H. ÇAYKENARI

PRODUCT MATURITY MANAGEMENT METHODOLOGY

IN AIRCRAFT DEVELOPMENT PROJECTS

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PRODUCT MATURITY MANAGEMENT METHODOLOGY
IN AIRCRAFT DEVELOPMENT PROJECTS

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Approval of the Graduate School of Social Sciences

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ABSTRACT

PRODUCT MATURITY MANAGEMENT METHODOLOGY
IN AIRCRAFT DEVELOPMENT PROJECTS

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The aim of this study is to develop a model for monitoring the technical maturity of the aircraft which is a multidisciplinary and complex product, throughout its lifecycle. Problematic has been created from common challenges seen in the aircraft development project in Turkey. Solutions have been sought for the deficiencies experienced in the monitoring of technical maturity at the platform level. The conceptual framework was examined existing maