entirely on a cloud-based digital workplace platform using a digital workspace and cloud collaboration. A live document in the cloud can have all stakeholders added to it. Individual team members can contribute to work without physically being present in the workplace, giving collaboration a whole new meaning.

Virtual Collaboration. Virtual collaboration has gained worldwide traction due to the development of digital workplace technologies. Interdisciplinary teams need to become more adept at virtual meetings. They are now extensively accepted by companies around the world. The essential of effectiveness inside such an environment is to make an investment in a digital workplace platform that can provide your company all the advantages of virtual meetings and the ease of a platform that also lets you access work materials inside of it (Morrison-Smith & Ruiz, 2020). You can achieve all of this and much more with a very small number of tools. The secret is to concentrate on the demands of your firm before going out and acquiring them.

Some companies have started using computer-supported cooperative work (CSCW) programs as a virtual collaboration method. Their goal is to boost cooperation and coordination within and among the teams. Most relevant applications can be named as JIRA, MeisterTask, ClickUp, Nifty, ProjectManager.com and so on. Almost all of them are created in recent years thanks to the improvement of computers, work practices, internet, and networks. Many of the web tools on the market, such as WebEx or Microsoft Office Live Meeting, allow meeting participants to work concurrently on projects (Kennedy, 2019).

These updates on the project management support the creation of *Virtual Collaboration*, and its effects may include unwanted forms of communication and collaboration.

2.2.1 Why is collaboration important to defense industry projects' success?

In order to establish a collaboration, a mindset for collaboration among team members is necessary. Organizations in the defense industry that aim to compete in the current competitive materiel market may now include cross-functional work teams. Materiel means equipment, apparatus, and supplies used by military (*Definition of MATERIEL*, n.d.). These work groups are made up of subject matter specialists from diverse organizational divisions, each with a unique set of abilities and responsibilities (Parker, 1994).

Additionally, decentralization of knowledge, advancement in the internet and many other technological enhancements such as human-robot interactions, highly complex and precise systems, and information process power have made Parker's suggestion in-need of revision. This revision could be completed with only one move; changing cross-functionality with at least interdisciplinarity. Therefore, high-level collaboration is required for interdisciplinarity; and interdisciplinarity is required for defense industry projects' success.

2.2.2 What is successful collaboration?

The importance of collaboration is mentioned in the section 2.2.1; however, how successful collaboration can be achieved? The future of design innovation depends on the capacity to merge different perspectives, which is made possible by interdisciplinarity, which is a fundamental component in expanding the range of design explorations. This point of view is emphasized and supported by several collaborative work studies; however, creative cooperation can result in disputes, primarily because of interpretive discrepancies between people with different disciplinary backgrounds. In order to increase creativity and efficiency, it is a prevalent belief in design and transdisciplinary practice that communications should be clear and that efforts should be made to minimize ambiguity. However, some case studies from interdisciplinary partnerships have shown that the opposite may be true.

> Miscommunications are indeed a key component of creativity and fortuitous exploitation of various interpretations can spawn new creative solutions (Torrisi & Hall, 2013, p. 581).

Depending on the team environment, difficulties that develop during multidisciplinary work can act as a bridge or a barrier. The chance for translation can be increased by being able to recognize and examine the nature of these challenges (Torrisi & Hall, 2013).

In order to increase the opportunity to turn obstacles into bridges more efficiently, Morse et al. (2007) explore the identification and study of concerns that might aid or inhibit an interdisciplinary team effort. According to the context of the team, Morse and his team discovered that every issue is placed on a range and may either act as a bridge or a barrier, as cited in the work of Torrisi & Hall (2013). An example was also given for more clarity, if a person is willing to try something different and push disciplinary limits, the problem of "taking risks" might even become a bridge to interconnection and integration. At the same time, it can also become a barrier if the individual wants to perform a standard disciplinary study (Morse et al., 2007).

Additionally, Torrisi & Hall (2013) has discussed that misinterpretations between interdisciplinary team members can become the secret ingredient of innovative solutions, mentioned as:

> “Provocative stimuli components in an idea generation method may lead to creative misinterpretations. (...) Misinterpretations lead designers along unexpected paths, increasing the chance for novel ideas” (p. 583).

2.3 Cross-functional Teams (Disciplinary, Multi-, Cross-, Inter- ,Trans-)

In today’s world, technology is exponentially enhancing over time and consequently bringing new challenges to be solved. Highly competitive, demanding, and economically challenging world, integrated product design and development is a complicated process that depends on the involvement of many people, groups, companies, and even communities that work together to actualize the product. The multidisciplinary resources needed for the design process are due to the multi-technology character of contemporary goods (Gericke et al., 2013).

Therefore, technology companies started to create their design teams from various disciplines and not solely on engineers like it is used to, and as a result of that, cross-functional project teams are gradually becoming a necessity for project management (Kennedy, 2010).

Erich Jantsch (1972) provided a list of hierarchical terminology to characterize modes of collaboration involving different disciplines at the first international conference for interdisciplinary studies, which was held in 1970 (Klein, 2000; Dykes et al., 2009).

These concepts are often used outside of their context. For instance, cross-disciplinary is frequently used in adjectival form to express movement across disciplines, while interdisciplinary is frequently used in an unspecific manner and has become a popular word for generic collaboration across disciplines (Kotter & Balsiger 1999; Dykes et al., 2009). As a result, there is an uncertainty when using the phrases, and they are frequently misunderstood and ill-defined inside businesses.

Disciplinary Member. The disciplinary design includes working within a particular framework. It employs a single methodology and keeps the principles of that particular design discipline (Dykes et al., 2009).

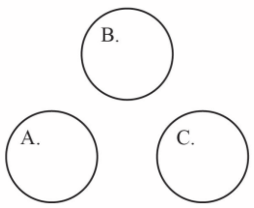

Figure 2 Disciplinary Team Member (Dykes et al., 2009, p. 107)

As stated in the Design Council (2006), companies like Apple, usually, look for professional industrial designers that maintain the clarity of a design, who believe in and hold on to both aesthetics and utility as well as the art of designing goods. Therefore, specializing in one discipline or subject can be very useful in some cases.

Multidisciplinary Member. describes it in the study and established a visual to represent the situation:

> A multidisciplinary designer will be someone with knowledge in more than one discipline or domain, allowing him or her to act as the equivalent of two or more specialists. These disciplines remain within their original context; they may inform each other although they do not intersect (Dykes et al., 2009, p. 108).

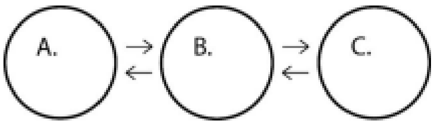

Figure 3 Multidisciplinary Team Member (Dykes et al., 2009, p. 108)

Multidisciplinary project groups will be composed of specialists who communicate with external actors. This includes consulting with experts from fields in order to offer a different perspective on a topic or take into account their work in other fields that are pertinent to a project. For instance, the majority of applied design projects collaborate with manufacturers, scientists, or curators in order to consider their work inside a design project (Leinss, 2007).

In the work of Koretsky et al. (2015) they focused on the term productive disciplinary engagement (PDE) from learning sciences in the case of design tasks (Engle & Conant, 2002; Engle, 2012). PDE was constructed as a framework that would allow scientists to compare case studies of creative and innovative projects (Forman et al., 2014). They concluded that PDE develops when teams encounter productive conflicts, and such conflicts are caused by interlocking parts in both situations. PDEs are more likely to lead to the assimilation of practices and deep learning of concepts. PDEs are more likely to result in a deep understanding of concepts and incorporation of practices.

Crossdisciplinary Member. Crossdisciplinary design refers to a principle that uses competence from another field to address project-related challenges. It distinguishes from multidisciplinary research "through constructive collaboration, going beyond communication between disciplines to active intersection and involvement" (Dykes et al., 2009, p. 109).

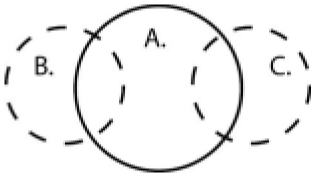

Figure 4 Crossdisciplinary Team Member (Dykes et al., 2009, p. 109)

These people will comprehend how ideas and approaches from different disciplines of study could connect to their work. This will enable them to investigate possible applications and constructively communicate in a problem-focused manner (Dykes et al, 2009; Stein, 2007).

Interdisciplinary Member. Interdisciplinary design practices will clearly contain at least one different discipline, with one being predominant (Leinss, 2007).

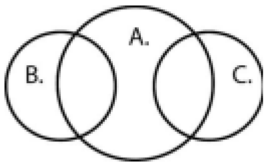

Figure 5 Interdisciplinary Team Member (Dykes et al., 2009, p. 110)

An interdisciplinary designer will have expertise in at least two different disciplines and be capable of combining concepts and approaches from each at a comprehensive level (West, 2007).

Transdisciplinary Member. In transdisciplinary design, at least two disciplines should be incorporated into the practice, but none would be the dominating one (Stein, 2007). This work may be innovative, represent brand new concepts, and understandings, and it will represent a new kind of practice that combines several disciplinary specialties into a single, unified hybrid form (Dykes et al., 2009).

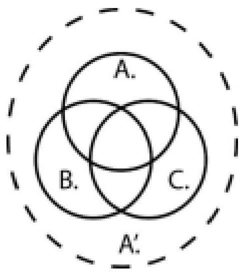

Figure 6 Transdisciplinary Team Member (Dykes et al., 2009, p. 111)

Therefore, this framework combines several disciplinary knowledge together to investigate upon challenges and draw new possibilities.

2.4 Project Team Members

Project team members are becoming more multi-disciplinary, and inter-disciplinary which could be explained by the advancement of technology. With the technological advancements, people specialize in a few subjects and do them in the best manner, or they can have knowledge of almost every discipline so that they can look at a broader project perspective.

Knowledge Areas	Project Management Process Groups				
	Initiating Process Group	Planning Process Group	Executing Process Group	Monitoring & Controlling Process Group	Closing Process Group

Figure 7 Knowledge Areas of Project Team Members (*PMBOK*, 2021 p. 43)

A general overview of the project teams and their roles is given in Figure 7. Although there are different groups for each project management process, that does not necessarily mean that they are different individuals. For instance, a systems engineer is a member of all groups mentioned above. Industrial designers could be a member of all groups except initiating and closing process groups. Mechanical engineers could be a member of the same groups as industrial designers and so on.

In defense industry projects, team members' roles and disciplinary backgrounds are unevenly distributed. What does that mean is, for example, in the executing process group where preliminary and detailed design is taking place, there are some team members with interdisciplinary perspectives and some with more specialized perspectives. So, we cannot say the team is fully interdisciplinary like a mechatronics designer or interface designer; however, what we can say is that all team members are multidisciplinary.

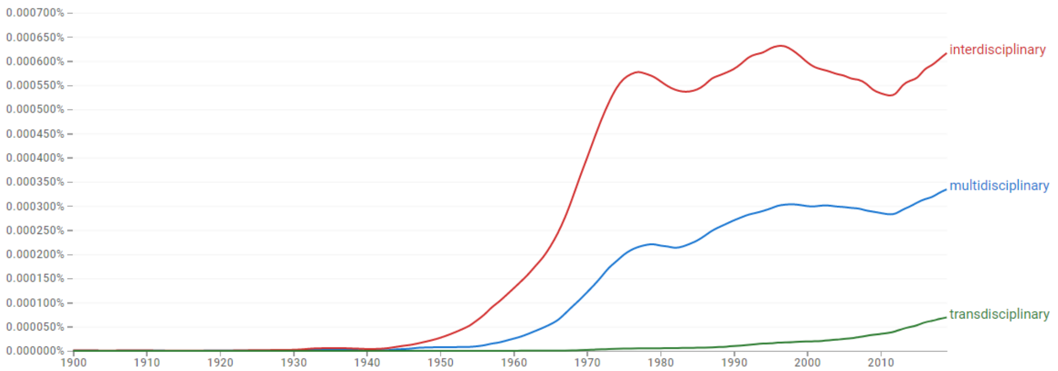

Figure 8 Google Ngram Viewer (*Google Books Ngram Viewer*, n.d.)

Google Ngram, an online search engine, depicts the frequency density distribution of any collection of search terms over time. It uses a periodical count of words from printed sources that are transferred to Google’s text Corpora, which are published between 1500 and 2019 in various languages, such as English, French, German, and many others. Therefore, Ngram is an algorithm that analyzes and displays a frequency density graph for any group of search terms over time.

In the Ngram search engine, three words have been analyzed and plotted on the same graph in Figure 8, which are multidisciplinary, interdisciplinary, and transdisciplinary. Search engine parameters are set as follows: the searching period of 1900-2019, case-insensitive, and smoothing coefficient of 3.

This analysis aims to understand the change in usage frequency density in the literature. The horizontal axis is time, which has a solid correlation with the technology level. Therefore, we may interpret from the plot that the use of multi-, inter- and trans-disciplinary terms in the literature have been on a positive trend since the 1950s. Interdisciplinarity has always existed in modest doses. For instance, physicists or chemists would collect and collaborate on crystal samples with geologists. However, effective multidisciplinary programs were only achieved after the post-World War II era (Sproull, 1987). Nevertheless, this accelerating behavior around the 1940s is very relatable because, after WW2, technological developments and complex military materiel system projects grew (Locatelli, 2013).

Hence, systems engineering has been established in order to manage such highly technological and multidisciplinary projects (Locatelli, 2013). This circumstance is also studied in other papers, and they find similar conclusions to the discussion mentioned above (Ferris, 2007a; Ferris, 2007b; Gorod et al., 2008; Brill (1998), as cited in Hossain, 2020). They examined systems engineering's early history in the pre- and post-World War II eras. Therefore, terms like multi-, inter-, and trans-disciplinary have started to be used more often than before. Furthermore, today, decentralization and remote work trends support the explanation of why projects are growing more multinational across sectors.

Gericke et al. (2013) argued that while multi-, inter-, and trans-disciplinarity can often be used interchangeably in the literature, taking a multi- and interdisciplinary perspective is interpreted here as focusing on the transfer of knowledge and methods between specific disciplines in defense industry projects. Transdisciplinarity, as opposed to multi- and interdisciplinarity, concerns the simultaneous actions between disciplines and beyond disciplines. Ertas et al. (2003) define trans-disciplinary design as the integrated use of tools, techniques, and methods from various disciplines.

However, there are some limitations of the Google Ngram; for instance, terminologies can appear to be losing frequency density as there is more scientific material (Zhang, 2015). Therefore, even staying at the same frequency density level indicates a growing number of use due to the ever-increasing number of total scientific materials; a positive trend indicates the exponential growth in the use of the term, which we are observing in the Figure 8.

2.4.1 Industrial Designers’ Profession

As discussed earlier, design is defined as a process consisting of different activities and requiring different skills. By referring to design processes, Lawson (2005) proposed a design model that outlines the way of thinking, the activities to perform, and the skills to have during different phases. His design model includes ‘formulating’, ‘moving’, ‘representing’, ‘evaluating’, and ‘reflecting’.

Kuru & Öztoprak’s study (2016) contains substantial information related to this thesis. They communicated with twenty defense industry companies regarding the role and contributions of industrial designers to their projects and company. As a result of their work, one conclusion they drove was that industrial designers' activities in the defense industry should be included in the product development processes from the beginning of the project. Otherwise, customer needs and expectations may not be thoroughly understood, and this may cause additional unnecessary work (Kuru & Öztoprak, 2016).

Kuru & Öztoprak mentioned that ergonomics and design practices were usually conducted according to the related military standards. Additionally, it was mentioned that industrial designers could be responsible for designing easy-to-learn interfaces, product development processes, contributions to the project requirements, user experience studies, and ergonomic and production-friendly model designs.

Moreover, considering that industrial designers explore user needs and requirements in the product development processes, it can be deduced that the role of industrial designers in the defense industry is essential (Kuru & Öztoprak, 2016). Furthermore, the study of Kuru & Öztoprak has found that the companies that employ in-house industrial designers have claimed some advantages, including increased customer and user satisfaction, market success, the promotion and institutionalization of the company, awareness of user experience.

2.4.2 Systems Engineers’ Profession

Currently, systems engineering has yet to be considered one of the major engineering disciplines. This should not be considered as something negative because systems engineers do not specialize in one, or two, specific disciplines; but rather, they are and must be knowledgeable about all the disciplines that their system involves (Hossain et al., 2020).

Systems engineers are interested in the big picture. They supervise and control not only the engineering aspects but also the business and management aspects of a project or a system and ensure that every one of the parts works appropriately. Hence, they can comprehensively understand the project as a whole (Hossain et al., 2020).

System engineers use many alternative ways to manage their projects. V-model in Figure 9 is one of the common visual representations of a project development lifecycle. Its objective is to minimize risks, improve and guarantee the specified quality and requirements, and improve communication with the reduction of unnecessary workforce and cost.

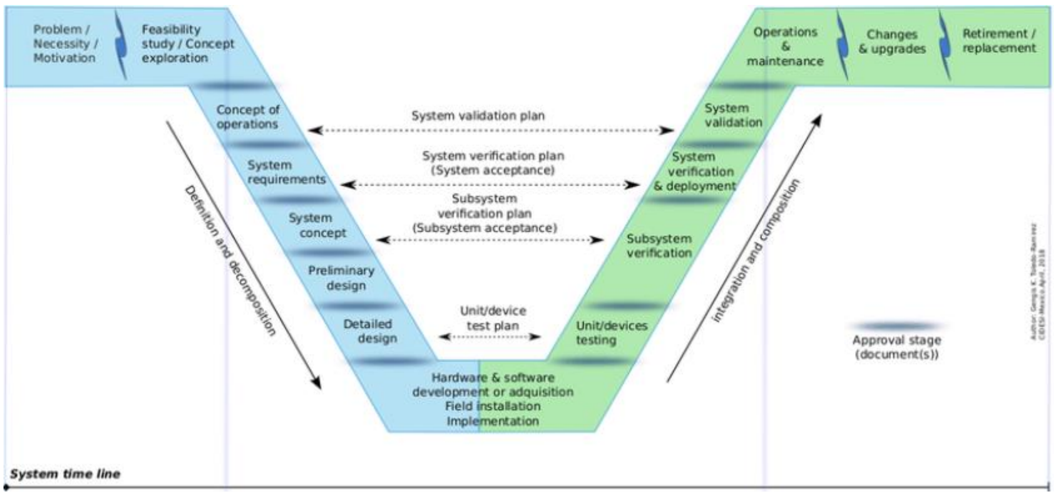

Figure 9 V Model Project Development Life Cycle (Contreras-Moreno, 2018)

Project development phases may follow a pattern, as demonstrated in Figure 9. In defense industry projects, systems engineers’ project development life cycle method starts with the necessity of customer needs (Elm & Goldenson, 2014). After that, the concept, preliminary and detailed design phases are completed. When the designing phase is completed, sub-system and system verification procedures follow. If project team members encounter problems during varication phases, they need to troubleshoot and resolve problems by demoting the system or sub-systems to relevant design phases.

Additionally, if we consider the interests of this thesis, Elm & Goldenson's case study (2014) can be a useful source to address the differences of systems engineers' working in defense industry and non-defense industry domain projects. They examined 148 distinct projects about the systems engineers' deployment and effectiveness.

Their work is demonstrated above, in the Figure 10, informing the interdisciplinary fields of systems engineering roles and their comparison among defense and non-defense industry projects.

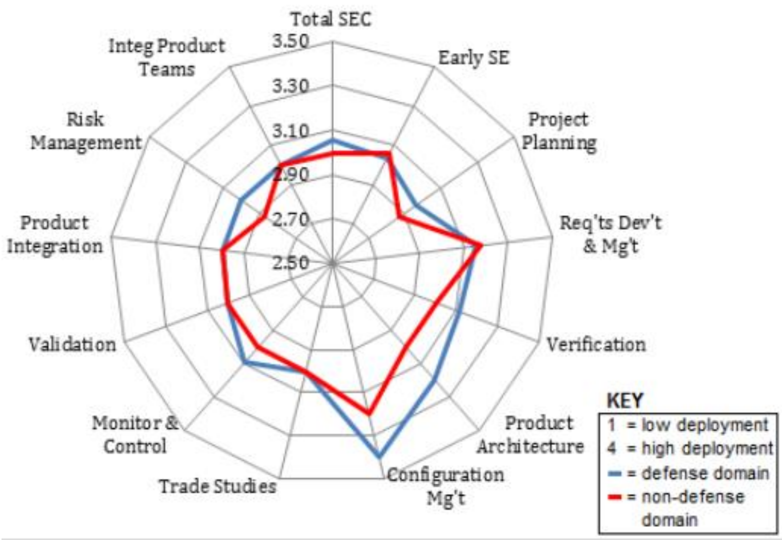

Figure 10 Systems Engineering Deployment (Elm & Goldenson, 2014)

This study also points out that systems engineering is an interdisciplinary field of study. They have many project responsibilities, and some of their roles are mentioned in the spider-web diagram, Figure 10. From this demonstration, it can be concluded that defense or non-defense domain systems engineers have a similar pattern of roles.

Systems engineers in both domains have the greatest deployment in configuration management. On the other hand, they can be differentiated by considering the second-most involvement of systems engineers. Defense domain systems engineers' second-most deployment is project architecture, while non-defense domain systems engineers' second-most deployment is requirements development and management.

2.5 Work Packages

A work package is a subsection of a project that may be allocated to a particular project group for implementation in project management. It is widely acknowledged and accepted that dividing work into manageable units is a typical procedure for effectiveness and diagnostics (*PMBOK*, 2021).

In the following parts of this section, there are other work package definitions in literature; for instance, construction work package, assembly work package, installation work package, product-oriented, phase-oriented, etc. which are essential in their scope, but for the sake of the focus of this thesis, we will not introduce them all.

Work packages are created with the decomposition of the project by work breakdown structure (WBS). There are various essential elements that compose a project WBS. In project management and systems engineering, a WBS is a deliverable-focused division of a project into more manageable parts (*PMBOK*, 2021). MIL-STD-881E Work Breakdown Structures for Defense Materiel Items is the military standard that offers uniformity in definition and consistency of approach for developing all levels of the WBS for defense industry projects. MIL-STD-881E defines WBS as follows:

> The WBS provides a framework for specifying the program objectives by first defining the program in terms of hierarchically related, product-oriented elements and the work processes required for their completion. Each element of the WBS provides logical summary points for assessing technical

> accomplishments and for measuring the cost and schedule performance accomplished in attaining the specified technical performance (*MIL-STD-881E*, 2020, p. 9).

Therefore, several main elements are created to compose the logical summary of the WBS hierarchy. They can be important when referring to the project management and generation of WBS structures. Hence, some of the aspects of WBS are briefly explained below.

WBS Dictionary. It is a document that describes all the different WBS elements. It is a crucial feature of a WBS since it makes it easier for project participants and stakeholders to comprehend the language used in a WBS (*PMBOK*, 2021).

WBS Levels. The WBS levels define a WBS element's hierarchy. Most work breakdown structures include these three levels of WBS: control accounts, project deliverables, and work packages (*MIL-STD-881E*, 2020*; PMBOK*, 2021).

Control Accounts. Work packages are grouped into control accounts, which are then used to assess their status. They are intended to regulate project scope elements. In the WBS, control accounts are positioned at specific management points; each control account assesses performance, scope, cost, and schedule compared to the planned management control point goals. For example, the detailed design phase could be considered as a control account because it is related to several deliverables and work packages (*MIL-STD-881E,* 2020; *PMBOK*, 2021).

Project Deliverables. The intended output of project activities and work packages are known as project deliverables. Deliverables are a combination of the outputs that constitute the project's product, service, or supplementary outcomes, such as prototypes and documentation. Some examples of project deliverables of WBS may include the performance criteria, budget goals, or ergonomics goals (*MIL-STD-881E*, 2020; *PMBOK*, 2021).

Work Packages. A work package is the "lowest level of the WBS," according to the project management institute's (PMI) definition in its project management body of knowledge book (*PMBOK*, 2021). The lowest level deliverable or project work component for each branch of the WBS. This could be due to the fact that a work package is a collection of related tasks that are compact enough to be delegated to a team member or department. Then project managers may estimate the time and cost of these work packages, making them a critical WBS component (*MIL-STD-881E*, 2020).

Tasks. Tasks define work packages for responsible parties and the scope of your project. You may specify tasks' responsibility, length, description, status, dependencies, and requirements using a WBS (*MIL-STD-881E,* 2020; *PMBOK*, 2021).

In Figure 11 shown below, the WBS of an aircraft project has been demonstrated as an example. Aircraft and air vehicles include four main sub-systems: airframe, propulsion, avionics, and armament/weapon. The avionics sub-system, then, include detect, aim, fire, and track properties.

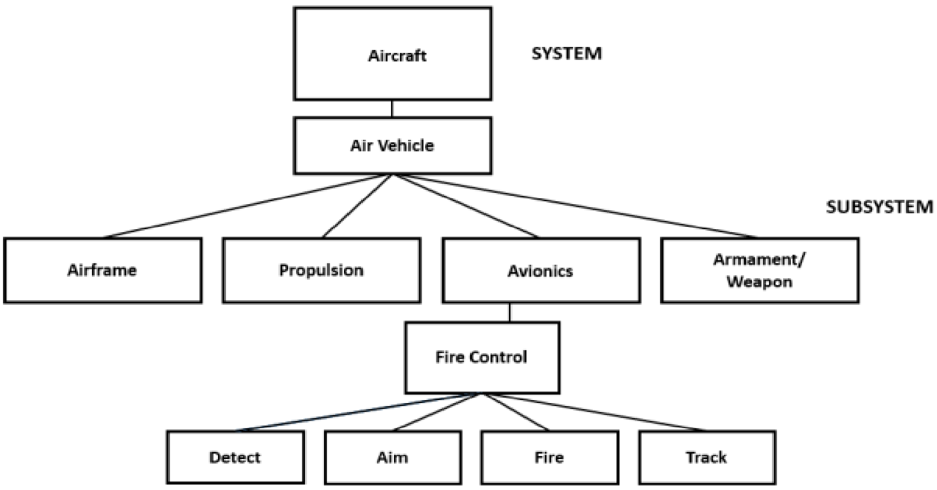

Figure 11 Sample WBS of an Aircraft System (*MIL-STD-881E,* p. 10)

In this example, sub-systems are the deliverables, and properties are the work packages of the WBS of the project. Moreover, in some cases, a sub-system may act as a system on its own and have its deliverables and work packages. The complexity of the requirements or modularity of the design may lead to such WBS. Usually, modularity leads sub-systems to act like systems on their own because modular sub-systems are used as plug-and-use units to the main system (*PMBOK*, 2021).

2.6 Requirements Management

Clear, concise, error-free requirements are going to help project teams detect errors early, reducing project cost and risk. IBM technology company defines requirements management as follows: “The purpose of requirements management is to ensure product development goals are successfully met.” (*IBM*, 2022). Therefore, it is a collection of prioritizing, analyzing, documenting, and approving requirements to ensure that engineering teams always have authorized and up-to-date requirements. By managing creation and changes to requirements and promoting stakeholder communication from the beginning of a project through the entire lifecycle, requirements management offers a method for avoiding errors.

Figure 12 shows the general flow of constraints and requirements from the initial requests from the mission authority down to the sub-systems' responsible and their allocated and derived requirements. Two main actors generate constraints and requirements: customers and implementing organization. The term “implementing organization” is used for the project group, company, or other project structure.

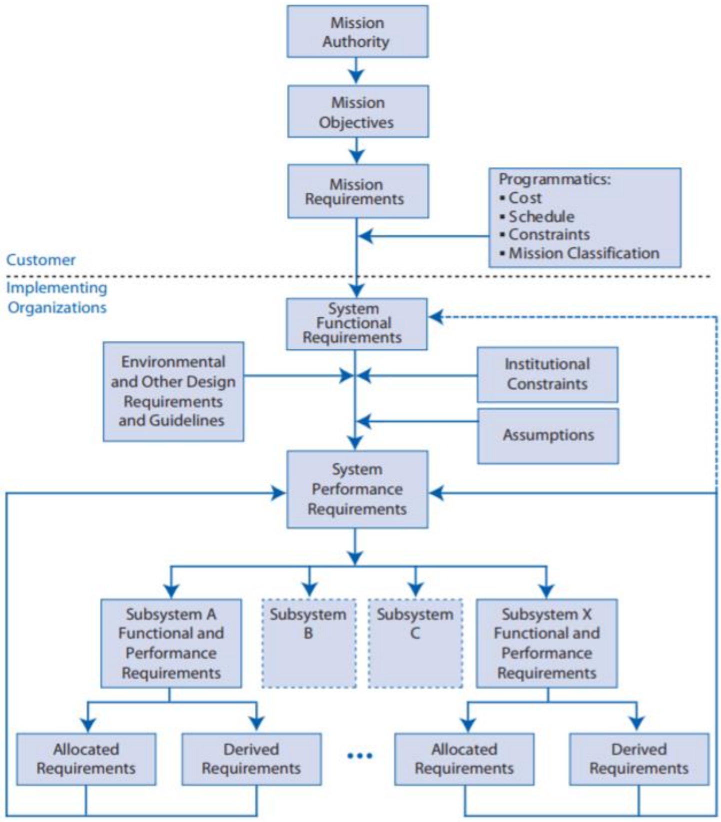

Figure 12 Flow of constraints and requirements (*Arxterra*, n.d.)

In the case of defense industry, as shown in the Figure 12, customers come up with a request about a system and its capabilities. The details of the project objectives are the base of the project requirements and constraints. Then with the collaboration of implementing organization and customer, preliminary system requirements and constraints are generated. One of the constraints this study will focus on is the packaging constraints. They are preliminarily generated, including geometric limits of the system; at this phase, they are not considered in detail.

As shown, the system performance requirement block has output and input arrows. This indicates a closed-loop feedback mechanism feeds the system knowledge for the upcoming iterations because, as mentioned, requirements and constraints are iteratively issued to modify and adapt to the updated system's conditions over time with the changing maturity level of the project (*Arxterra*, n.d.).

2.6.1 Project Requirements and Differences from Constraints

Requirements or constraints must be accomplished in order for project to be completed or finished. They present an illustration of the required task. They are created to correspond the project's resources to the objectives of the company. The benefits of generating more accurate project requirements include cost reduction, increased likelihood of success, shorter time schedule, and improved communication between all actors (Sadiq et al., 2005).

When contemplating a product's design and project team members may have many alternatives to consider. They might have to choose physical specifications like the product's size or the quantity and placement of its sensors. The project goals are for the selection of one or more sets of these properties that optimally fulfill the requirements of the product.

While constraints usually define the non-functional facets of a component or a system, such as limitations on available technology, resources, or geometry; requirements capture the functions or features of a system or a component, such as performance requirements. Although constraints influence non-functional requirements, they usually cause some possible solutions to be eliminated for the system if there are any conflicting aspects between them (Glinz, 2007).

In this study, we will be focusing on packaging constraints, and related requirements with their effect on the project processes and team members (Palton & Andrew, 2019).

2.6.2 Constraints

The term *constraint* refers to a condition that the project should meet. Cambridge Dictionary explains it as “something that controls what you do by keeping you within particular limits” (*Cambridge Dictionary*, 2022). They define the limitations or restrictions. Predominantly, constraints are directed by external drivers like surrounding mechanics and locational and geometrical limits. In most cases, constraints are the consequence of the general project specifications. Thus, it is crucial to report the constraints and requirements alongside the project targets so that project team members can have up-to-date knowledge of them (*PMBOK*, 2021).

Constraints are the numerous aspects of a design project that should be considered to be feasible and adequately completed. Most of the time, any work that does not satisfy pre-defined constraints and requirements is considered a failure (Sadiq et al., 2005).

Constraints and requirements are created by projects' systems engineers to ensure that the project criteria are met at both the system level and sub-system level (Crowder et al., 2016b).

Additionally, conflicting constraints and requirements are the conditions that the project management and team members should be cautious about. They are mentioned in Demarco's study (2020), which argues by giving an example. The study mentions that when a business begins to develop, for example, an armchair, a number of design criteria are accepted, and they are frequently in conflict with one another. Maximum load resistance, structural stability, safety, maximum comfort, and minimal raw material usage are some of the examples to conflicting requirements. If the project's goal is to reduce production costs, then comfort and structural stability could be reconsidered. On this topic, Wang & Shan (2004) and Selvi et al. (2018) have introduced their work on multi-objective design optimization. Their work aimed to find an optimal requirement set in case of dependent parameters, just like the minimum cost and maximum safety. The design constraints must be considered in addition to these requirements; they must be viewed as the problem's initial boundary conditions.

2.6.3 Packaging Constraints (Geometric Constraints)

Multiple disciplines are using the same term, packaging constraints with different meaning or different ways but similar meaning. For instance, software engineers use packaging constraints to define parameter types for the declared variables (Vahid et al., 1998). Packaging constraints can be found in internal combustion engines' design processes (Meek & Roberts, 1998), and in the micro electromechanical systems (O'Neal et al., 1999). They can be found in the form of constraints of packaging of products as well. Interestingly, packaging constraints are used in molecular biology and genetics disciplines, indicating the amount of information that can be packed in a segment of genetic material (Burkhardt et al., 2014).

Therefore, packaging constraints can be generously applied to a diverse range of disciplines, thanks to its generic identity. However, in this thesis, we will be using the definition in Fischer's study (2008), which mentions that packaging constraints control the length, diameter, weight, distance, clearance, layout, and space needed for the physical products of the system.

In this study, we will use packaging constraints as the dimensional limitations of designable space. Thus, they are the set of requirements that define the spatial limits to which the project team can use and has no permission to intervene outside of the boundaries.

2.6.4 Design Space Exploration (DSE)

When contemplating a product's design, engineers have a wide range of alternatives. Technical specifications such as the quantity and placement of the product's sensors or the size of overall dimensions may need to be determined. Additionally, they could have to decide amongst more intangible factors such as the design of an algorithm, computational power, supportive systems and so on. All of them are included in the category of design parameters requirements, and the project team members' goal is to determine one or more sets of these characteristics that optimally fulfill the requirements of the product (*Design Space Exploration*, 2022).

DSE, basically, is the process of assessing the effectiveness generated by various design requirements in order to choose the "optimum" requirements set. The process could be manually controlled by the systems engineer of the project (Kang et al., 2010). In the process of generating initial requirements set, findings from earlier simulations, projects or company know-how could be used.

2.7 Standards

Standards are mentioned in dictionaries as a pattern or model that is generally accepted and advised to follow. Standards are used in every aspect of our lives (*Standards in Daily Life*, n.d.). Even a plastic bag we use in the vegetable aisle at a supermarket has to meet some standards and have a RoHS certificate; a washing machine must meet Regulation EU 2019/2014 for its energy consumption (Canale et al., 2019). So, with this reminder, one can wonder what types of standards exist in defense industry projects. Overall, there are two main types of standards that can be used in defense industries: commercial standards and military standards (*Specifications and Standards*, n.d.).

Standards are especially crucial in defense industry because they establish standardization in multiple aspects, such as performance and requirements of projects. European Defense Agency underlines some of the most significant advantages of standardization. Mainly, they aid in achieving military interoperability by minimizing related risks in operational, material, and information exchange domains. Collaboration between nations or contractors can benefit from standardization, and it can provide clear technical statements that are available for references. Standardization promotes and assures product and service life quality regarding safety and the environment. Standardization improves industrial efficiency by controlling variation and aids in achieving and demonstrating a constant and consistent level of equipment safety and regulatory compliance (Wilkinson & Kopold, 2007).

2.7.1 Commercial Standards

Commercial standards are collections of technical requirements or other exact criteria that are meant to be applied consistently as a rule, guideline, or definition. They contribute to improving life and enhancing the efficacy and reliability of numerous goods and services (*Ergonomics Standards*, 2022).

General Ergonomics Standards. These include methods, practices, and design considerations that ensure consumer and worker performance, protection, and wellbeing in a variety of contexts (*Ergonomics Standards*, 2022).

Vehicle Ergonomics Standards. Vehicle ergonomics regulate the temperature conditions in the driver's compartment, the auditory, tactile, and visual interactions between the vehicle and the driver, and also give testing methodologies for assessing the effects of these aspects on the driver's performance and comfort (*Ergonomics Standards*, 2022).

Machine Ergonomics Standards. Standards for machine ergonomics are essential to prevent severe harm from temperature exposure, crushing, piercing, and cutting. These international standards include the arrangement of actuators, the dimensions of service access slots, whole-body access to the system, and user engagement with displays and controls (*Ergonomics Standards*, 2022).

Standards for Human System Interaction Ergonomics. Design concepts and a framework for implementing them in the study, design, and assessment of human-computer interaction systems are provided by the Human System Interaction Ergonomics Standards. This collection of guidelines for human system interaction ergonomics addresses issues related to the design of tools and services for people with a wide range of sensory, physical, and cognitive abilities, including those who are permanently or temporarily disabled, and older people. Moreover, ergonomic considerations for the design of input devices, such as control panels, can direct how interactive system hardware and software components can enhance usability (*Ergonomics Standards*, 2022).

Standards for Accessibility Ergonomics. They define the standards for accessible design ergonomics and provide test procedures and design considerations for audible, tactile, and visible cues for consumer goods' design (*Ergonomics Standards*, 2022).

2.7.2 Military Standards

Military standards, on the other hand, establish and communicates standards for how things should be developed, constructed, and tested in a controlled, recognized, and accepted way, so that all contractors know exactly what is expected from the products. Unlike commercial standards, military standards are a must-have requirement for defense systems. Materiel customers look for the list of standards during market research. Military standards can be perceived as the guarantee that the system will work with specified performances under specified conditions (DSP Policies & Procedures, 2000).

MIL-STD-1472 Design Criteria Standard: Human Engineering. In the standard, extensive human engineering design standards for the creation of military equipments and systems have been established. Its objective is to provide human engineering design standards, guidelines, and methodologies that may be used when developing new structures, machineries, systems, sub-systems, and equipment (*MIL-STD-1472F*, 2020).

MIL-STD-810 Environmental Engineering. This standard contains instructions on how to plan material acquisition programs to take environmental stressors into account at every stage of the material's service life. The fact that this document does not enforce design or test standards should be noted. Instead, it outlines the environmental tailoring procedure that leads to realistic material designs and testing procedures based on the demands of the material system (*MIL-STD-810G*, 2019).

2.8 VR-Aided Design and Digital Human Models in Design Processes

Virtual Reality (VR) can potentially improve the act of design by generating a greater understanding of unbuilt landscapes (Law et al., 2020). Carreiro (2013, p. 34) described this situation as follows: "To sum up, new tools emerge for 1:1 scale vision of a wholeness design as if one has access to the architect's mind". VR-aided designs and analyses have been in the literature for more than twenty years but have started to be implemented in defense industries recently (Zimmermann, 2008; Jayaram, 1997; Garrison, 2021).

VR-aided design practices are not something new. Around the 1990s (Donath & Regenbrecht, 1996), the idea of modifying an environment in virtual reality was first started to be investigated. Whereas they are relatively new in the defense industry and they can be useful to assist designers in modeling more accurate and quality work at an accelerated pace. Such advantages may lead to the shortening project schedule, requiring fewer revisions throughout the project phase, more trusting design and planning decisions, and cost-efficient solutions to be made.

As Chaffin (2005) explains, digital human models are tools that enable designers to generate efficient ergonomics designing and analyzing activities. They can be used by designers in the early phases of a project in order to enhance packaging constraints of systems for ergonomics. However, these models usually represent the solid body. Acquired ergonomics results can be quite divergent if designers only use these solid body models. Therefore, dynamic human models are generated in a simulation environment, with more than 37000 motions being recorded from 100 men and women (Chaffin, 2002). Additionally, Reed et al. (2014) have generated dynamic human models and diverged them based on different waist circumferences and body mass index.

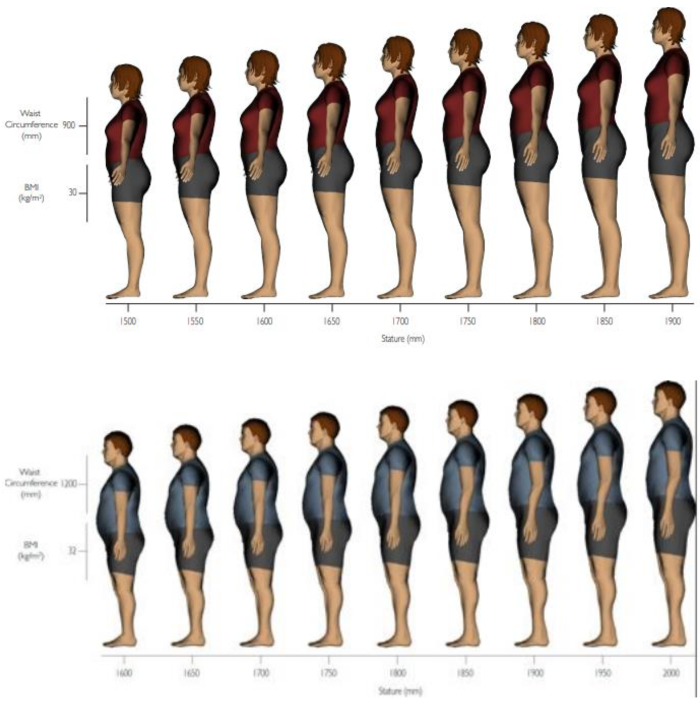

Figure 13 Scaled Human Models (Reed et al., 2014)

This parametric shape modeling can be useful to cover different body types for more accurate ergonomics analyses results (Reed et al., 2014).

Therefore, human models are widely in use of ergonomics analyses, and their advancements are leading to more accurate analyses and simulation results; hence, enabling industrial designers to proactively design more appropriate systems (Chaffin, 2002).

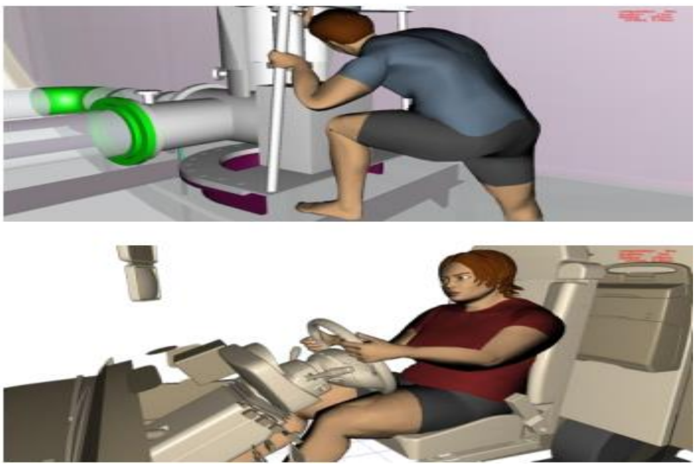

Figure 14 Body Shape Model Implementation (Reed et al., 2014)

Reed et al. have uploaded the models to the human simulation ergonomic analysis tool, Jack software. Then they run the simulation to resolve two objectives. The first one is to generate best fitting candidate profile. Then, to determine the results of each generated human model for comparisons of simulations.

Moreover, environmental ergonomics can be integrated into this simulation to achieve more realistic and accurate results. Environmental ergonomics can involve the effects of cold, heat, noise, light, and vibration stresses to which human models could be exposed (Parsons, 2000).

2.9 Summary

This chapter has reviewed the associated literature. Throughout the literature review, packaging constraints were the focus, and all other presented sub-titles were to comprehend the scope of packaging constraints better.

Packaging constraints and associated aspects in meeting them have been the subject of extensive research in this chapter. However, not much study exists on how industrial designers and engineers, who work in defense industry companies, meet packaging requirements.

This chapter is structured with nine (excluding summary) sub-titles. They all, as mentioned, aimed to contribute to the overall understanding of packaging constraints and how they are established and accomplished by project team members. In order to establish such a literature review structure, it is essential to present project development phases, collaboration, and its variations, cross-functional teams, project team members, particularly systems engineers and industrial designers, work packages, requirements management, and its sub-section of packaging constraints, standards used in the defense industry, VR-aided design, and use of the virtual human model in meeting packaging constraints.

Furthermore, after data analyses and findings, the literature review has included some of those sub-titles additional to feed its literature review findings in conclusion along with the field studies.

The next chapter, on the other hand, will outline the methodologies employed in every part of this study.

CHAPTER 3

METHODOLOGY

Packaging constraints are the dimensional constraints that industrial designers and engineers have to work together on it to fit necessary sub-systems into the system. Packaging constraints are generally iteratively improved, but this takes time and workforce. If a sufficient packaging constraints set is established in the early phases of a project, this can reduce the project cost, time, and workforce significantly. That is why, this study focuses on how packaging constraints are met in the defense industry and the industrial designers' role in this process. As an objective of the study, it is aimed to explain how packaging constraints are met in the defense industry so that the project members can use it to implement into their applications and create a supportive base for future research.

To respond research questions sufficiently, a qualitative study is conducted by adopting various data collection methods. As a first step, generating a rough idea for the question was completed with the literature review. Then, exploratory, unstructured interviews were conducted to fill the remaining gaps in the initial picture. When the rough ideation was completed, more information and real-life examples were required to combine the gathered knowledge to answer research questions. At this stage, a case study was conducted to generate the answers we have been seeking from the beginning. More detailed information about the mentioned process is explained under the related topics.

3.1 Research Design

Research approach of this study focus on how packaging constraints are created and met in defense industry projects and the team members' and industrial designers' roles in this process. It is important to examine the process from the actors' experiences perspective. As a result, the research will be a qualitative investigation using an interpretive methodology. A qualitative study is needed, because how engineers and industrial designers working in the defense industry, collaborate and improve packaging constraints can only be understood by listening to their experiences in the field. Moreover, according to interpretive philosophy, “interpretive researchers assume that access to reality (…) is only through social constructions such as language, consciousness, shared meanings, and instruments” (Myers, 2019; Littlejohn & Foss, 2009). Interpretive research, therefore, aims to identify and understand the meaning created by events and experiences. Therefore, interpretive research is found to be a suitable methodology for this research.

3.2 Research and Sampling Strategy

The research strategy of the study consisted of two stages. In the first part of the field study, exploratory unstructured interviews are conducted with the involvement of seven engineers working in the defense industry for more than four years and an industrial designer retired from defense industry company in 2004. These people are easily reached since they are within my friends and colleagues circle whom I work in the same office or projects. This stage of the study is mainly aimed whether strengthening the literature review or validating the ideas found while searching the literature in the field.

The exploratory interviews aimed to create a rough idea about how packaging constraints were generated, how project teams are meeting them, and who are the members of project teams. Moreover, these interviews also aimed to determine how other defense industry engineers' personal views and experiences aligned with my experiences and observations. Therefore, unstructured interviews were adopted to acquire as much information as possible thanks to its advantages of focusing on personal experiences, being informal, and being flexible. Additionally, unstructured interviews allow interviewers to change the direction of the probe with respect to interviewees' responses. In total, seven interviews were conducted within Roketsan Inc., Turkey's missile and defense industry. The participants ranged from systems engineers, sub-system work package leaders, and work package engineers from different sub-systems and disciplines. The participants were deliberately selected from various projects in order to have diversity due to the exploratory nature of this study. In addition, all participants were questioned about their observations of other level work packages they are responsible for and how issues could be improved and resolved regarding their experiences. After the constitution of a basic understanding towards what is real experiences and applications in the field and matching them with the relevant theory found in the literature, I tried to give meaning to the problems they face and prepared the second stage of the field study questions.

Additionally, one participant in the exploratory study worked as an industrial designer at Company M for more than eighteen years and retired in 2004. The participant will be mentioned as Participant 3 hereafter. Although Participant 3 retired some time ago, the findings from his/her experience resulted in some additional information and noteworthy conclusions about the transition of their roles in the defense industry Company M.

In the second stage of the field study, semi-structured in-depth interviews are conducted in light of what is problematized in the first stage. Therefore, the second part was carried out to provide the final ingredients to the issues we have been looking for since the beginning of this study.

During this part, two people were interviewed. I reached Participant 1 thanks to the guidance of my thesis supervisor, and the first participant directed me to the second participant. Interviewees wanted their names and companies to be masked in the study due to the confidentiality of defense companies. Therefore, they will be mentioned hereafter as: Participant 1, Participant 2 with Company R.

Participant 1 and Participant 2 are from Company R. Participant 1 is a professional in-house industrial designer; Participant 2 is a systems engineer at Company R. Both of the participants have more than ten years of professional experience; Participant 1 and Participant 2 are currently working as group managers in Company R.

Focus of the interviews was the case study. The case study was the project that completed in 2021 and Participant 1 was the industrial design department responsible, and Participant 3 was the systems engineer of the project. That case was intentionally selected as it was the most recent completed project that the participants involved in. Therefore, their experiences regarding the processes of the project would be easier and more accurate to recall in detail (Cherry, 2019).

Interviewing with group managers was quite valuable because they are more responsible with project management aspects of the project rather than working on an assessed duty. Hence, their perspective is more useful in the scope of this study. Moreover, since they have a considerable amount of experience, they can contribute to the study by answering questions not only regarding the specified case but also some additions with their previous experiences and know-how. Additionally, the field study with Participants 1 and 2 were conducted on a case study, which was determined before the interviews. The case was a completed project conducted in Company R.

It was intended to select at least two participants, one systems engineer and the other one industrial designer. Participants' project responsibility difference was crucial in eliminating departmental project management variations that may be influencing team members' experiences (Purvis, 2004). So various team members that worked for the same project were aimed to be interviewed. As argued by Shore (2008), there are unavoidable biases within project processes that may be caused by multiple reasons, such as organizational culture, project budget, and schedule, and systematic biases. Moreover, two participants, one from systems engineering and one from industrial design, are the two opposite ends of a project management process. As a result, interviewing with the two opposite ends could provide a helicopter view, a general description or opinion of a situation of the overall project management process and its effect on team members' experiences.

The selection criteria of the case were based on two main conditions; the first condition was that Participants 1 and 2 had worked together on the project, and the second condition was that the project must have been recently completed for the ease of remembering details and experiences.

The reason for the first criterion of being worked on the same project was that their experiences could be related to the same project; therefore, they worked towards a common goal. Both participants experienced the same project management procedures; hence, their experiences would be isolated from other possible variables.

The second criterion of the recently completed project was necessary to have an understanding of overall project phases and management processes. Both participants were involved in the project from new product introduction (NPI) to the qualification and closure phases. This enabled the study to gain a helicopter view of every procedure within the defense industry Company R and the project in this case.

3.2.1 Time Dimension

In the study, cross-sectional data were collected in the year 2022. Cross-sectional data is a form of information that is collected by studying subjects at a particular period in time, such as people and businesses. Time-dependent variations were not taken into account in the analysis. The cross-sectional data analysis compares the similarities and differences among selected participants. Since we are living in a fast-paced world where technological developments are faster than before, the data collected in the field can only be interpreted within the constraints of current technological developments because engineers and industrial designers highly depend on technological tools and features to work on their project. For instance, 10 years ago, to store a 1 GB information we needed to carry a very big external hard drive, but today we reached a point that we use cloud systems where there is no physical storage system required for users. Or virtual communication and collaboration methods are introduced especially after the recent global pandemic

(Bojadjier & Vaneva, 2021). Therefore, with the development of technology, perspectives are subject to change. Therefore, the results of the study should be evaluated within the understanding of current technology.

3.2.2 Ethical Considerations

Conducting a field study with human subjects requires a permission from METU Human Subjects Ethics Committee beforehand. Thus, we applied for the METU HSEC approval before conducting the field study (Appendix A). The consent form is given to the participants which includes the brief content of the study, and their signature is taken. During interviews, audio records were taken with the permission and consent of the participants, in order to analyze the interviews later. The main reason for the necessity of audio recording was its semi-structured nature. Each participant was asked different questions, depending on their answers. Although they were asked different questions, the theme, and main objectives behind the questions were similar in order to merge and utilize in the analysis phase. The main concern of the participants was confidentiality; so, interviewees and company details will be masked.

3.2.3 Data Analysis

Before starting to analyze the data collected from the field, the voice recordings are transcribed verbatim. Transcription was performed by the simultaneous use of MS Word and Audacity. Audacity software (see appendix D) is a free and open-source digital audio editing and recording software that can be used in multiple operating systems. By assigning shortcuts to Audacity pausing, starting, and rewinding was possible with ease while writing transcription. Although transcribing interviews verbatim were extremely time-consuming, researchers have some advantages in doing so. For instance, reworking and repeatedly listening the same sentence enabled the researcher to catch minor but crucial details that could have been missed otherwise.

After the completion of transcription, analytical codes were created to organize and catch the commonality in the participants' phrases, making the data more meaningful for what I am specifically looking for. Coding is done by using computer-assisted qualitative data analysis software. As an analysis program, MAXQDA was selected due to its user-friendly and easy-to-learn interface. Additionally, MAXQDA helps pick over what is specifically essential for the study and accelerates the data analysis process. Moreover, coding via MAXQDA helped me create visual outputs and make connections among the codes so that it became easier to understand the relations between them. In qualitative analysis, thematic coding can enable researchers to code text or picture sequences connected by a similar subject or concept that are recorded and identified. Qualitative data is easier to comprehend when it has been coded. By using this method, researchers may organize the material and, hence, create a "framework of thematic ideas about it" (Gibbs, 2007). It is vital to examine the material theoretically or analytically rather than solely descriptively. During this phase, repetitive reading was carried out to ensure that almost all of the critical ideas in the text were extracted and internalized.

3.2.4 Thematic Coding

During the thematic coding, a total of eight thematic codes and two sub-codes were generated in MAXQDA. Each research question has an assigned code to work on the intended focus. So, during the coding, I could easily submit the related codes to participants' answers. Codes were submitted to sections that either supported or disagreed with the submitted codes' referring research question.

This will enable to code specific quotations in transcriptions and find their relations. For each research question, their corresponding thematic codes were indicated in the parenthesis.

- (Meeting PC) How do project teams meet packaging constraints in the defense industry?
- (PC's Scope) What is the scope of "packaging constraints" in the defense industry?
- (Generation of PC) How are these constraints generated? Through which processes and by whom?
- (Project Phases) What are the project phases, activities, methods, and tools involved in meeting packaging constraints?
- (Role of Team Members) What are the roles of project team members in meeting packaging constraints in various phases of the project process?
- (Role of Team Members) What is the involvement of industrial designers as project team members in meeting packaging constraints in the project process?
- (Challenges) What are the major challenges in the project process towards meeting packaging constraints?
- (Areas of Improvement) What are the potential areas for improvement in the project process toward meeting packaging constraints?

Two research questions are intentionally assigned to the same thematic code, *Role of Team Members*. This is because they can be answered via similar themed answers of the study. In addition to these codes, one more code was added, namely *Bonus*. This code collects sections that are not directly related to the research questions. Nevertheless, they could be helpful during the analysis phase and give clues and ideas about future research areas.

3.3 Summary

In this chapter, the study's research design, research and sampling strategy, time dimension, ethical considerations, data analysis, thematic coding and methodological limitations are introduced. Interpretive research design is adopted for this study due to the focuses on participants' experiences. Then the research strategy was constructed upon two stages; exploratory study consisting of unstructured in-depth interviews and a case study with semi-structured in-depth interviews. A total of ten interviews were conducted, where participants were distributed to three different defense industry companies. During the study, cross sectional data was collected, which underlines the time dimention aspects. Before conducting the field study, we applied to the METU HSEC for the ethical considerations of the field study. After conducting the field study, voice recordings were transcribed verbatim. This phase was labour intensive but allowed me to go over the same records multiple times and understanding them thorougly. Then they are transferred to MAXQDA to complete the thematic codings of the verbatim transcriptions.

CHAPTER 4

FINDINGS

This chapter offers the analysis of information acquired from seven exploratory study interviews and three case study interviews. In addition to the findings from exploratory and case studies, my experiences as a defense industry engineer will also be infused throughout the section.

4.1 Exploratory Study Findings

This section presents the exploratory study findings under four main sub-titles and a summary. During the data collection period, as mentioned in the methodology, exploratory study interviews were conducted in order to create a basic, rough idea and knowledge about the understanding of packaging constraints, their creation procedures, how they are used, their distribution to team members, and their meeting practices in a defense industry company, namely Roketsan Inc.

Roketsan Inc. is established to design, develop, and manufacture rockets and missiles for the use of national security. The company currently involves more than 4000 employees; however, there is no in-house industrial designer. The necessary works are completed with the cooperation of industrial design consultancy firms. Therefore, as mentioned, all participants will be engineers in this section, except Participant 3, who works in Company M.

4.1.1 Understanding of Project Phases and Establisment of Packaging Constraints

The exploratory study has revealed some note-worthy findings. As mentioned, eight employees were interviewed and almost every participant mentioned that they work under packaging constraints. The paticipants' roles were distributed as three participants from systems engineering and four participants from sub-system engineers. Expectedly, during the interviews, the participants mostly gave similar answers on the focus of questions. The main reason for this could be the project management procedures are very similar within the company; therefore, everybody is exposed to the same procedures and development cycles.

The participants uniformly mentioned that constraints and requirements come from the systems engineering department. The systems engineering department usually defines the system functions and capabilities; then, they design sub-systems' requirements to achieve the system requirements. Therefore, the participant mentions the existence of an outside-in strategy in design processes where the project management initially sets the system requirements. Afterward, WBS is structured with the work packages and deliverables of the project. One of the participants gave an example to clarify; however, due to confidentiality concerns, its paraphrase will be given: In a project, the customer wanted the system to meet a specific military standard, and that standard directly defines the packaging constraints of the overall system. Thus, systems engineers may initially define the project's exterior design and then define the possible sub-systems and their optimal packaging constraints in the system's interior.

Those packaging constraints are generated solemnly by the systems engineers. Even if customers deliver their expectations and requirements, systems engineers take those requirements and run feasibility and multi-objective optimization analyses to adapt delivered requirements for the project objectives. From the conclusions of those analyses, they create a concept configuration of the system.

With the concept configuration is being set, they divide the system into more manageable sub-systems, basically, they create the work breakdown structure of the project. At this phase, project team members receive their work package details and their related requirements and constraints set and start to work on the concept design. After the concept design has been completed, systems engineers arrange a concept design review (CDR) meeting with all sub-system responsibles. In this meeting, each sub-system prepares a presentation about the details of their work, the design's feasible operating range, to what extent they can meet the initial requirements set, and their feedback to the system.

Afterward, systems engineers collect this information and feedback and try to re-configure the project in a way that delivered feedback and requests by project team members are comprehended. At this stage, systems engineers mostly use Monte Carlo simulation. It is a statistical sampling approach that employs a random selection of parameter values so as to capture the original problem's unpredictable physical processes with a comparison of each simulated sample.

After completing analyses, a new and improved configuration version of the system is usually created and then shared with project team members. This configuration contains more matured requirements and constraints set, which is the necessary input for the upcoming preliminary design phase. In the preliminary design phase, engineers try to work with as much detail as possible to understand if there are any ill-defined requirements or improvement aspects of the work package.

4.1.2 Practices of Meeting Packaging Constraints

During the interviews, the participants are asked how they approach packaging constraints to solve them.

The participants' answers and findings were reasonably alike and uniform, with only differences in minor personal preferences. This effect was somewhat expected as almost all participants had been in the same company for the last five years, and they naturally adopted the company culture of project management. Therefore, their answers were expectedly similar. So, in order to acquire as much knowledge as possible, another approach is adopted. Rather than only meeting with one department, different departments in the company were interviewed. Its purpose was to understand the various experiences of departments even within the same project management. They mentioned that they have reliable and trustworthy systems that have proven to be working. Since they have quite a lot of know-how about those systems, they usually approach packaging constraints similar to any other project. They try to work with their mentioned best-known system with reasonable modifications; however, they try to keep the idea and principles similar to other systems. Sub-system engineer participants mentioned that sometimes they study on novel designs and mechanisms to acquire knowledge about their potential and enhance their know-how, as one of them said, "(…) because we are a research and development center. We need to develop novel systems that could be useful in the future works". The reason for this question was that most of the designed systems rely on parallel principles of mechanism that are proven to be working.

Occasionally, sub-systems design engineers work on novel systems, mechanisms to improve know-how and study new working areas. During those novel systems' designs, their developmental procedure is similar to product development (P&D). The primary purpose of P&D, product development, is to create a product, as its name suggests. It is often said that P&D covers "development" activities in a product, in other words, incremental improvements (Ozturk, 2017). They do necessary calculations and run analyses for P&Ds before they are sent to the manufacturers. It is because once you manufacture it, you cannot change it. One has you re-manufacture the revisioned part to repeat the tests. In order to control their calculations and verify the system requirements, engineers need to manufacture and then execute tests to demonstrate that the system is, indeed, meeting the requirements.

4.1.3 Evolving Role of Industrial Designers in Defense Industry

Participant 3, has a unique role for this section to point out the evolution of industrial designers' role in defense industry, focusing on meeting packaging constraints. The participant has over eighteen years of experience in the defense industry, Company M; and is one of the first industrial designers in the company. Hence, Participant 3 witnessed the evolution of industrial designers' roles in defense industry. Therefore, the participant' encountered challenges within the team will be mentioned.

Industrial design discipline was, unfortunately, not recognized in defense industry around the 1990s. Hence, a quotation from Participant 3 will be an indicatiton of how defense industry, Company M, was employing its in-house industrial designers.

> At that [earlier] time, the designers were considered directly as a graphic designer. When I entered there, the first thing they gave me was a very thick how-to-label document (1, Participant 3).

If readers would like to know what participants exactly said during interviews, the first number in the parentheses refers to the related quotation in the Appendix H. Quotations are in Turkish as it was the interview language.

Taking this knowledge as a reference point, the participant continued the interview how they managed to evolve engineers' view towards industrial design and the struggle of the conversion process.

> At the beginning, there was an uncertainty about what an industrial designer does for design [system]. From that point, we came to a stage of how we [industrial designers] should be involved in the project and from which phase. We had a friend, who joined later than me, and I remember that we were joining meetings, sometimes even forcefully, to be able to involve in projects from the beginning. They were looking at the situation like this; if the industrial designer is going to make the outer cover, they can be involved when the project reaches that maturity. They were planning to contemplate the sub-systems or components initially and then pass it to us so that we would make an outer coverage to it. The electronic engineers will make their circuit boards, mechanical engineers will determine the thickness of the outer coverage and we will design it according to their requirements and maybe add some buttons or key slots on the coverage (2, Participant 3).

Participant 3 revealed that initially, they were not invited to the meetings of the projects at early phases because project managers were not considering they needed to be involved at such a low level of project maturity. Project managers were planning that the engineers would contemplate their work and then pass it on to industrial designers for the designing of packaging and coverage of related components. Hence, the participant and her friend were vigorously and insistently joining the early phase meetings to make them understand that the industrial design department has a lot more potential than they think and; therefore, should be included to the project from the beginning.

> (…) we forcefully joined project meetings and got on the project managers to convince them that industrial designers should enter projects from the beginning. We have managed to evolve the industrial designers' role from the initial mentioned point to a stage where we are the decision-maker of the placement of electronics and mechanical components in the system, ultimately changing the style of packaging constraints. At the beginning of this evolution, many people resisted; their attitudes were like as if we were taking their jobs away from them (3, Participant 3).

Participant 3 pointed out the hardships they have encountered in the course of finding their profession and roles in defense industry projects. Moreover, the participant remarked on the fact that, those hardships were not specific to industrial design but to every profession or discipline that recently entered the industry. She, then, gave another example regarding the involvement of material engineers to defense industry. Unfortunately, the specified period of participation in materials engineering could not be asked.

> Many years later, material engineers started to get involved; and again, their main professional field could not be found for some time back then. Their profession was questioned and overlooked. It was a long time before they finally found their own professional branch (4, Participant 3).

Participant 3 revealed that material engineers also encountered similar hardships when they were introduced to the industry and questioned before being accepted in the field. Hence, we can deduce that such hardships could be a common issue for every emerging discipline in the industry. And after surpassing the hardships and obstacles, project processes become more manageable and accessible.

> After the fact that we should be involved in the project at earlier stages is being agreed upon, everything became much more accessible. We could receive requirements firsthand, and communication with the user has become more accessible. They [project management] took us to the meetings with the customers and military personnel, too. This was much better for us (5, Participant 3).

Participant 3's effort has flourished into something valuable because the participant managed to create recognition for industrial designers in the defense industry. Although deducing overall defense industry information may not seem the most sensible generalization while relying solemnly on Company M; it is one of the first defense industry company that started to employ in-house industrial designers.

> For this reason, many people after us could now sit in front of the computer and reveal and show the expected model without the engineers' overview. This made it easier for industrial designers to get involved earlier in the project. Because it does not waste the time of a mechanical engineer with it. They [industrial designers] can put in front of them in a 3D model, much more tangible for them; when I say *them*, I am talking about the managers. **Therefore, they found the designer much more functional.** It was a period when Company M was also divided into multiple different locations based on its projects. During that division, it was said that there should be a designer in every team and a designer should be in every project group, so things got easier [for industrial designers]. They hired a lot of people as [industrial] designers. Therefore, I cannot say how the project processes have changed, but the [industrial] designers' place have definitely changed (6, Participant 3).

The participant also added that the evolution of recognition of industrial designer is not only taking place within the company but a broader area as well. During a military team's visit to Company M, managers introduced industrial designers as *artists* while a member of the military team corrected the manager as *industrial designers*.

> They realized that the designer was much more capable and could be much more helpful to them. In my first year at Company M, we were two people, and they gave us a separate room. Company managers were showing the company site to a military team outside and as they passed in front of our

> room's window, one of the managers said, "This is where our artists work". Interestingly, one of the soldiers who was walking around said, "Do you mean industrial designers?" and our eyes were filled with tears. I had to fight this a lot; We had many arguments saying, "You are not getting what you pay for, I can do much more than that". So, I can easily say that there is change (7, Participant 3).

As a result, with the persistent acts of Participant 3 and her team, the company finally realized the potential of industrial design. Therefore, project managers and systems engineers started to incorporate it from the early phases of projects. Additionally, Company M has decided to employ in-house industrial designers for every project group. They comprehended the fact that industrial design is not only about good-looking products, but it is as significant as any other discipline. If we recall the participant's first role in Company M, we may conclude that there is a considerable evolution regarding the industrial designers' recognition and their roles in defense industry projects.

Last but definitely not the least, Participant 3 has shown that packaging constraints can also be highly dependent on the existing technology. This view is quite important and worth the attention as it shows the transformation and adoption of industrial designers in a defense industry company.

4.1.4 Challenges in the Project Team

Participant 3 has mentioned some challenges encountered within the project team during the transformation of the industrial designers' role in Company M and in meeting packaging constraints. The participant was in constant cooperation with the mechanical and electronics engineering departments, where the participant got directions for her work and designs according to the requirements. Nevertheless, the directed requirements were causing oversafe designs and bulky, heavy products.

> We worked with engineers directly, and we really struggled. They were like h*ere it is or this is how it is.* First, you treat the electronic cards like a black box and place them, and then you design their outer cover. In terms of ergonomics, the attitude of both the military and our managers was something

> like; he is a soldier, he will do it no matter how you design. Therefore, the ergonomics of soldiers were utterly discarded, and quite massive and bulky products were produced as a result of that (8, Participant 3).

The participant mentioned that this problem might have been initiated by the military and managers' outlook on soldiers around the 1990s and 2000s. This issue also affects the participant's design and work because the participant continues to describe her experience where the directed packaging constraints for the electronic circuit were probably unnecessarily extended. This issue causing some problems in the packaging constraints of the neighboring components or sub-systems. As a result, the participant wanted to receive the full model of the circuit board but the participant encountered with departmental outlook.

> In the beginning, it was just the dimensions. Our only communication was at *take it and make it* level. You would have to know both electronics and the mechanics aspects of the work in order to understand whether the given dimensions were over-safe or not. As a designer, we need to learn it in order to be heard. In fact, we may need to learn about the alternatives [in the market] and convince them by saying, "Look, this is how they [competitor companies] did. This means it can be done in another way." They [engineers] were giving the dimensions of the black box according to the highest points on it. However, maybe it is in only one spot, and the rest is smaller. Maybe I will be able to place one more thing next to it. For this reason, you were saying, "Give me the whole image of the card". So, it is no longer only a black box (9, Participant 3).

The participant tried to get the detailed model so that the participant could make a better placement for the components in her design. She, as quoted, had struggled to get detailed designs of the components because other departments were not considering the participant would need it and their, over-safe, directions and requirements were sufficient enough.

Another challenge was encountered by Participant 3, regarding the fast pace of market dynamics. The example given by the participants refers to the early 1990s as lithium-ion batteries first introduced to the commercial market (Kanno, 2022).

> I will give an example about the times of transition to lithium-ion batteries [around the 1990s]. At that time, the battery had to be located according to the devices' needs. Then, the outer cover had to be worked by regarding

> lithium-ion batteries as a gel. Before that, they were overly massive batteries. We tucked them in and tried to cover them with closure. We were saying, "Look, it is starting to happen with phones; maybe we can use these batteries [Lithium-ion] too." Because engineers were also looking for a battery manufacturer to make lithium-ion; however, there is none. Alternatively, when we were new to LCD screens, they were not available in various sizes. There were only one or two manufacturers worldwide at that time. In other words, whichever company produces it, you have to use it, as well as the others. So, you have to learn the constraints and limitations of such components. You must know what is in the market, and which one I should use; you have to learn them extensively (10, Participant 3).

The participant has described two separate technology transitions during her work life. Both of these technologies may involve promising aspects, but their developers and manufacturers are very limited throughout the world. Hence, they had to learn and use what was commercially available in the market. This poses another challenge because including ready-to-use products in a system design will cause additional constraints due to their un-customizable and unalterable designs. Therefore, the participant has mentioned two challenges of meeting packaging constraints while using ready products from the market: knowing the products and their up-to-date details; and the necessity to adjust system requirements and constraints according to the ready, unchangeable products’ requirements.

Additionally, the participant also mentioned that packaging constraints are changed over the time with the enhancements in technology.

> There have been some updates [in packaging constraints]. Materials have especially changed drastically. Batteries have become thinner, and materials such as magnesium, titanium, and composites got involved, resulting in smaller packaging [constraints]. There have been significant changes in electronics, as well. (...) the material has become smaller, so the electronic cards got smaller (11, Participant 3).

From the quotation, it can be understood that packaging constraints can be highly dependent on the available technologies of the time. Technological enhancements could play an essential role in the establishment and meeting practices of packaging constraints. Therefore, there is a mutual understanding across disciplines that the sum of answers would create a greater and more comprehensive understanding of packaging constraints.

4.1.5 Summary

In the first part of the study, participants' experiences on project phases and the generation of packaging constraints were presented. Aim of the exploratory study and data collection was to create the rough idea and knowledge about the understanding of project phases, scope of packaging constraints, their establishment procedures, distribution to team members, and meeting practices of those constraints in a defense industry. It should be noted that, since the exploratory study was conducted before the finalization of research questions and case study, most of the discussions are unfortunately not applicable to the current focuses of the thesis.

4.2 Case Study Findings

This section will provide the findings of the collected data, of case study, in nine main aspects: Collaboration at the Early Phases of a Project, Design Modifications at User Involved Phases of a Project, Industrial Designers' Role as System Co-architects, Contradicting Understandings Between Systems Engineering and Industrial Design Departments, Requirements Management's Iterative Procedure Understandings of Packaging Constraints in Defense Industry, Reverse Pyramid Scheme of Project Phases to Establish and Accomplish Packaging Constraints in Defense Industry, Challenges Encountered in Meeting Packaging Constraints, and lastly Improvement Areas in Meeting Packaging Constraints. We will be focusing onto the system of the case study which was designed and manufactured by Company R. The case study is a project that completed within the company in 2021. It was the most recently completed project, participants were agreed to study on it. Any identifyer that could determine the company or project was requested to be masked; therefore, the purpose and objective of the project could not be revealed in the thesis.

4.2.1 Collaboration at the Early Phases of a Project

In defense industry, due to the complexity of the projects, multiple actors and various disciplines have to work in collaboration. Collaboration among team members is important to maintain at a sufficient level throughout the project; however, collaboration could be especially crucial at the early phases of a project. Participant 1 has described an instance where the design modification must be executed at an advanced phase of the project. The update was regarding the workability of the crew inside the system. During industrial designers' analysis in CAD software, they realized that personnel couldn't properly accomplish the tasks within the allocated space. Then, they transferred their design to the virtual reality environment in order to demonstrate the problem to systems engineers and get their feedback.

> *We* gave the first signal that a human, doctor, patient, or crew cannot work appropriately in this compartment together. First of all, through our analysis in the CAD environment we saw a problem when we placed the crew models [human models]. Then we uploaded the whole system design to the virtual reality to share this problem with the system engineers. In virtual reality, you are in the system, in 1:1 scale and you can experience it as if you are actually inside the vehicle (12, Participant 1).

And the participant continued with the challenge of contradicting system requirements. Conflicting requirements cannot be satisfied simultaneously since they are in opposition to each other.

> When we started working on the project, we wanted to have as low silhouette profile as possible in the rear crew section; this was the requirement for survival during operation. Making a system with a low silhouette is a systems requirement; on the contrary, high maneuverability and ergonomy are the other requirements. In this project, ergonomy requirements were found to be more critical. Therefore, we started the process of re-shaping according to the ergonomy requirements. In conclusion, we raised the ceiling, and our team's initiation has led to this update (13, Participant 1).

The participant mentioned that they are the leading team to resolve the challenge of conflicting packaging constraint and other system requirements. In order to solve this issue and proceed, they communicate with the systems engineering department and other related actors to explain the conflicting requirements and find a solution that meets common interest of every actor.

Systems engineers also agreed that the design had some ill-defined packaging constraints and it needed to be updated. However, since the project reached a certain level of maturity and involved some completed neighboring work packages, systems engineers had to inform the top management for the other completed systems to be updated as well.

> We saw that tasks could not be accomplished here; thus, we informed the top management and explained the necessity of a revision. After explanations and discussions, they agreed, and we revised the packaging constraints. (Was the top management approval necessary?) Yes, it was necessary because our decisions affect many other sub-systems and work packages. You make the system heavier and more expensive and change other sub-systems that have been built, so when we see a problem in such processes, we include the top management and support decision-making by saying that there is a common problem (14, Participant 1).

Furthermore, Participant 1 described the procedure of collaboration between industrial designers and systems engineers in the early phases of the project as follows:

> In most projects, we try to fit into the assigned packaging constraints. If packaging constraints are too limiting for our conventional designs, we approach the circumstance with new design methods. This is the only way we can fit here. For instance, if the ceiling of a driver's compartment is very low, we say that if we use the seat in a horizontal position, if we put the watch panel here, we could fit into this compartment. Our primary goal is to fit into the compartment. However, if there is a situation where the user cannot fit in, we say that the end-user is unable to work under these conditions (15, Participant 1).

Since the first output of the project management is creating project charter, it could be beneficial to include at least crucial work package responsibles to that phase. Industrial design department should definitely be one of the contributors to it because their designs are directly affecting other sub-systems and work packages. If we recall, " (…) our decisions affect many other sub-systems and work packages" explains the situation clearly.

> While system engineering is working on the placement of sub-systems and packaging constraints. They approach to the work package responsible as "I want it here". They say, I want you to fit into this area [packaging constraints]. Here, the decision-maker is the systems engineering (16, Participant 1).

"Here" in the last sentence in the quotation above refers to Company R. This referral can be supported by Participant 2's answers. Moreover, exploratory interviews have concluded similar implications as well.

> We begin a project like this, a customer comes with a request, and if there is no customer, benchmarks are made where we reveal the potential customers' demands and set (the project) requirements that are developed by those benchmarks. We ask the question, what do we want to do in this project? After answering this question to some extent, a set of requirements are formulated, while considering multiple factors such as functionality, performance, environmental, electromagnetic interference, and human-system compatibility of the project to be produced. Then a design process begins (17, Participant 2).

Participant 2 is also supporting the current structure with the quotation of "Systems engineers are defined for this (18)".

Additionally, every interviewed participant during the exploratory study were mentioned that packaging constraints are generated by systems engineering department and they (interviewees) are assigned by systems engineers to fit in specific dimensional constraints.

4.2.2 Design Modifications at User Involved Phases of a Project

In human-in-the-loop defense systems, ergonomics, accessibility, and maneuverability aspects are iteratively developed with the military personnel who are the customers. Participant 1 emphasize that designing with such aspects requires close cooperation with the end-users, not only with the purchasing executives. End-users are the people who would actually use the product.

> Of course, users are also contacted here. For example, there were times when the health personnel came and examined the design and said it should be there (19, Participant 1).

These systems often include constant interaction between a person and the design. Additionally, acquired know-how from the human-in-the-loop studies is especially important for companies working in such systems. With the acquired knowledge, they will upgrade their human-models. A more accurate model gives designers a better understanding of user experience results, which will also lower the iteration count of designs.

Participant 2 has mentioned that each company has its own human-models. Companies use their human-models to simulate real-life situations and determine if there is any problem caused by ill-designed systems.

> After all, we use the human-models, and each company has their own human-models. So, does everything work correctly in the virtual models? Of course not. There are inaccuracies in your analysis (which may be caused by human-model errors). After producing the system, many analyses may not hold in real-life. So, it is imperative to make mock-ups to progress to a more accurate design there (20, Participant 2).

Therefore, we can deduce that the more advanced and precise human-models will conclude the more accurate analysis results with real-life experiments. However, there are always deviations in real-life; so, depending on analysis, results could be risky and require other experimental measures to be implemented as well.

Moreover, as Participant 2 mentioned, they have multiple human-models because every individual is different from each other. Hence, they are creating somewhat generic human-models to comprehend 5%, 50%, and 95% of the personnel and use these models during the designing as well as personnel task-assigning phases. Therefore, industrial designers at Company R have created a personnel compression scale to categorize the deviations in personnel and human-models.

> While these analyzes are running, there is also the issue of making them according to the average person. We define them [human models] as 5%, 50%, and 95% personnel comprehension. Therefore, design optimization will be performed with 5% and 95% personnel with minimum loss in the ability to perform related tasks is also included in the responsibilities of the industrial design department (21, Participant 2).

Therefore, personnel comprehension percentages are related to specific pre-defined tasks by the mentioned 5%, 50%, and 95% levels. If a task is defined to 5% comprehension, at least 5% of customers' personnel should be eligible to perform the assignment. In order to analyze this aspect and generate designs accordingly, industrial design departments have the role to generate and enhance multiple human-models.

Design modifications usually occur in the case of uncertainties or change in project requirements. Therefore, we expect no or very few major changes to the project towards the end of the detailed design phase. On the other hand, this quotation from Participant 1 introduces the opposite cases are occasionally possible as well:

> The ergonomics of the crew were critical in this project, and many updates were made by us (which caused other sub-system designs to update as well) regarding the usage areas. The greatest challenge, I think, was when the structural design had to be changed to improve the maneuverability of the crew inside (22, Participant 1).

This statement does not fit into the traditional project development life cycle model demonstrated by Figure 1 traditional defense systems development life cycle in the literature review. However, we can still credit the disagreement because the human-in-the-loop systems' design has to reach some level of maturity to properly test and analyze ergonomics, accessibility, and maneuverability for end-users. Therefore, an updated demonstration might be required to demonstrate the project development life cycle model in the case of human-in-the-loop defense system projects.

Meanwhile, the Figure 1 is almost identically fits to the project at Roketsan due to the exclusion of users in the operation. Of course, there are human-involved processes, such as target selection, fire command, mission cancellation, etc.; however, once the missile is locked to the target and launched, it controls itself using a built-in autopilot and completes the mission without any further human involvement. So, we can assume there is no human-in-the-loop process in such systems.

4.2.3 Industrial Designers' Role as System Co-architects

Beforehand the findings of this section being presented, the content and explanation of the *Co-architect* term could be addressed; so that we can establish a consensus among readers about how the *Co-architect* term has been used. The *Architect* term in engineering projects refers to the system architects who are responsible for specifications that characterize the system's behavior, structure, and other project-related aspects and they tailor the design processes. They define a system's functions, requirements, and constraints and consult with project teams in case of any issues (Jaakkola & Thalheim, 2011; Crowder et al., 2016a). There could be several architects in a project from different departments with different goals, leading to multi- or interdisciplinary project management and architecture (Crowder et al., 2016b).

Industrial designers are at a junction point between being design creators and project managers. This phenomenon is emerged from two distinct conditions; the first one is because industrial designers are actually the creators of their designs.

> While designing, we are working on the details of the vehicle's width, height, and height, how it will look outside, how the crew inside will be positioned, and how the equipment will be placed, by considering both visual and ergonomic controls (23, Participant 1).

Industrial designers' work package spectrum is wide, and they should consider UX along with packaging constraints. Additionally, they have to consider system performance requirements as well. As far as I have experienced at Roketsan and learned from the field study, every part in the project has a purpose. This designing perspective comes from what is called the *LEAN Design* practice. It aims to minimize waste and use only value-adding functions (Baines et al., 2006). Therefore, if every part of the project has a crucial purpose, then all of them must work in harmony to appropriately service during operations; otherwise, catastrophic problem series may occur. The following statement from Participant 2 supports such usage of practice in defense industries:

> For example, a device is scorching hot (emits heat), so it is obvious which systems you can or cannot use due to the heat pulses and how close you can get to the neighbor systems (24, Participant 2).

Secondly, they work as a consultant of other sub-systems and affect their designs as well. Participant 1 has mentioned this statement as:

> We direct the systems engineers for the placement of external equipment, such as headlights. (…) we direct the designs of other sub-systems or structural elements with accordingly to the ergonomics analyzes we make (25, Participant 1).

And the participant also referred their consultant role in the project while discussing about another question:

> The ergonomics of the crew were critical, and multiple related sub-systems' designs were updated many times regarding the usage aspects (26, Participant 1).

Furthermore, industrial design department has the only project team members who design and iterate with the optimization focus of human, end-user. Participant 1 calls the attention of readers to industrial design departments are not just about ergonomy or good-looking designs. They are at the junction of user and engineering with the following quotation:

> We have to think about the user. A magnificent weapon that the user cannot use has no meaning. It does not make any sense for the tank to have 1500 horsepower that can do 60 or 100 km per hour if the driver cannot drive or control it, or it has a 120 mm gun, a very precise target aim, but if personnel cannot load ammunition on that barrel, it doesn't make much sense. **Our greatest impact comes from interaction with people** (27, Participant 1).

This role is unique to industrial designers because no other project team members are responsible for such end-user aspects.

With the findings from the field study, we can understand industrial designers in the defense industry are not like regular, in-house engineers who only work for the given requirements and constraints but they also work in close cooperation with the requirements management aspects as well.

Likewise, it is introduced at the beginning of this section, we can deduce that industrial designers have an identity as a co-architect of the system where they influence the whole project with their decisions.

4.2.4 Contradicting Understandings Between Systems Engineering and Industrial Design Departments

During the field study, an unexpected answer was given by Participant 2. The question was:

> How are packaging constraints created? In particular, what are the packaging constraints of the work packages (which involves industrial designers), how industrial designers involved and which criteria are determined for packaging constraints (28, Participant 2)?

And Participant 2 answers as "I don't know much about packaging in our industrial design team, I haven't seen it." (29). The answer, as mentioned, was unexpected because it contradicts the initial expectations, findings from the literature review, and most importantly, answers of participants 1 and 3. If we recall, Participant 2 is the group manager of the systems engineering department at Company R. So, the participant is constantly in communication with every department and team member in the project. Hence, Participant 2's answers were expected to be aligned with Participant 1.

Most probable reason of this contradiction could be misinterpretation of the question. Because the participant follows his words as:

> What we understand from packaging, system-level packaging, is if I'm going to carry it from one place to another, we call it portability. We do it under the name of portability analysis. After all, I have to send this system to customers. I may use air, road, sea, or rail, and I must comply with the specified gauges of those transportation facilities. Since we are also responsible for the portability aspects of the vehicle, this is usually operated in our systems

> engineering (department) when the layout and volumetric studies are carried out according to the standards' gauges (30, Participant 2).

In this quotation, the participant is interchangeably using packaging and portability. Then, the participant explains that there are specific gauges that the overall system must fit in. Although this can be considered as a packaging constraint of the whole system, the answer diverges from its intended response. Instead, it describes the logistics aspect of the system and its portability through transportation means.

> In our applications, I couldn't remember where the industrial design team was involved in a packaging-related issue until now (31, Participant 2).

As understood from the continuation of the discussion, Participant 2 has confused packaging constraints with packaging design at that time. Although the meaning of the packaging constraints was introduced and explained in detail before the interview, it could not prevent the misunderstanding and confusion of the participant.

Moreover, since the meaning of packaging constraints were described beforehand, I could not think a participant could imagine it as packaging rather than packaging constraints. During the study, I was focused on the questions and corresponding answers. Though I realized something was not aligned with his answer, I prepared myself for the next question. Luckily, I had another chance to correct the participants misunderstanding and asked my questions in detail. Participant 2's reaction to the correction was also involving valuable a finding:

> Well, when you say packaging constraints, I perceive the system's packaging. Since our dimensional constraints are strictly defined, you design them to fit in those constraints (32, Participant 2).

This acceptance of the misunderstanding has led to something much greater than the expected answer. The first one is the notion that gives the clue of terminological divergence and lack of unity in the industry. Secondly and most crucially, the participant passes the knowledge that packaging constraints are not only at the sub-systems or work packages level, but the overall system has to meet its packaging constraints as well.

4.2.5 Requirements Management's Iterative Procedure

As expected prior to the field study, defense industry projects involve many iterative cycles. These cycles can loop between any two-consecutive project phase. Meanwhile, most iterations usually occur between system requirements definition and design phases. During this interval, the system has too many unknown parameters that interrupt a linear project development life cycle process. Team members and especially systems engineers of the project have to define the majority of those unknown parameters. The remaining unidentified parameters are denoted as TBD (To Be Determined). There are multiple reasons for the TBD parameters, requirements, or constraints. One of the reasons could be that they depend on other unknown parameters or the outputs of the project. Thus, project team members are unable to determine TBDs at early phases of the project. Another reason could be the project teams may need to conduct experiments, analysis, or other studies in order to make an input for the TBD sections. Participant 2 has defined the iterative phases into two main parts. The first part is the concept development and preliminary design phase. Then the participant continued with "The second part, which is the most essential part, the part where so many iterations run, is the part with the human (33).". Therefore, we can understand that iterations and final parameters of the system regarding end-user can be postponed to human-in-the-loop experiments.

On the other hand, Participant 1 mentions about the system's requirements creation phase and its iterative behavior as:

> In this process (PDR), our team understands the requirements thoroughly, designs according to them, and compares their requirements with other systems engineering, sub-systems, structural, electrical, and electronic designs. Then we give and receive feedbacks (34, Participant 1).

Additionally, project objectives may be updated over time. Since project objectives are one of the strongest indicators of the project requirements, their updates will directly affect the update on system requirements. For example, Participant 1 has mentioned that the project was once designed according to the maximum chance of survivability; however, other system requirements were conflicting with it.

> When we started working on the project, we wanted to have a low profile in the rear crew section as much as possible; this is a system requirement for survival. Making a vehicle with a low profile is a requirement; being able to move ergonomically inside the vehicle is another requirement. Therefore, the height of the vehicle, which was initially designed according to the survivability requirements has been updated to raise the vehicle's profile in the continuation of the project. We initiated the requirement change to raise the ceiling so that personnel could fit into the volume with a sufficient ergonomics level (35, Participant 1).

Later in the project timeline, industrial designers proposed changing the system’s profile because personnel ergonomics were crucial. After discussions with systems engineers and other executives, they agreed that ergonomics is more important than the acceptable level of decrease in survivability.

During the interview, Participant 2 has discussed that they segregated iterative processes into two stages.

> During the concept design stages, it is given to the industrial design team for a style design of the vehicle according to the rough layout of the vehicle according to the width, length, height, and other platform properties. In the first stage, the industrial design department makes iterations with respect to other requirements. The second part, the most crucial part, is the part where so many iterations go, is the part with the human (human-in-the-loop experiments). If I am designing a military ambulance, then it has a driver, commander, gunner, and wounded soldier. If I am developing a maintenance vehicle, there is a maintenance crew in the vehicle (36, Participant 2).

Therefore, industrial designers are usually working with two main iteration phases. The first phase is where they create iterations regarding the concept designs; and secondly, they iterate on the more matured system regarding the related end-users. End-users may include multiple variant personnel, and they may differ for each project.

Modifications on concept phases are easy and desired to create more effective solutions; however, any change in the advanced phase is not welcomed. The most probable reason is the modification may affect other sub-systems and cause unintended problems. Therefore, working with a more detailed design have some disadvantages. Detailed design means that it may involve *frozen* parts, where they are detailly designed, tested, and verified.

Any change that could affect frozen parts can be very costly to the company and project management because any update on a frozen part requires almost all of the tests and verification procedures to be restarted and the project schedule to be reset.

Moreover, participants were asked the question of whether their packaging constraints were updated without their initiation or not, and they are all answered *yes* and then describe their observations as:

> *Participant 1.* It is actually the nature of this business because all systems are trying to integrate. I do not see it as a competition for space allocation but as an optimization to get the job done. We are constantly working on optimizations (37).
>
> *Participant 2.* When you think about the function of the relevant unit, you know the test results of field data, you can apply an additional design solution there, or you can make a reasonable sacrifice. There may be a deviation; these deviations are, of course, still should be acceptable deviations (within the tolerance limits (38).

Participant 1 mentioned that iterations are the must-have procedure of system design for work packages to integrate optimally into the system. It is not a competition of who gets with space allocation, but rather who fits there best. Since there is no formula that outputs optimal packaging constraints, iterations are obligatory for project team members.

Then Participant 2 has discussed the issue with the introduction of sacrifice. The participant mentioned that some sacrifices on requirements or system performances can be made within tolerable limits to introduce new possible design solutions for the system.

4.2.6 Understandings of Packaging Constraints in Defense Industry

A straightforward question was sufficient to understand what packaging constraints mean in the defense industry: *Can you explain what "packaging constraints" mean to you?*

This question was also asked during the exploratory, unstructured interviews. Participants' answers were quite similar and oscillated between two different understandings, which are;

Four participants understood packaging constraints as its use in this study; the geometric dimensional limitations of a design. Six participants understood packaging constraints as packaging design and dimensional limitations to package the system.

However, none of the participants have mentioned that they use this term in their work or company. This may be caused by the terminological disharmonization. Literature studies are very insufficient in this area; therefore, I will not be able to support this finding with a literature review. However, field study outcomes can show that more than three terms are in active use in different companies. So far, these terms have been used to refer to packaging constraints by participants: Design Space Management, Gabarite, Envelope, Envelope Budget and Requirement. Their referred names in Turkish are relatively as follows: Hacim Yönetimi, Gabari, Envelop, Zarf Bütçesi, Gereksinim.

After receiving the answers from participants, I confirmed that they really meant *packaging constraints* with their terminologies with a follow-up question of "So you are using (…) to refer geometrical constraints that define the space your design has to fit in?" and every participant agreed the follow-up question.

4.2.7 Reverse Pyramid Scheme of Project Phases to Establish and Accomplish Packaging Constraints in Defense Industry

So far, we have found out that there are two possible ways to obtain packaging constraints for a project. In the first alternative, customers define the system requirements, so packaging constraints, or company may initiate a project with its own resources with the expectation of potential future customers.

Before accomplishing packaging constraints, they have to be established. Doing so may require requirement management, as mentioned, and NPI of the project. NPI scheme can be described in reverse pyramid theme. Customers can initiate the project at Lv. 1, the lowest part. In some cases, this level does not exist due to the absence of customer; therefore, first step becomes the *Company/Top Executives* and they behave as the initiating actor, Lv. 2. System requirements are initially set between the transitional phase of Lv. 1 to Lv. 2. Participant 1 has explained this as follows:

> The initial requirements document comes from the customer. If the project has started within the company, then we (Company R) are creating this document ourselves, systems engineering department initiates the first requirements set (39, Participant 1).

These initial requirements, constraints and assumptions are released with the project charter document. After the release of the document, project is officially started and team members are started with the concept design phase.

Participant 1 continued explanations about the project phases regarding the packaging constraints.

> First, there are the requirements. After that, concept design studies which are suitable for these requirements begin. The concept design phase ends with a phase called CDR, concept design review. CDR will preliminarily reveal the extent to which of these requirements can be accomplished. Then the preliminary design phase starts. At the end of preliminary design, first design will be frozen with PDR, preliminary design review. Therefore, the process starting from the requirements becomes where the design is matured and documented (40, Participant 1).

After the start of detailed design, work package responsible start to finalize their works and promote their design to frozen state. In order to protect team members, a frozen design cannot be demoted and changed without the permission of systems engineers or higher executives, it can only be revised. Therefore, designers make sure they include all of the assigned requirements and constraints into their work packages. Participant 1 mentions that:

> We [the industrial design department] are making these prioritizations while meeting packaging constraints. The volumetric space of the engine is at the forefront of the engine compartment design procedures. During the crew compartment design procedure, we make packaging that the crew can efficiently work ergonomically (41, Participant 1).

In meeting packaging constraints, Participant 1 has mentioned about the use of standards. The participant gave an information that they use MIL-STD-1472 design criteria standards for human engineering. As a result, they set broad human engineering standards for the creation of their systems.

> Here [in meeting packaging constraints], we may use standards. They are the references or guidelines for us. Before we start the prototype, the packaging constraints of the content are essential. For example, we first look at the volume of the interior with virtual reality together with the team. We decide on some parts of the arrangement of packaging constraints here. Then we may create mock-ups (42, Participant 1).

Meanwhile, the participant informed that the goal of using design standards is to have a guideline, that may be used when designing new systems. Nonetheless, they do not obey with some of the standards mandatorily. Participant 1 says that the company has its own know-how and would rather use that, rather than complying with the standards entirely.

> ... we do not precisely comply with these standards; I look at these standards as a reference. If we anticipate another method may give better results in our design, we will do it in our way; not the standard-referred way. We do not use standards if they put us in trouble (43, Participant 1).

4.2.8 Challenges Encountered in Meeting Packaging Constraints

In thematic coding and analysis, *Challenges* code was specifically crafted to answer the challenges that are encountered by the team members while meeting packaging constraints. In total, 38 responses of the study found to be promotive the answer the related sub-research question. In the process of meeting packaging constraints, Participant 1 has mentioned that their packaging constraints may change over time; their allocated space may be decreased.

> While starting the design, you usually get large envelopes, but your envelopes can be reduced as project uncertainties become more defined over time (44, Participant 1).

The participant gives another example where range of motion of crew was problematic so they had to re-design the structural body of the system in order to create more space. Expanding the structural body of the system allowed designers to allocate more space to the personnel within the system:

> The most challenging difficulty, in my opinion, was the necessity of changing the structure for the crew's range of motion inside the system. The crews ergonomy was essential (45, Participant 1).

Furthermore, Participant 2 has added a supportive response to the challenge encountered by Participant 1 and gave the following explanation from his standpoint.

> In this system, there are many pieces of equipment and devices that the personnel are responsible for performing during their operations. As a result, these equipments need to be packaged into the system, and this is a subject that progresses with iteration. Starting from the concept design, a seat and a location layout should be made so that each personnel can use their responsible equipment in the system. Can the person reach and see the relevant equipment from where they sit? These studies are carried out by the industrial design team, and feedback is given to the design (46, Participant 2).

The participant mentions the importance establishing packaging constraints are as important as meeting them. If the packaging constraints are not well established, then the system may still be useless even in all the packaging constraints are met during the detailed design phase.

Additionally, Participant 2 has continued with the importance of packaging constraints' construction and important aspects of the process.

> If these people [crew] are using surveillance equipment, such as periscopes, there is a subject called the field of view. A device is getting very hot, and because of that, it is obvious how much distance you should not place something else next to it due to heat spikes and how it will dispense the heat. Therefore, based on the technical features of these systems, it is necessary to analyze the view of the personnel placement. According to these analyses, the assigned locations of those personnel may change, as well as the equipment placement, in a way that does not create a dead zone on the vehicle (47, Participant 2).

The participant explains the importance of the helicopter view of work packages or sub-systems that will be implemented to the system. Systems engineers should know the crucial aspects of sub-systems in order to set a common fundamental understanding prior to the packaging constraints. In this way,

Moreover, the project schedule was considered as a challenge because design outcomes do not develop linearly but usually feature multiple iterations. A work package may involve multiple interdependencies with other sub-systems; thus, preceding work packages had to be completed to detail the dependent design. This could obstacle team members to improve their work simultaneously with other sub-systems and work packages. Dependent designs have to wait for other related work packages to be completed. Additionally, designing with human-in-the-loop iterations can also be an issue for project scheduling. This is due to the fact that system design has to be developed to some extent of maturity so that human-in-the-loop tests can be properly conducted. Any major iteration request resulting from end-user testing may disrupt the project schedule and process plan. Participant 1 has mentioned about the allocated project schedule to industrial designers and its challenges caused by the work-package dependency and the role of their designs:

> The project schedule was very limited; we did this work in a short period of time. However, I think we would have reached the same constraint if the

> project schedule had been extended. This is due to the fact that some of the systems we work with are the ones that can be detailed after all other systems are completed. Therefore, even if the project duration was extended, the time allocated to us is very limited and we have very little time left since the first installed and assembled parts are also our parts (48, Participant 1).

In addition to these challenges, industrial design department was also responsible for the delivery of their work package to the system, including manufactured parts and their supply to the company as well. This circumstance was not the everyday situation; however, they had to take the responsibility due to the limited time of the project schedule.

> We had to keep track of the manufacturing and supply processes a lot since there was limited time. We have kept communication active with the manufacturing companies since we are also responsible for the assembly (49, Participant 1).

Hence, these additional responsibilities and workloads have indirectly caused a challenge in meeting the packaging constraints. Although it was not the root cause of the encountered packaging constraint challenges, it is still worth mentioning to demonstrate that there may be indirect effects to initiating challenges for meeting packaging constraints.

4.2.9 Improvement Areas in Meeting Packaging Constraints

Towards the end of interviews, each participant were asked about an issue they encountered while meeting packaging constraints. The question was:

> When you look back to your experiences, what could have been changed to improve anything related to meeting packaging constraints during the project period? Do you have any suggestions (50, Interviewer)?

Interview responses to that question show that each participant has encountered multiple hardships, which they would like to resolve. Therefore, this section will focus on the findings regarding the possible changes in order to enhance the experience of packaging constraints implementation.

As a start, Participant 1 has suggested that project scheduling could be modified in order to spare some time in between project completion and assembly phases.

> Maybe we could do it like this: Nothing will be done for two months after everyone has completed their work. There will be only the procurement processes. Then we could have handled the project processes more efficiently. We have experienced such projects as well, by the way. After the project is over, I find it useful to have a certain period of time for assembly (51, Participant 1).

The participant's proposal of a time gap between the detailed design phase and manufacturing and system integration could be somewhat controversial, which we will discuss in the conclusion chapter. The reason for this proposal could be rooted down to the project scheduling and workload issues. Therefore, more manageable, and well-structured project schedule is something that could be desired by project members for their overall work.

Moreover, Participant 1 has described a problem which is probably caused by the project planning and scheduling again. The participant wanted to have more communication and interaction with the end-users at the early phases of the project.

> It could have been better if we could spend some time with the crew that would use such a vehicle at the beginning of the work because we did not have the opportunity to do so. If we could observe their real needs in the field, we would make a few alternatives in the project calendar. It would be better if we could go over them as well (52, Participant 1).

This comment could be grounded upon the iterative processes, as the participant noted, where they could build a better common understanding of the expectation among the designers and end-users and would help them to establish and meet packaging constraints more efficiently.

Participant 2 has mentioned on the technological enhancements, such as the emergence of virtual reality, could speed up the testing, iterative design processes and project schedule, and deliver cost efficient solutions than traditional mock-ups in meeting packaging constraints.

> Technology does not stand still, it develops. Is mock-up the only solution available? Of course not. Now, visual reality issues, in which these mock-ups are transferred to the digital environment, have started to come into play. Designs can be observed and experienced as if the design has its final form. Many different issues, such as the system's exterior, interior appearance, and interior layout were perhaps [analyzed via] alternative to mock-up [with virtual reality]. Mock-up is effective, but it is time-consuming and costs extra. The accuracy of the designs here [virtual reality] will also increase because models are now done in the virtual environment. In fact, even the crew's scenarios are starting to be executed. This [virtual reality analysis] also comes across as a more effective and budget-friendly method that accelerates the iteration updates and project schedule (53, Participant 2).

On the other hand, Participant 2 has briefly stated a conditional view of sole virtual reality analyses are currently insufficient to validate and approve designs. Afterwards, the participant commented on the superior areas of virtual reality over mock-ups:

> Only analysis is not enough, we still need a mock-up model. Therefore, virtual reality models are actually critical, I think it is an effective solution to make an analysis as accurately as possible in the virtual environment without going to production and to develop tools that will enable the accurate analysis of many experiences. I think virtual reality is important. I think it would be very beneficial to improve and spread this issue as much as possible (54, Participant 2).

The comments of Participant 2 include the findings of importance and beneficial potentials of virtual reality on projects'…

- Design phases
- System integration and testing
- Validation and verification phases and
- Project management and scheduling aspects.

Hence, the remark of Participant 2 on the virtual reality implications on project has direct potential benefits to packaging constraints management and meeting them, as well as many other improvements.

4.3 Summary

In the second section of the study, findings from the field study are presented under ten sub-titles. During the data collection period, the combined knowledge of the literature review and exploratory study findings were used to revise and finalize the thesis research questions. Afterward, the field study was designed to obtain more detailed and focused answers to the research questions. The field study's structure and its questions were created in such a way that all the research questions could be answered. Moreover, some questions aim to reveal the un-questioned but essential experiences of the participants just in case. Likewise, every research question was aimed by multiple field study questions to extract the participants' experiences in detail.

Interviewees were selected from two defense industry companies of Turkey. Since the participants were requested their names and company information to be masked, participants will be masked as Participants 1, 2 and 3; companies will be masked as Company R and Y. In total, the study covered 10 participants and 3 defense industry companies.

In the section 4.2.1 Collaboration at the Early Phases of a Project, participants have emphasized on the collaboration among team members. Participant 1 gave examples of design modifications due to ill-defined packaging constraints at the beginning. Participant 1 has mentioned that systems engineers are the decision-makers in a project process and responsible for the requirement management. Possible reason of the ill-defined constraints may because of the lack of communication at early phases of the project and working practices of systems engineers. As Participant 1 quoted 'They approach to the work package responsible as "I want it here"'. Systems engineers work on the optimized layout of packaging constraints for system's optimal performance outputs. The systems engineering department starts project by receiving customer requests and then formulate necessary requirements set. If there are no customers at that time, they start to calculate system design requirements according to potential customers' potential expectations. When requirements set is established, it is distributed to the project team members, afterward. However, when industrial designers start to get involve in the project processes after project requirements have been established, they could encounter some problems on those requirements or layout plan and raise a no-goflag. A go or no-go flag is used as a checkpoint to decide whether or not the project should move on to its next phase. In the case of a no-go flag, top managers of the company should be informed because the necessary rework may affect other, neighboring work packages and hence, they may need to be modified as well. Revisions at advance phases of projects are not generally desired because they may prolong the project schedule, cause additional costs, and cause to mandatory modifications of completed, frozen work packages, as mentioned.

On the other hand, Participants 1, 2 and 3 have mentioned that their project processes involve iterative design procedures because they work on human-in-the-loop systems. No matter how accurate models and simulations they run, their results may differ; and therefore, they need to validate their systems or sub-systems with real-life mock-up experiments. Additionally, their requirements are also matured iteratively and with the involvement of end-users, as mentioned in the section 4.2.5 Requirements Management's Iterative Procedure.

Although they have multiple human-models and analysis procedures to be used during design phases, every participant mentioned analysis and models have deviations from reality; therefore, it is desired to manufacture necessary mock-ups and test them with end-users, if possible. Using multiple and different characteristic human-models can enable engineers and industrial designers to create more accurate systems and lower the necessary iteration count. Moreover, helps them to classify the average crew members' comprehension to their assigned tasks. They classify crew's comprehension level into three levels to simulate real life situations more accurately; namely 5%, 50%, and 95%.

Meanwhile, I realized that Participant 2 has misunderstood one of my questions. Although I described *packaging constraints'* meaning and intended purpose of use before the question, the participant understood it as *package* design and answered accordingly. Unfortunately, I was focused on the next question and the course of the interview; so, I could not imagine the participant misinterpret it and answer something else. As a result, it appeared as if there is a conflicting result between participants and opposing to literature review. After the answer, I realized the participants answer was focusing on the package and not the packaging constraints; hence, I redirect the question and found gold while I was searching for some copper. I was only thinking about sub-system and work package level packaging constraints; yet, Participant 2 has shown me that overall system has its own strictly defined packaging constraints as well. These packaging constraints can be derived from related standards.

In defense industry projects, usually customers expect from projects to meet related military standards, so that, they can rely on the system. Company M, for instance, meets MIL-STD-1472 in its projects to prove its customers that their systems are designed to satisfy at least a certain level of ergonomics (defined in the standard) for the crew while accomplishing their tasks.

Iterations are crucial for human-in-the-loop systems because the design must ensure the best conditions for the end-users; so that, they can accomplish their tasks without any problem.

Moreover, as a result of the interviews with Participants 1 and 2 indicate that, after industrial designers involved to the project, their role profile behaves similar to a system architect. As Participant 1 noted that they direct systems engineers and design of other sub-systems and structural elements with their ergonomics and human-model analyzes. They have an authorization to shape and direct the overall system thanks to their subject matter expert knowledge on ergonomics and human-in-the-loop system's design. If necessary, industrial designers can alter the system and sub-systems design with the notification of the related work package responsible and top managers, if necessary. Industrial design departments greatest impact comes from their interaction and cooperative design practices with customers and end-users.

CHAPTER 5

CONCLUSION

This thesis does not aim to conclude any generalization; rather, its main aim is to provide introductory knowledge for possible related areas and future research.

Conclusion chapter provides the combined knowledge acquired from the literature review and findings chapters. At the beginning of the chapter, an overview of the study will be recalled. Following that, the significant conclusions drawn from the findings chapter will be introduced with respect to the literature review. Those conclusions are the research questions' potential answers, which we have been searching for from the beginning. Afterward, the study's limitations and recommendations for future potential research are presented.

5.1 Overview of the Study

At the beginning of this study, background information and motivation for this study were presented. The study aimed to understand the practices for meeting packaging constraints in defense industry companies in Turkey. Therefore, one main and seven sub-research questions are developed to achieve the study's aim. These questions were focused on different possible aspects of meeting packaging constraints practices, including; how packaging constraints are being used, how they are established, what are the practices and challenges in meeting them, and project procedures regarding packaging constraints.

In order to fulfill every research question, the study started with an in-depth literature review. Research questions and potential supportive areas were studied during the literature review phase. An inductive method is used for combining smaller and more manageable knowledge to sum a greater knowledge. This method was necessary because very limited studies are available for my research focus. Therefore, various disciplines’ literature is reviewed, and the following areas are explored for the benefit of the thesis: Constraints, packaging constraints, project requirements, requirements management, systems engineering, work packages, project development phases, project team members, standards, design space exploration, cross-functional teams, industrial designers’ roles in industry, collaboration and its emerging forms and design-specific disciplinary framework.

The third chapter presents the methodology of the exploratory and field studies. Qualitative research methods were utilized to investigate participants' experience-based perspectives in defense industry projects. These studies were conducted with a total of ten participants and three defense industry companies. Firstly, exploratory studies aimed at creating a rough idea about how packaging constraints were generated, how project teams meet them, and who the members of project teams are. Subsequently, research questions and field study design were refined with the knowledge acquired from the exploratory study. Secondly, the field studies were conducted because the collaborative practices regarding packaging constraints among engineers and industrial designers working in the defense industry could only be understood by listening to their experiences in the field. Therefore, interpretive research is found to be a suitable methodology for the thesis. In the fourth chapter, acquired knowledge from the exploratory studies and findings of the field study were presented.

In the fourth chapter, acquired and analyzed data from the exploratory studies and findings of the field studies were demonstrated, respectively. Although exploratory and field study findings were separated into two main sub-sections for structural clarity of the thesis, their exploratory studies' findings were also used in the field study section to support quotations. Regarding the research questions and beyond, the general points of interest of the field study were focused on; the importance of collaboration at early project phases, industrial designers' roles, requirements management in defense industry projects, packaging constraints, and practices to meet them.

All in all, for the last chapter of the thesis, the main conclusions and answers to the research questions were discussed in detail with the knowledge of literature review and field studies. At last, the thesis is completed with the limitations of the study and recommendations for future research.

5.2 Revisiting Research Questions

Each research question has been linked and analyzed with their thematic codes regarding the field studies. With the presence of the literature review and findings chapters, we can unearth the answers to these questions and fulfill the aim of this thesis.

The sub-questions were structured in such a way that their individual answers could build up to resolve this main research question. Therefore, deduced conclusions from the combination of both literature review and field studies will be classified under the following sections.

5.2.1 (PC's Scope) What is the scope of "packaging constraints" in the defense industry?

Packaging constraints' scope is mentioned as length, diameter, weight, distance, clearance, location, and space in the literature. Apart from the weight aspect, this thesis focuses on and compensates for all other mentioned scopes of packaging constraints.

It was found in the field study that there is a terminological disharmonization when referring to the packaging constraints among the defense industries of Turkey. Although there are different terms, such as design space management, gabarite, envelope, envelope budget, or requirement; they refer to the same scope of packaging constraints.

5.2.2 (Generation of PC) How are these constraints generated? Through which processes and by whom?

Generation and meeting of packaging constraints may require high level of knowledge, helicopter view and interdisciplinary work in order to establish well-built, well-scheduled, non-conflicting and efficient packaging constraints. Literature reviews have concluded that packaging constraints are delivered by customers, directly or indirectly. In direct-delivery, customers define the packaging constraints of the system and maybe some of the critical sub-systems as well. In the case of indirect-delivery, customer may expect system to meet some standards and those standards may include limiting factors or conditions for the packaging constraints of the project. Alternatively, in the case of no presence of a customer, systems engineering department can generate project requirements and constraints using various methods, some of them are namely benchmarks.

As a contribution to this section, I would like to introduce *Concept Requirements Set.* They are the initial, unprocessed form of the requirements and constraints sets that customers or systems engineers generated. It is named as *requirements* and not *constraints* because, as mentioned, constraints are one of the sub-divisions of system requirements. In addition, systems engineer may use Monte Carlo simulations or market research in order to benchmart the performances of different configurations and then select the optimum configurations as the concept requirements set. While the Monte Carlo density simulation method is widely used in multiple defense industry companies to generate best performing systems, analysis conditions program has to be well established. Unfortunately, it can combine contradicting properties of the system and cause ill-defined requirements sets.

With the field study findings, following conculusions have been reached. Packaging constraints can be divided into two main classes: system packaging constraints and sub-system packaging constraints. System packaging constraints define the overall system exterior’ the geometric limitations. They are usually defined by customers’ or potential customers’ specifications, related standards, or external factors such as gabarites. Gabarites are controlled by transportation methods; therefore, their extension or rework is not possible. Sub-system packaging constraints define the geometric limitations of the sub-systems or work-packages which will be used in the system. They are commonly established by systems engineers of the project. On the contrary to system packaging costraints, they are a little more flexible and open to rework. We may visualize the differentiation as follows:

Figure 15 System and Sub-system Packaging Constraints (*Airplane On Ground iStock*, n.d.; *Passenger Plane Interior Aircraft Cabin Shutterstock*, n.d.)

Figure 15 aims to demonstrate the difference between system and sub-system packaging constraints. System packaging constraints affect the overall exterior geometric limits of the design, whereas sub-system packaging constraints can be the distance between seats for the optimal comfort and profit for an airline.

Systems engineers initially establish more fundamental and general requirements and constraints. The concept design phase will start after they distribute the requirements to the project team member. At the end of the concept design phase, CDR takes place, and the requirements and constraints set will be more mature to input the preliminary design phase. The preliminary design phase is completed with the PDR. At this stage, the first system design will be promoted to frozen, and project requirements and constraints will be more mature. Occasionally, some requirements may not be matured even at the end of the PDR phase. So, they will be denoted as TBD until they are clearly defined and accepted by all actors because updated constraints may affect other completed or frozen work packages.

However, as Mullineux (2011) has described the designing challanges in the existence of frozen parts, work packages or sub-systems:

> This (designing at early phases) is because the designer needs to explore design possibilities and full information about the geometry involved has yet to evolve. What are clearer are the constraints which bound what is possible.

Developing the system imposes more hardships to designers because the developed frozen parts may act as new constraints for the system.

Additionally, there is little to no iterative design work for packaging constraints at advanced phases of projects in the case of fully autonomous systems, such as missiles or plane autopilot systems. For such projects, systems engineers can baseline their requirements set at the end of PDR and detail the design accordingly. On the contrary, in the case of human-controlled or human-in-the-loop systems' projects, there are intense iterative redesigning and refining of requirements phases, especially regarding the packaging constraints.

During the establishment and maturation of requirements and constraints, systems engineers and project team members should work in close cooperation to create a baseline for project requirements (Mullineux, 2011). Project team members cooperatively refine and correct the concept requirements set with the systems engineers in the concept and preliminary design phases. Suppose industrial designers and other related project team members got involved in the early phases of the project. In that case, the number of necessary iterations for the maturity of the requirements set may decrease. This may provide the benefits of a shorter project schedule, less human source involvement, and a lower necessary project budget (Mullineux, 2011). The participants' arguments and literature reviews are found to be aligned with these circumstances.

All in all, if we could demonstrate the process and actor's involvement in a visual, it would be something like Figure 16. It explains the generation procedure and includes actors for packaging constraints in a reverse pyramid scheme. In fact, this figure can be applicable to other requirements as well; however, we will not focus on them in this thesis.

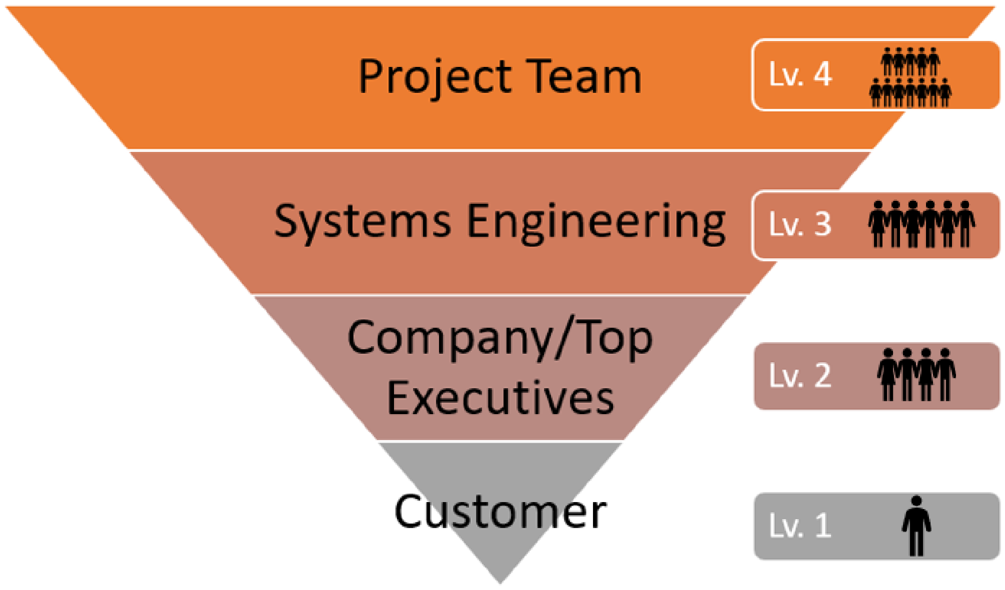

Figure 16 Defense Industry NPI Scheme

The project can be started by customers, as shown in Figure 16. However, this stage is not mandatory. In some cases, this stage does not exist since the Company/Top Executives function as the initiating actor and take the first step. Initial system requirements and constraints are established in between the phases of Lv. 1 and Lv. 2. The project charter document releases these initial requirements, constraints, and assumptions. After the document's release, the project officially starts, and team members start with the concept design phase.

There may be three main drivers found during the creation of packaging constraints: technology, ergonomics, and standards. As mentioned, technology plays a crucial role and packaging constraints are highly dependent on the existing technologies at that time. Ergonomics are dependent on the human body limitations and its capacities. Lastly, standards may play direct role in establishing or meeting the packaging constraints.

5.2.3 (Project Phases) What are the project phases, activities, methods, and tools involved in meeting packaging constraints?

In defense industry projects, meeting packaging constraints can be challenging especially respecting to all other kinds of requirements as well. Even though there are no rule-of-thumb for the actions of meeting packaging constraints, the studies' conclusions will be presented under three sub-sections: Phases, Activities, and Methods and Tools.

5.2.3.1 Project Phases

Phases regarding meeting packaging constraints may involve many individual distinct phases to be completed. Starting from the requirements and constraints generation phases, as mentioned, concept, preliminary, and detailed design phases include not only the generation and maturity activities for packaging constraints but also practices of meeting them. In fact, most of the time, requirements and constraints are matured while team members work and find some unfeasible or contradicting issues. Therefore, we may say that requirements' maturity activities and meeting practices for packaging constraints are intertwined. Once concept requirements set has established and added to the project charter, team members start for a concept design where they try to meet every requirement and constraints that have been forwarded to them. After the CDR phase, team members declare which constraints can be met or cannot be met. Then, preliminary design phase starts with the updated constraints from CDR. At the end of preliminary design, PDR takes pleace and systems engineers and project team members try to baseline for the requirements and constraints at that stage. It is important to baseline at this phase because detailed design phase follows it. Detailed design phase is a work intensive process; therefore, project team members usually do not want any uncertain requirements or constraints at that point.

However, as mentioned, in the case of human involving system projects, there is an additional design and packaging constraints phase at the advanced phases. This iteration takes place with the involvement of end-users and their feedbacks will be used to reconsider the current system.

In addition to those entangled practices, there may be a need to iterate and redesign project requirements, especially packaging constraints, if the project involves human-in-the-loop operations. The system is usually expected to meet certain commercial and military ergonomics standards. They are essential in defense industries because customers can ensure the system satisfies at least a certain level of ergonomics and performance under its operational conditions by the standards that the project has met.

5.2.3.2 Activities Towards Meeting Packaging Constraints

Project team members, especially systems engineers' and industrial designers' meeting packaging constraints activities may involve designing in CAD environments, running appropriate analyses and cooperatively working with customers or end-users.

Currently, almost all defense industry companies use CAD environments to 3D model their projects. They allow designers to see the layout and overall structure of the system and allow them to implement necessary modifications with ease. Moreover, CAD environments enable designers to transfer their work to other necessary environments, such as CAM for manufacturability check and analysis environments to analyze various aspects of the system. Project teams may execute various analysis for; for example, structural strength and integrity, dynamics of the system, ergonomics of end-users, etc. These analyses will be more detailly explained in the **5.2.3.3** section.

Another significant conclusion is about the collaborative design practices with end-users in meeting packaging constraints. Literature mentions human-supervised design iterations; yet does not specifies at which phase it usually takes place. From the findings of the exploratory studies and field work, this activity usually takes place towards the end of detailed design but before the system verification and qualification phases. However, there is a crucial finding to be noted. In order to experiment as accurate as possible, related sub-systems are integrated into the main system; meaning that system integration phase is also started. In the given previous figures, each step is demonstrated as connected but discrete part, where previous phases have to be closed to move on to next phase.

On the other hand, this study was intended to introduce a new possible implication and a term, Multi-lined Project Development Life Cycle. This established implication was focusing more on the sub-systems' or deliverables' development life cycle. As its name suggested, it is not a single process or loop; it was separate, individual development life cycle with different project schedules. Its structure was aimed to be like in the following figure:

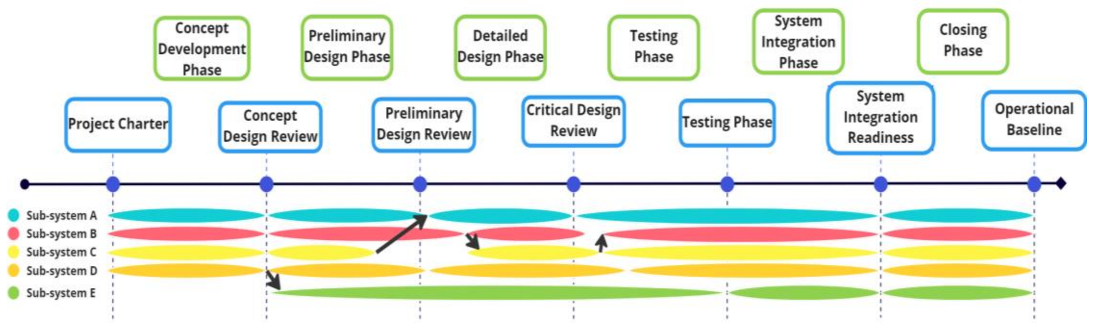

Figure 17 Multi-lined Project Development Life Cycle

Upper rectangular boxes represent the system development phases, and colored ellipsoids represent sub-systems. The aim for this visualization was to demonstrate that, unlike Figure 1 traditional defense systems development life cycle, the project development life cycle is not a single life cycle; rather it is a combination of multiple sub-systems' life cycles. Sub-system A may have a different allocated time period for its detailed design. Alternatively, some sub-systems may have a dependency between them, which requires, for example, the CDR of Sub-system B so that Sub-system C could use the outputs of that and start its work in the critical design phase. This can enable the project to shorten its schedule because more developed sub-systems do not have to wait for other sub-systems to be developed and reach the same readiness. This new implication is valid for the system processes and not sub-system or work package processes since it already showed the sub-systems' development and interdependencies if they existed. However, while this figure was created, it was found that a highly similar method is already in use in project management.

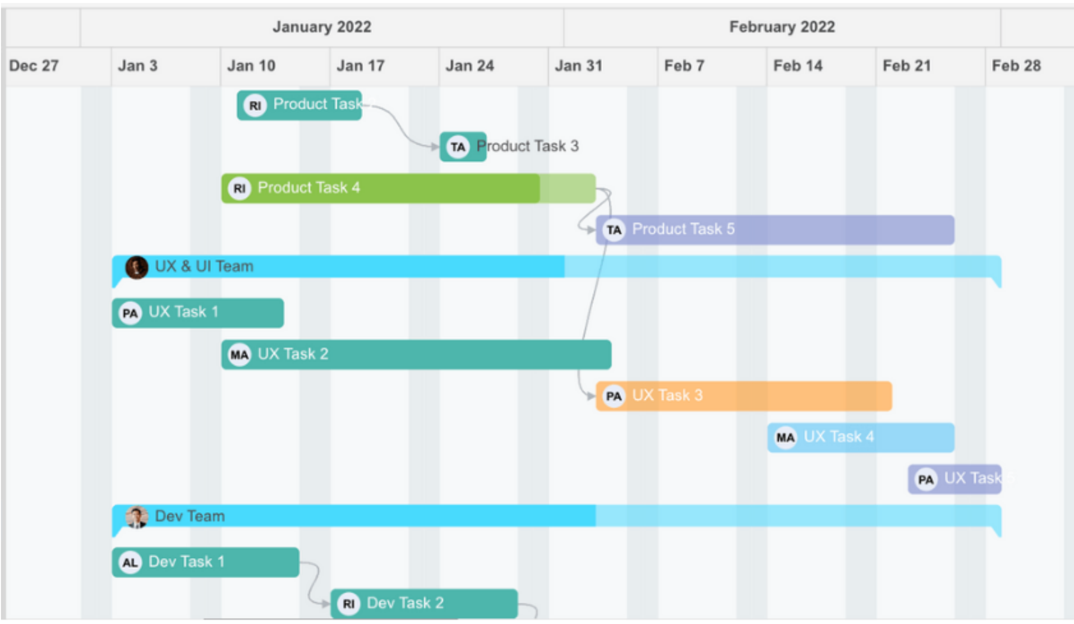

Figure 18 Project Management Gantt Chart Sample (*A Complete Guide to Gantt Charts*, n.d.)

That method was the project gantt chart, and it can be used to plan and define project tasks and their sequence. An example of a project management gantt chart is shared in Figure 18, showing multi-lined development life cycles throughout the project. It can present individual yet dependent tasks throughout the project schedule. Therefore, the study in Figure 18 will not be further developed in this thesis.

5.2.3.3 Methods and Tools Used for Meeting Packaging Constraints

During the procedure of meeting packaging constraints, it can involve multiple methods and even tools to design systems appropriately. Such methods or tools can be classified as mock-ups, human-models, system or sub-system analyses, and commercial or military standards.

They may act as a supervisor and a guide about how the system should behave; therefore, they directly affect the meeting packaging constraints practices. These methods are, generally, adopted by systems engineers, industrial designers, and other related project members.

Analyses are frequently substantiated in defense industry companies. Especially at early phases of a project, team members usually rely on the results of those analyses and take an action plan for the upcoming phases accordingly. If analyses run accurately, their outputs can benefit projects in the form of shorter schedule, better requirements management and planning and lower the number of design iterations that could caused by the ill-constructed inputs from diverged results from the real-life.

Moreover, the recent technological tool, VR is started to be implemented in meeting packaging constraints of projects. They are showing great potential in meeting packaging constraints, as mentioned in the field study and literature review. Participants mentioned that VR is easy to generate because system's design is already processed in CAD environments; thus, advantages of VR could easily be obtained. Some advantages that industrial designers use is that the VR models can be built in 1:1 ratio. Therefore, as participants gave the example, anyone in the VR could experience the system as if it is fully manufactured and constructed. After VR environment is generated, industrial designers and systems engineers can assess necessary ergonomics, maneuverability and other necessary analysis in the environment and design accordingly to meet packaging constraints. All in all, this section covered its research question with the support from both literature and field study.

5.2.4 (Role of Team Members) What are the roles of project team members in meeting packaging constraints in various phases of the project process?

There are multiple teams and many more team members involved in a defense industry project. If we can recall the Figure 7, and the findings of the field study, we can classify project teams in five main groups. Every member's role is crucial in a project and we acknowledge their contributions. In this thesis; however, we will be only focusing on systems engineers' and industrial designers' roles and contributions throughout the project timeline. Industrial designers' involvement in meeting packaging constraints will be presented in the next section 4.2.3 Industrial Designers' Role as System Co-architects with the dominant conclusions from the field study.

Systems engineers' main roles can be distinguished as requirements management, configuration management and overall system's 3D model ownership. As concluded from the literature review and field study, the requirements management is one of the single-most crucial tasks of systems engineers. In order to successfully develop a system that satisfies all requirements, objectives, goals, and needs, interdisciplinary systems engineers must manage multiple disciplines' requirements set to specify the system and ensure an efficient project process for every team member. Therefore, they execute interdisciplinary multi-objective design optimization and they are the system's architects. They try to find the best system configuration that delivers the optimal system performance while distributing optimal requirements sets for project teams.

However, their role is not completed only with requirements management. They are also responsible to manage and control of the verification and validation of the system. At this phase, they validate whether packaging constraints, or any other requirements, are satisfied accordingly or not.

5.2.5 (Role of Team Members) What is the involvement of industrial designers as project team members in meeting packaging constraints in the project process?

As we can conclude from the field studies, industrial designers are at the intersection of being designers and decision-makers for projects. They receive and give feedback to project team members and systems engineers. These roles make industrial designers differentiate from other team members and perform as a co-architect of the system. While meeting packaging constraints, they are working and optimizing on the details of the system's geometric limitations, its outside appearance, the interior design where the crew will be positioned, and how the equipment will be placed by considering both visual and ergonomic controls.

Most significantly, their role shines when they work in iterations with the customers or end-users. A quotation from Participant 1 perfectly explains the significance of industrial designers in defense industry projects: *a tank with incredible firepower is useless if no crew can use it properly*. Therefore, industrial designers' most significant influence comes from their interaction with people in meeting packaging constraints; because no-other team member has this role, at least from the conclusions of the literature review and field study.

5.2.6 (Challenges) What are the major challenges in the project process towards meeting packaging constraints?

As concluded from the findings of Paticipant 3, around the 1990's industrial designers could not find their rightful place and role in Turkish defense industry companies. Industrial designers were considered only as people who could do visually appealing stuff. They were probably not able to contribute their potential to projects. Unfortunately, literature review findings are lacking to conclude any supportive or contrary argument about this issue. Therefore, anyone who would like to use this information should take that into consideration.

Over the time, as determined from the findings, industrial designers got more attention from the project managers and engineers most probably with their works and intrapreneurship. As a result, industrial designers manage to overcome the resistance of recognition by other more *settled disciplines*, like electronics or mechanical. Then, they started to be involved in projects at early phases with a wider responsibility spectrum. Additionally, from the given information in findings, this resistance had occurred to another recently emerged discipline in the defense industry company. On the other hand, Harvard Business Review mentioned in one of its studies that; corporate firm managers usually do not recognize emerging variations and also prevents people from recognizing fresh opportunities. The first recognition of a potential opportunity often refers to a situation where a business performs better than anticipated (Drucker, 2002), just like the Participant 3 and her team did; " (…) **they found the designer much more functional**". Therefore, as deducted from the literature, unless emerging disciplines prove their potential and perform better than expected, they would be recognized. However, there may be some more fundamental reasons and drivers in behind this initial resistance because, as mentioned, very similar patterns repeat itself.

Such recognition is crucial because, otherwise, systems engineers or any other work-related team member would not give them sufficient attention and information. In those cases, industrial designers' work may become disruptive and time pressured due to late notifications.

Moreover, in the findings, it is founded that project schedule can be a challenge in meeting packaging constraints, because properly satisfying every requirement and constraint may take some time. If the allocated time period falls too short; then its pressure over team members can be a bit overwhelming. They may need to work on things that they should not do. Additionally, studies in literature have concluded that pressure usually impairs performance and efficiencies of project team members. Eventhough team members can meet deadlines, it is usually happening in exchance of quality (Moore & Tenney, 2012). Therefore, optimally meeting requirements and packaging constraints may necessitates a well-planned project schedule.

5.2.7 (Areas of Improvement) What are the potential areas for improvement in the project process toward meeting packaging constraints?

As concluded from the findings of both field study and literature review, collaboration in establishing and meeting requirements' practices are crucial for the project management and team members. In the current situation, customers and systems engineers define the concept requirements set in the project charter; however, this may cause problems and delays in the project as it does not include direct involvement of team members' perspectives.

Another aspect could be the project scheduling, as mentioned in both literature and field study. Allocating insufficient amount of time for task could result in pressure on team members and decreased quality of design. Therefore, project scheduling can be an area of improvement towards meeting packaging constraints, or other requirements, of a project.

Furthermore, VR aided design and analysis practices pose some praiseworthy potentials. Thanks to VR's fully virtual identity, any design that worked in any CAD environment can easily be transferred to VR environment and necessary analyses or modifications can be completed. Since system models can be transferred in 1:1 ratio, industrial designers and systems engineers can get the benefit of experiencing the near-real-life situations.

As mentioned in the literature and in interviews, VR aided design and analysis practices have started to be implemented in defense industry project. One of the main drivers of this could be mentioned as the advancements in technology (Zimmermann, 2008). Hence, VR enables designers of the project to evaluate systems before any mock-up or manufactured parts.

However, due to the inaccuracies of analyses and as VR still being under development, mock-ups are continuing to be compulsory step for the system integration, verification, and qualification phases of projects in defense industry companies. Mock-ups are noted to be reliable and simple method; nonetheless, they may cost money, time and they are mostly less iteration friendly. Therefore, VR and its sub-division of VR aided design and analysis practices are noted to be an area of improvement and its enhancements mentioned be followed closely.

5.3 Limitations of the Study and Recommendations for Future Research

Due to the scope of this study, defense industry companies require a high level of confidentiality for their project details and company infrastructure. This could have created a concern for the participants because they wanted their names and project-specific details to be masked. This concern may have caused some participants to keep valuable information secluded during the field study. Therefore, interviewing defense industry company engineers and industrial designers may have created a limitation in accessing participants' knowledge and experience.

Seven out of eight exploratory study participants were from the same company; so, naturally, the same company employees may be needed to follow the same procedures in projects. Hence, they described very similar practices. Furthermore, as the researcher of this thesis, I have been exposed to the practices of my company, in the past three years, which could have caused some proclivities toward the project processes and practices in meeting packaging constraints.

The recommendations for future research can involve a more comprehensive field study with various defense industry companies and more participants. This addition may allow researchers to extract more findings and support the existing findings with more cases.

Moreover, in future studies, not only packaging constraints but also other constraints and requirements can be studied; hence, their multi-objective optimization practices can uncover the practices in meeting and maturing them.

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APPENDICES

A. METU AERC Field Study Approval

UYGULAMALI ETİK ARAŞTIRMA MERKEZİ
APPLIED ETHICS RESEARCH CENTER

ORTA DOĞU TEKNİK ÜNİVERSİTESİ
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20 MAYIS 2022

Konu : Değerlendirme Sonucu

Gönderen: ODTÜ İnsan Araştırmaları Etik Kurulu (İAEK)

İlgi : İnsan Araştırmaları Etik Kurulu Başvurusu

Sayın Fatma KORKUT

Danışmanlığını yürüttüğünüz Kadir Erdem Karaca'nın "Savunma Sanayisinde Paketleme Kısıtlarının Karşılanması: Mühendisler ile Endüstriyel Tasarımcılar Arasındaki İş Birliğinin Algılanan Yararları" başlıklı araştırması İnsan Araştırmaları Etik Kurulu tarafından uygun görülmüş ve **0283-ODTUİAEK-2022** protokol numarası ile onaylanmıştır.

Saygılarımızla bilgilerinize sunarız.

Prof.Dr. Mine MISIRLISOY
İAEK Başkan

B. Consent Form

Ocak 2014

ARAŞTIRMAYA GÖNÜLLÜ KATILIM FORMU

Bu araştırma, ODTÜ Endüstriyel Tasarım Bölümü öğretim elemanlarından Doç. Dr. Fatma Korkut danışmanlığında yürütülen yüksek lisans tezi kapsamında Kadir Erdem Karaca (erdem.karaca@metu.edu.tr) tarafından gerçekleştirilmektedir. Bu form sizi araştırma koşulları hakkında bilgilendirmek için hazırlanmıştır.

Çalışmanın Amacı Nedir?

Çalışmanın amacı, savunma sanayinde proje süreçlerinde paketleme kısıtlarının nasıl ve kimler tarafından oluşturulduğunu ve karşılandığını, endüstriyel tasarımcıların bu süreçteki rollerini araştırmaktadır.

Bize Nasıl Yardımcı Olmanızı İsteyeceğiz?

Çalışmaya katılım gönüllülük esasına dayanmaktadır. Elde edilen veriler bilimsel amaçlarla kullanılacaktır. Yapacağımız görüşmede size araştırma konumla ilgili sorular soracağım. Bu çalışmaya katılım ortalama olarak 60 dakika sürmektedir. Konuştuklarımızı daha sonra tam olarak hatırlayabilmek için görüşmemizi kaydedeceğim.

Sizden Topladığımız Bilgileri Nasıl Kullanacağız?

Cevaplarınız araştırmacılar tarafından değerlendirilecektir. Katılımcılardan elde edilecek bilgiler değerlendirilecek ve bilimsel yayımlarda kullanılacaktır. Kurum ve kişi adları kesinlikle maskelenecektir.

Katılımınızla ilgili bilmeniz gerekenler:

Görüşme, katılımcıları rahatsız edebilecek sorular içermemektedir. Bununla birlikte, görüşme sırasında herhangi bir nedenle kendinizi rahatsız hissederseniz, gerekçe belirtmeden istediğiniz zaman görüşmeyi durdurabilirsiniz.

Araştırmayla ilgili daha fazla bilgi almak isterseniz:

Görüşme sonunda, bu çalışmayla ilgili sorularınız cevaplanacaktır. Bu çalışmaya katıldığınız için şimdiden teşekkür ederiz. Çalışma hakkında daha fazla bilgi almak için Endüstriyel Tasarım Bölümü öğretim üyelerinden Doç. Dr. Fatma Korkut (e-posta: korkut@metu.edu.tr) ya da araştırmacı Kadir Erdem Karaca (e-posta: erdem.karaca@metu.edu.tr) ile iletişim kurabilirsiniz.

Yukarıdaki bilgileri okudum ve bu çalışmaya tamamen gönüllü olarak katılıyorum.

(Formu doldurup imzaladıktan sonra uygulayıcıya geri veriniz).

İsim Soyisim	Tarih	İmza
	---/----/-----	

C. MAXQDA Screen View

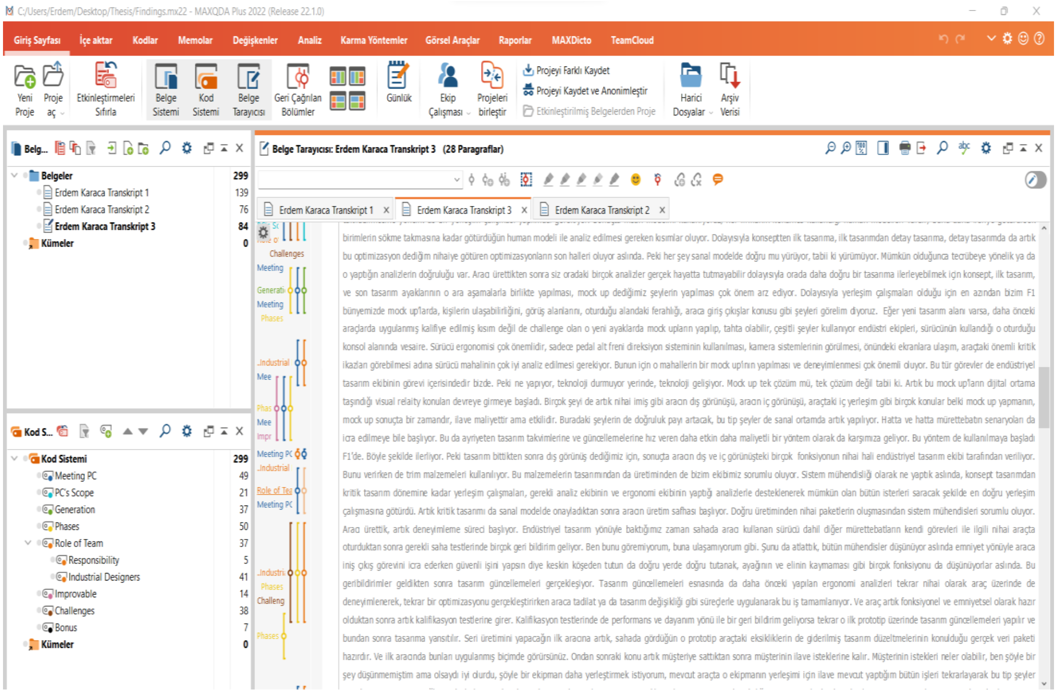

Figure 19 MAXQDA Screen View

D. Audacity Software

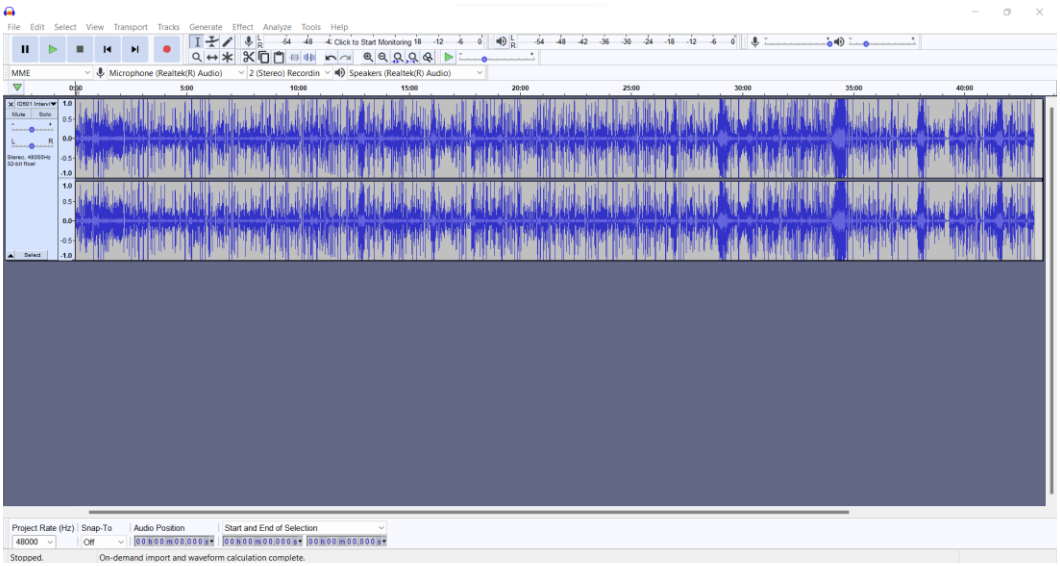

Figure 20 Audacity User Interface

E. MAXQDA Analysis Export

B	C	D	E	F
Belge adı	Kod	Bölüm	Alan	Kapsam %
Erdem Karaca Transkript 1	Role of Team	Tasarım sürecinin başında konsept tasarımından itibaren çalışmaya başlıyorum.	77	0,30
Erdem Karaca Transkript 1	Role of Team\Industrial Designers	Tasarım sürecinin başında konsept tasarımından itibaren çalışmaya başlıyorum.	77	0,30
Erdem Karaca Transkript 1	Role of Team	birincisi iç trimleri yapan arkadaşlarımız var, konstrüktif ağırlıklı çalışan arkadaşlarımız.	93	0,36
Erdem Karaca Transkript 1	Role of Team\Responsibility	##	406	1,59
Erdem Karaca Transkript 1	Role of Team\Industrial Designers	##	406	1,59
Erdem Karaca Transkript 1	Meeting PC	Bunların dışında üçüncü bir yaklaşımımız var. Kullanıcı deneyimi ve ergonomi analizleri	87	0,34
Erdem Karaca Transkript 1	Role of Team	##	341	1,33
Erdem Karaca Transkript 1	Role of Team\Industrial Designers	##	341	1,33
Erdem Karaca Transkript 1	Role of Team\Responsibility	Bunun dışında da telsizdi, aküydü, mürettebatın etkileşimde olduğu torpido yerleşimi gibi fonksiyonel yerleşimleri bir	136	0,53
Erdem Karaca Transkript 1	Role of Team\Responsibility	Diğer tarafta da dış görselde ve ergonomi çalışmalarında da diğer ekiplere destek oluyoruz,	91	0,36
Erdem Karaca Transkript 1	Meeting PC	alt sistemlerin dışında bir de sistem mühendisliği ile paralel çalışıyoruz.	75	0,29
Erdem Karaca Transkript 1	Role of Team	alt sistemlerin dışında bir de sistem mühendisliği ile paralel çalışıyoruz.	75	0,29
Erdem Karaca Transkript 1	Role of Team	Çünkü dışarıdaki ekipmanların mesela farların yerleşimi için sistem mühendisliğini yönlendirici oluyoruz. Veya yaptığımız ergonomi analizleri ile diğer alt veya yapısal sistemlerin tasarımlarına yön veriyoruz.	209	0,82
Erdem Karaca Transkript 1	Role of Team\Industrial Designers	Çünkü dışarıdaki ekipmanların mesela farların yerleşimi için sistem mühendisliğini yönlendirici oluyoruz. Veya yaptığımız ergonomi analizleri ile diğer alt veya yapısal sistemlerin tasarımlarına yön veriyoruz.	209	0,82
Erdem Karaca Transkript 1	Role of Team	Hem konsept tasarım yapıyoruz hem de yaptığımız tasarımların detayına kadar girerek üretilmesini sağlayacak kadar detaylandırıyoruz.	132	0,52
Erdem Karaca Transkript 1	Role of Team\Industrial Designers	Hem konsept tasarım yapıyoruz hem de yaptığımız tasarımların detayına kadar girerek üretilmesini sağlayacak kadar detaylandırıyoruz.	132	0,52
Erdem Karaca Transkript 1	Meeting PC	##	374	1,46
Erdem Karaca Transkript 1	Role of Team	##	374	1,46
Erdem Karaca Transkript 1	Role of Team\Industrial Designers	##	374	1,46
Erdem Karaca Transkript 1	Role of Team	Ama biz sistem tasarımı yapıyoruz aslında.	42	0,16
Erdem Karaca Transkript 1	Role of Team\Industrial Designers	Ama biz sistem tasarımı yapıyoruz aslında.	42	0,16
Erdem Karaca Transkript 1	Role of Team\Responsibility	AA mesela bir sistem tasarımıdır. Yani motoruyla her şeyiyle tasarımına karar verdiğimiz bir unsurdur.	102	0,40
Erdem Karaca Transkript 1	Role of Team	Bir şeyin sadece bir kısmını çalışmadık hiç, bütün aracı düşünerek çalışıyoruz o zaman da bir sisteme giriyor. Mesela denizaltı bir sistem tasarımıdır, uçak bir sistem tasarımıdır gibi	185	0,72

Figure 21 MAXQDA Exported Analysis on Excel

Cells with “########” could not viewed in main screens because they are too long to display, but they can be opened by clicking on them.

F. Interview Guide (Turkish)

1. Bölüm

1.1 Firma R'daki sorumluluklarınızı anlatır mısınız?

1.2 Şimdiye kadar ne tür projelerde çalıştınız?

1.3 Firma R'daki proje süreçleriniz nasıl işliyor?

1.4 Proje ekipleri genellikle kimlerden oluşuyor?

1.5 Proje gereksinimleri ve kısıtları genellikle hangi başlıklardan oluşuyor?

1.5.1 "Paketleme kısıtları" sizin için ne anlama geliyor, açıklar mısınız?

(Paketleme kısıtları: Proje ekibinin müdahale edebileceği uzamsal sınırları tanımlayan bir dizi gereksinimdir.)

1.5.2 Firma R'da bu tür kısıtları nasıl adlandırıyorsunuz, genellikle hangi terimleri kullanıyorsunuz? (Kimi firmalar "envelop" veya "hacim yönetimi" terimlerini kullanıyor.)

1.6 Görüşmemizin bundan sonraki bölümünü daha önce kararlaştırdığımız (Projenin Başlığı) projesi üzerinden sürdürebilir miyiz?

2. Projenin Detayları

2.1 Öncelikle projeyi ve amacını anlatır mısınız?

2.2 Proje toplam ne kadar sürdü, hangi tarihte başladı?

2.3 Proje hangi aşamalardan oluşuyordu?

2.4 Bu projenin ekip üyeleri kimlerdi ve görevleri nelerdi?

2.5 Geliştireceğiniz çözümlerin ne tür gereksinimleri karşılaması bekleniyordu?

2.6 Bu projede paketleme kısıtlarınız nelerdi?

2.7 Proje gereksinimlerini ve paketleme kısıtlarını kimler, hangi aşamada, nasıl oluşturdu?

2.8 Proje gereksinimleri ve paketleme kısıtları oluşturulurken dikkat edilen ölçütler nelerdi?

2.9 Proje gereksinimleri ve paketleme kısıtları oluşturulurken (endüstriyel tasarımcı/mekanik tasarım mühendisi) olarak siz sürece dahil edildiniz mi? Ayrıntılı bir şekilde anlatır mısınız?

3. Paketleme Kısıtlarının Çözülmesi

3.1 Proje gereksinimleri ve paketleme kısıtları oluşturulduktan sonra ne gibi çalışmalar yaptınız? Benchmarking (yani mevcut çözümlerin karşılaştırılması), fizibilite/performans çalışması, üretilebilirlik ve benzeri.

3.2 Bu projede paketleme yönetimini nasıl yaptınız?

3.3 Bu projede paketleme kısıtlarına uygun bir tasarım geliştirmek için hangi yöntemleri ve yaklaşımları kullandınız?

3.4 Paketleme kısıtlarına yönelik çalışmalarda hangi ekip üyeleriyle veya uzmanlarla daha aktif çalıştınız?

3.5 Proje süresince paketleme kısıtlarınız güncellendi mi?

3.6 Bu güncellemeler projenin hangi aşamalarında gerçekleşti?

3.7 Bu güncellemeler kimler tarafından, hangi amaçlarla yapıldı?

3.8 Proje sürecinde paketleme kısıtları açısından karşılaşılan en önemli güçlükler nelerdi?

4. Proje Yönetim Süreçleri

4.1 Proje süresince farklı disiplinlerden ekip üyeleri paketleme kısıtlarına yönelik olarak birlikte çalıştılar mı? Projenin hangi aşamalarında, nasıl çalıştılar? (Sayısal modeller, fiziksel modeller veya prototip üzerinden; kullanıcı araştırması veya kullanıcı testleri sürecinde ve benzeri.)

4.2 Sizce bu projede paketleme kısıtlarını karşılamak açısından endüstriyel tasarımcı(lar)ın konumu ve etkinliği nasıldı?

4.3 Geriye dönüp baktığınızda bu proje sürecinde paketleme kısıtlarını karşılamak açısından neler iyileştirilebilirdi? Önerileriniz var mı?

5. Son Sorular

5.1 Proje süreçlerinde paketleme kısıtlarını karşılamak için hangi açılardan, hangi aşamalarda, ne gibi önlemler alınabilir?

5.2 Proje sürecine ve paketleme kısıtlarına ilişkin üzerinde durmadığımız, eksik kaldığını düşündüğünüz bir konu var mı?

5.3 Bu konuya ilişkin belirtmek veya eklemek istediğiniz herhangi bir şey var mı?

6. Katılımcıya ait Kişisel Bilgiler

6.1 Doğum tarihiniz

6.2 Lisans eğitiminizi hangi üniversitede, hangi alanda ve ne zaman tamamladınız?

6.3 Yüksek lisans veya doktora yaptınız mı?

6.4 Çalışma hayatınız boyunca hangi firmalarda, pozisyonlarda ve departmanlarda çalıştınız?

G. MAXQDA Thematic Code Mapping

Kod Sistemi	Meeting PC	PC's Scope	Generation	Phases	Role of Team	Responsibility	Industrial Designers	Improvable	Challenges	Bonus	Açımlamalar
Meeting PC		13	20	26	16	2	16	4	24	1	1
PC's Scope	13		13	6	6	1	5		13	3	1
Generation	20	13		21	9		10	3	16	2	
Phases	26	6	21		12		13	5	21		
Role of Team	16	6	9	12			9	2	9	1	1
Responsibility	2	1					1		1		
Industrial Designers	16	5	10	13	9	1		3	15	2	
Improvable	4		3	5	2		3		5	1	
Challenges	24	13	16	21	9	1	15	5		2	1
Bonus	1	3	2		1		2	1	2		
Açımlamalar	1	1			1				1		

Figure 22 Code Usage Frequency

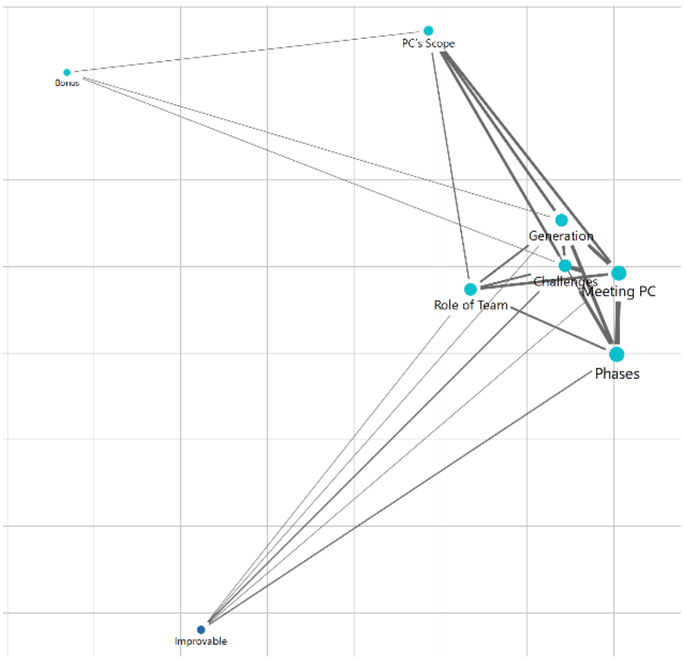

Figure 23 Code Relation Map

H. Quotations of Participants in Turkish

(1) O dönemde tasarımcı doğrudan grafik tasarımcı gibi tanımlanıyordu, ben oraya girdiğimde bana ilk iş olarak çok kalın bir dosya verdiler, etiket nasıl yapılır dosyası.

(2) Böyle bir endüstriyel tasarımcı tasarım için ne yapar sorusundan projede ne kadar yer almalı, hangi aşamadan itibaren yer almalı gibi bir yere geldi. Benden daha sonra dahil olan arkadaşımız vardı onunla birlikte toplantılara projenin başından itibaren girebilmek için toplantı bastığımızı biliyorum. Çünkü olaya şöyle bakıyorlardı, tasarımcı dışın kılıfını yapacaksa hiç olmazsa o aşamaya geldiğinde, elektronikçi kartlarını yapacak, makineci zarfın kalınlığını vesaire belirleyecek, biz de alacağız üstüne tuş varsa tuşun üzerindeki şeylere basacağız falan şeklinde.

(3) Biz toplantıları ve proje yöneticilerini zorlaya zorlaya tasarımcı bu işe baştan girer aşamasına getirdik. Elektronik kartların yerleşimi dahil olmak üzere, iki kartı alt alta mı koyacaksınız dikine mi koyacaksınız kararını vermeniz bile sonuçta paketin tarzını değiştirecektir aşamasına getirdik. Ama ne olursa olsun şöyle şeyler oluyor, sürekli bizim işimizi mi elimizden alıyorlar gibi bir tavırla karşılaşıyorsunuz.

(4) Çok yıllar sonra malzeme mühendisleri işin içine girmeye başladı, onların da asıl mesleki alanı bulunamadı o dönemde olmadığı için. Kimya mühendisleri bu işe bakar mı oldu. Her şey kendi branşını bulana kadar baya bir zaman oldu.

(5) O aşamada (gereksinim tanımlama aşamaları) projeye dahil olmamız gerektiğini ispatladıktan sonra her şey çok kolaylaştı. Gereksinimlerin daha ilk elden duyulması, kullanıcıyla iletişim kurmak daha kolaylaştı. Bizi de askerlerle görüşmeye götürebilir oldular, o anlamda daha iyi oldu.

(6) Onun için bizim işe aldığımız öğrencimiz sayılabilecek pek çok kişi artık bilgisayar başına oturup, makineci yanında olmadan o modeli ortaya çıkarıp gösterebilir durumdaydı. Bu da onların projenin daha erken safhalarında işin içine girmesini kolaylaştırdı. Çünkü yanında bir tane de makine mühendisinin zamanını

heba etmiyor. Ne istiyorsa ne gösterilecekse üç boyutlu, onlar açısından çok daha anlaşılır elle tutulur bir şekilde önlerine koyabiliyor, onlar derken yöneticilerden bahsediyorum. Dolayısıyla tasarımcıyı çok daha işlevsel buldular. O dönem Company M'nin da projeler bazında bölündüğü bir dönem, onun için her ekipte tasarımcı olsun, her proje grubuna tasarımcı da girsin denildi, çok kolaylaştı işler. Çok da kişi aldılar tasarımcı olarak. Dolayısıyla proje süreçleri nasıl değişti çok net bir şey söyleyemiyorum ama tasarımcının yeri değişti.

(7) Tasarımcının kapasitesinin çok daha fazla olduğunu ve onlara çok daha yararlı olabileceğini fark ettiler. İlk yıllardaydı bizi iki kişiyiz odaya koymuşlardı. Dışarda askeri bir ekip gezdiriyor yöneticiler ve bizim odanın önünden geçerken de "Burada da artistlerimiz çalışıyor" dedi, çok ilginçtir gezdirilen asker "Endüstriyel tasarımcılardan mı bahsediyorsunuz" dedi, gözlerimiz dolmuştu. Bunun kavgasını çok yapmak zorunda kaldım; "bana verdiğiniz paranın karşılığını almıyorsunuz ben şunu da yapabilirim" diye tartışmasını çok yaptık. Değişim var yani.

(8) Makineci ile başına oturursunuz, gerçekten büyük bir savaş vererek; şurası şöyle olsun, burası böyle olsun şeklinde, öncelikle kartları birer kara kutu gibi ele alıp önce onları yerleştirirsiniz sonra dış kılıf ne olsun noktasına gelir. Ergonomi konusunda askeriyenin de bizim yöneticilerimizin de tarzı şuydu; askerdir yapar, sen nasıl yaparsan yap kullanır. Onun için bayağı büyük kütleli şeyler çıkabiliyordu.

(9) Başlarda sadece ölçüsü şu, al ve yap düzeyindeydi. Daha sonra bunun doğru olup olmadığını, üzerinde oynama yapılıp yapılmayacağını anlayabilmek için işin elektronik tarafına da mekanik tarafına da bilgi sahibi olmak zorunda kalıyorsunuz. Tasarımcı olarak sözünüzü dinletebilmek için onu öğrenmemiz gerekiyor. Hatta alternatiflerini öğrenip, "bak dışarıda şunu şöyle yapmışlar demek ki yapılabiliyor" diyerek ikna etmemiz gerekiyor. Onlar ister istemez üzerindeki en yüksek şeye göre o kara kutunun ölçüsünü veriyor. Ancak belki de o tek noktada öyle ve yanına bir şey daha sıkıştırabileceğim. Onun için ister istemez "kartın bütün görüntüsünü ver bana" diye zorlayabiliyorsunuz. Yani kara kutu olmaktan çıkmak zorunda kalıyor.

(10) Örneğin lityum iyon pillere geçişin yeni zamanlarından söz ediyorum. O zamanlar pilin cihazın gereksinimine göre paketlenmesi, dış kılıfının da onu bir jel gibi kabul ederek yapılmaya başlaması tam o sıralara denk geliyor. Ondan önce bayağı kütlesel pillerdi, onları bir yere sokuşturup kapakla da kapatmaya çalışırdık. Bakın telefonlarda böyle olmaya başladı belki biz de pilleri paketleyebiliriz diyorduk. Çünkü onlar da ister istemez lityum iyon yapacak pil üreticisi arıyorlar, yok ki. Ya da LCD ekranlara yeni geçmişsiniz, onların her boyu yok, üreticisi tüm dünya da bir ya da iki tane, dışarda hangi firma yapıyorsa o da onu kullanıyor, siz de onu kullanmak zorundasınız. Yani kısıtları öğrenmek zorundasınız, piyasada ne var ne yok, ben hangisini kullanayım, iyi yapmak istiyorsanız öğrenmek zorundasınız.

(11) Bazı güncellemeler yaşandı. Malzeme çok değişti. Piller inceldi, magnezyumdur titanyumdur, kompozit gibi malzemeler işin içine girdi dolayısıyla paket küçüldü. Elektronikte büyük değişimler oldu. (...) malzeme çok küçüldü, kart küçüldü dolayısıyla.

(12) Bu bölmede bir insanın, doktorun, hastanın veya mürettebatın beraber çalışamayacağının ilk sinyalini biz verdik. Öncelikle CAD ortamındaki analizlerimizle mürettebatı yerleştirerek orada sıkıntı olduğunu gördük. Sonra bu sıkıntıyı sistem mühendisleri ile paylaşmak için bütün modeli sanal gerçekliğe yükledik. Sanal gerçeklikte zaten 1:1 zaten aracın içinde gibi oluyorsunuz.

(13) Projeye başladığımızda olabildiğince arkada mürettebat kısmında silüeti düşük olsun istedik, bu bir beka isteri. Silüeti düşük araç yapmak, bu bir ister, diğer bir ister de ergonomik olarak içeride hareket edebilmek. Bu sistemin amacından dolayı sıkış tepiş olamaz. Dolayısı ile sürece başladığımızda beka isterine göre şekillenen araç yüksekliği, sürecin devamında bizim ekibin katkılarıyla tavanı yükseltilmesi ve oradaki hacme sığma şekliyle aracı yükseltmeye doğru gitti.

(14) Burada o işin yapılamayacağını görüp üst yönetimi çağırdık, revizyon yapılması gerekliliğini anlattık, onlar da hemfikir oldular ve revizyon yapıldı.

(Üst yönetim onayı gerekli miydi?)Evet gerekli, çünkü verdiğimiz karar birçok başka kararı etkiliyor. Aracı ağırlaştırıyorsunuz, zırhını çoğaltıyorsunuz, pahalılandırıyorsunuz, yapılmış bir aracı kesip biçiyorsunuz, dolayısıyla bu tip süreçlerde bir sıkıntı gördüğümüzde ortaklaşa bir sıkıntı var diyerek üst yönetimi dahil ediyoruz ve karar alınmasına destek oluyoruz.

(15) Biz aslında işi şey yapmak tarafında değil buraya şöyle sığabiliriz şeklinde yaklaşıyoruz çoğu projede. Mesela bir şoför bölmesinin tavanı çok düşükse diyoruz ki koltuğu yatay pozisyonda kullanırsak, bakış şeylerini de buraya koyarsak bu bölmeye sığarız. Öncelikli hedefimiz bölmeye sığmak oluyor. Ama sığılamayacağı bir durum varsa sığılamadığını söylüyoruz.

(16) Burada paketlemede neyin nerede olması gerektiğini sistem mühendisliği çalışırken detay tasarımcılara bunu burada istiyorum şeklinde yaklaşıyor, senin alanın bu kadar buna sığmanı istiyorum diyor. Ama bazı sistemler zaten hazır sistemler olduğu için onlar yerleşiyor. Burada karar verici sistem mühendisliği.

(17) Bizde hayat şöyle başlar, bir müşteri isteriyle başlar, ortada bir müşteri yoksa potansiyel müşteri isterlerini ortaya koyduğumuz benchmarklar yapar, bu benchmarklar sayesinde bir gereksinim seti oluşturulur. Bu projede ne yapmak istiyoruz. Bu projede nihaide üretilecek aracın fonksiyonel, performans, çevresel, elektromanyetik, insan araç uyumu gibi birçok faktörü düşünerek bir gereksinim seti hazırlanır. Daha sonra bir tasarım süreci başlar.

(18) Sistem mühendisleri bu işe tanımlandı.

(19) Burada kullanıcılarla da tabii ki iletişime geçiliyor. Ben mesela sağlık personelinin gelip tasarımı incelediği ve şunun şurada olması gerekir dediği noktalar vardı.

(20) Sonuçta insan modelini kullanıyoruz, her firmanın kendince kullandığı human modelleri vardır. Peki her şey sanal modelde doğru mu yürüyor, tabii ki yürümüyor. Mümkün olduğunca tecrübeye yönelik ya da o yaptığın analizlerin doğruluğu var. Aracı ürettikten sonra siz oradaki birçok analizler gerçek hayatta tutmayabilir

dolayısıyla orada daha doğru bir tasarıma ilerleyebilmek için konsept, ilk tasarım, ve son tasarım ayaklarının o ara aşamalarla birlikte yapılması, mock-up dediğimiz şeylerin yapılması çok önem arz ediyor.

(21) Bu analizler yapılırken ortalama bir insana göre yapma konusu da var. Biz bunları %5-%50-%95 şeklinde de tanımlıyoruz. Dolayısıyla söz konusu görevlerin minimum kayıpla olacak şekilde %5 ve %95 personelle yapılacak şekilde analizlerin optimizasyonu da endüstriyel tasarımın içindedir.

(22) Bu projede mürettebatın ergonomisi çok önemliydi, kullanım alanlarıyla ilgili çok güncellemeler yapıldı. En önemli güçlük bence içerideki mürettebatın hareket alanını iyileştirmek için yapının değişmesi gerektiği durumlardı.

(23) Tasarımı yaparken gerek görsel, gerek ergonomik kontrolleri göz önünde bulundurarak aracın eni, boyu, yüksekliği ne olacaktan başlayıp, dışarıda nasıl görünecek, içerideki mürettebat nasıl konumlanacak, hangi ekipmanlar nasıl yerleşecek detaylarını çalışıyoruz.

(24) Bu cihaz çok ısınan bir şeydir ısındığı için ısı atımlarından dolayı yanına ne kadarlık bir cihaz yerleştirmemen gerektiği, duvarlara ne kadar yaklaşacağın bellidir.

(25) Dışarıdaki ekipmanların mesela farların yerleşimi için sistem mühendisliğini yönlendirici oluyoruz. (…) yaptığımız ergonomi analizleri ile diğer alt veya yapısal sistemlerin tasarımlarına yön veriyoruz.

(26) Burada mürettebatın ergonomisi çok önemliydi, kullanım kısmıyla ilgili çok güncellendi.

(27) Kullanıcıyı düşünmek zorundayız. Kullanıcının kullanamadığı muhteşem bir silahın hiçbir anlamı yok. Çok performanslı 1500 beygirlik saatte 60 ya da 100 km yapan bir tankı eğer o şoför kullanamıyorsa tankın o kadar güce sahip olmasının bir anlamı yok, ya da 120 milim topu vardır çok güzel hedefi vardır ama o topa mühimmat yükleyemiyorsa çok da anlamlı değil. Bizim en büyük etkimiz insanla olan etkileşimden kaynaklanıyor.

(28) Paketleme kısıtları nasıl oluşturuluyor, özellikle bir endüstriyel tasarımcının çalışacağı bir alanda paketleme kısıtları nedir, endüstriyel tasarımcılar nasıl dahil ediliyor ve (paketleme kısıtlarında) ne gibi ölçütler belirleniyor?

(29) Bizde bizim endüstriyel tasarım ekibinde paketlemeye yönelik bir çalışma olduğunu çok bilmiyorum, görmedim.

(30) Paketlemeyi biz şöyle anlıyoruz, sistem seviyesinde paketleme, eğer ben bunu bir yerden bir yere taşıyacaksam biz buna taşınabilirlik diyoruz ve taşınabilirlik analizi adı altında yapıyoruz. Sonuçta ben bu sistemi bir yerden bir yere sevk edeceğim, sevk ederken havayolu, karayolu, denizyolu, demiryolu kullanacağım ve oradaki gabarilere uymak zorundayım. Aracın taşınabilirlik kısmı ile uğraştığımız için daha çok bizim sistem mühendisliğinde gabarilere göre yerleşim ve hacim çalışmaları yapılırken bu işi yapmakta.

(31) Kendi uygulamalarımızda endüstriyel tasarım ekibinin şu ana kadar paketlemeye yönelik bir konuya dahil olduğunu hatırlayamadım.

(32) Biz paketleme kısıtları dediğinizde burada sistem olduğu için sistemin paketlenmesini taşınabilirlik olarak algılıyorum. Bizim taşınabilirlikte gabarilerimiz çok net olduğu için o gabariye sığacak şekilde yerleşim yapıyorsunuz.

(33) İkinci kısım ki en önemli kısım, çok fazla iterasyonun döndüğü kısım insanla olan kısımdır.

(34) Bu süreçte bizim ekibimiz baştan gereksinimleri okuyup, bu gereksinimlere göre tasarım yapıp, diğer sistem mühendisliği ile, alt sistemlerle, yapısal tasarımla, elektrik elektronik tasarımıyla kendi isterlerini karşılaştırıyor hem feedback veriyor hem de alıyor.

(35) Projede önce işe başladığımızda olabildiğince arkada mürettebat kısmında silüeti düşük olsun istedik, bu bir beka isteri. Silüeti düşük araç yapmak, bu bir ister, diğer bir ister de ergonomik olarak içeride hareket edebilmek. Bu bir ambulans yani, sıkış tepiş olamaz. Dolayısı ile sürece başladığımızda beka isterine göre şekillenen

araç yüksekliği, sürecin devamında bizim ekibin katkılarıyla tavanı yükseltilmesi ve oradaki hacme sığma şekliyle aracı yükseltmeye doğru gitti.

(36) Konsept tasarımı aşamalarında aracın platform sahiplerinden verilen en, boy, yüksekliklerine göre kaba yerleşimlerine göre aracın bir stil tasarımı yapılması için endüstriyel tasarım ekibine verilir. İlk aşamada endüstriyel tasarım ekibinden iterasyonlar yapılır. İkinci kısım, en önemli kısım, çok fazla iterasyonun döndüğü kısım insanla olan kısımdır. Bunun sürücüsü vardır, komutanı vardır, nişancısı vardır, yaralısı vardır, bir bakım aracı yapıyorsam bakım aracındaki mürettebat var.

(37) Bu aslında işin doğasında var olan bir şey. Çünkü entegre olmaya çalışıyor tüm sistemler. Ben bunu yer kapma savaşı olarak değil de işin yürümesi için bir optimizasyon olarak görüyorum. Optimizasyonu da sürekli yapıyoruz zaten.

(38) Yani ilgili birimin de fonksiyonu düşündüğün zaman, saha verilerini de biliyorsun, orada ilave bir tasarım çözümü de uygulayabiliyorsun, ya da bir feragat yapabiliyorsun. Bir sapma olabiliyor, bu sapmalar tabii ki yine kabul edilebilir sapmalar.

(39) Gereksinim dokümanı zaten müşteriden gelen bir doküman, projeyi kendimiz yapıyorsak da bu dokümanı kendimiz oluşturuyoruz, sistem mühendisliği oluşturuyor.

(40) Önce gereksinimler var. Gereksinimlerden sonraki süreçte bu gereksinimlere uygun konsept tasarımlar başlıyor. Ve konsept tasarım aşaması CDR denen bir aşama ile sonlandırılıyor. Bu gereksinimlere ne kadar uyulabileceği bu CDR ile bir miktar ortaya çıkıyor. Devamında detay tasarım başlıyor. Primary design Review dediğimiz PDR, ilk tasarımın donmuş haline gelmek için bir süreç başlatılıyor. Dolayısı ile gereksinimlerden başlayan süreç artık tasarımın olgunlaştığı, dokümante edildiği bir şey oluyor.

(41) Bu önceliklendirmeleri yaparken motor bölmesinde motorun ve bölmenin hacmi ön planda olurken mürettebat bölmesinde mürettebatın kolay ulaşacağı, ergonomik olarak çalışması gereken boşlukları yaratarak bir paketleme yapıyoruz.

(42) Burada aslında standartlar referans oluyor, kullanıcılar referans oluyor. Biz prototipe başlamadan önce, içerinin hacmi çok önemli ya mesela öncelikle sanal gerçeklikle içerinin hacmine bakıyoruz ekiple beraber. Orayı belirliyoruz, paketlemenin bir kısmını burada karar veriyoruz. Sonrasında mock up'lar yapıyoruz.

(43) … birebir uymuyorum bu standartlara, referans olarak bakıyorum. Eğer tasarım el veriyorsa (ve) mock up'larda olacağını öngörüyorsak; burası böyle deniyor ama böyle de yapabiliriz diyebiliyoruz. Oraya uyacağız diye kendimizi zora sokacak bir tasarıma gitmiyoruz.

(44) Elinize gelecek ürünlerin boyutları da çok önemli. Tasarıma başlarken genelde büyük enveloplar size gelirken ilerleyen dönemlerde işler netleştikçe daha envelopu düşürebiliyorsunuz

(45) En önemli güçlük bence şeydi yani içeride mürettebatın hareket alanı için yapının değişmesi gerekliliği güçlülüğüydü. Burada mürettebatın ergonomisi çok önemliydi.

(46) Bu sistemde personelin bile bir kendi görevini icra etmekle sorumlu olduğu birçok ekipman ve cihaz vardır. Sonuçta bunlara bir yerleşim yapılması lazım ve bu iterasyon ile ilerleyen bir konudur. Konsept tasarımdan başlar her personelin bu araçtaki ekipmanları kullanacağı şekilde bir koltuk, bir lokasyon yerleşimi yapılması gerekiyor. Oturduğu yerden ilgili ekipmanlara ulaşabiliyor mu, ilgili ekipmanları görebiliyor mu, endüstriyel tasarım ekibinden bu çalışmalar yapılır ve tasarıma geri bildirimler verilir.

(47) Bunun haricinde bu kişiler eğer bir gözetleme ekipmanı kullanıyorsa, periskop gibi konuları konuşuyorsak görüş alanları denilen bir konu vardır. Bir cihaz çok ısınıyordur ve ısındığı için ısı atımlarından dolayı yanına ne kadarlık bir cihaz yerleştirmemen gerektiği, duvarlara ne kadar yaklaşacağın bellidir. Dolayısı ile bu sistemlerin teknik özelliklerinden yola çıkarak personel yerleşiminin görüş analizlerinin yapılması gerekir, bu analizlere göre hem o personelin yerleri

değişebilir, bununla birlikte söz konusu ekipmanların sistem üzerindeki ölü bölge oluşturmayacak şekilde yerleşimlerine kadar da gidebilir.

(48) Proje takvimi çok dardı, çok kısıtlı bir zamanda yaptık bu çalışmayı. Ama proje takvimi genişletilseydi de aynı kısıta gelirdik diye düşünüyorum. Çünkü bizim çalıştığımız bazı sistemler en son bütün sistemler tamamlandıktan sonra detaylandırılabilen sistemler. Dolayısıyla proje süresi çok uzun olsa da bize ayrılan vakit çok kısa ve ilk takılan montaj edilen parçalar da bizim parçalarımız olması sebebiyle bizim çok dar bir vaktimiz kalıyor.

(49) Tedarik süreçlerini de çok takip etmek durumunda kaldık kısıtlı bir zaman olduğu için. Firmaların peşinde koşturduk hep, montajı yapan sorumluluk da bizde olduğu için.

(50) Geriye dönüp baktığınızda bu proje sürecinde paketleme kısıtlarını karşılamak açısından neler iyileştirilebilirdi? Önerileriniz var mı?

(51) Bunu şöyle yapabilirdik belki, bütün herkes işini bitirdikten sonra iki ay hiçbir şey yapılmasaydı ve orada tedarik süreci olsaydı, böyle projeler de yaşadık ve daha rahat üstesinden geldik. Proje bittikten sonra da montaj için arada belli bir süre olmasında fayda görüyorum.

(52) Şu olabilirdi hani işin başında böyle bir aracı kullanacak mürettebatlarla beraber bir süre vakit geçirebilseydik, buna fırsatımız olmadı çünkü, onların gerçek ihtiyaçlarını sahada gözlemleyebilseydik, proje takviminde birkaç alternatif yapıp onlarla üzerinden geçebilseydik daha iyi olabilirdi.

(53) Teknoloji durmuyor yerinde, teknoloji gelişiyor. Mock-up tek çözüm mü, tek çözüm değil tabii ki. Artık bu mock up'ların dijital ortama taşındığı visual relaity konuları devreye girmeye başladı. Birçok şeyi de artık nihai imiş gibi aracın dış görünüşü, aracın iç görünüşü, araçtaki iç yerleşim gibi birçok konular belki mock-up yapmanın, mock-up sonuçta bir zamandır, ilave maliyettir ama etkilidir. Buradaki şeylerin de doğruluk payı artacak, bu tip şeyler de sanal ortamda artık yapılıyor. Hatta ve hatta mürettebatın senaryoları da icra edilmeye bile başlıyor. Bu da

ayriyeten tasarım takvimlerine ve güncellemelerine hız veren daha etkin daha maliyetli bir yöntem olarak da karşımıza geliyor.

(54) Sadece analiz yeterli olmuyor mock-up oluyor. Dolayısıyla sanal model tasarımı aslında çok önem arz ediyor, üretime gitmeden sanal ortamda mümkün olduğunca en doğru şekilde bir analiz yapılması ve birçok deneyimlemenin doğru bir şekilde analiz edilmesini sağlayacak toolların geliştirilmesi bence etken bir çözüm oluyor. Sanal gerçekliğin bence önemli olduğunu düşünüyorum, gerçekten sanal ortamda deneyebiliyorsunuz hemen modelleyerek birçok alternatifi mock-up yapmadan dijital ortamda yapmak önem arz ediyor. Bu konunun mümkün olduğunca iyileştirilmesi ve yaygın hale getirilmesi bence çok fayda sağlayan bir şey.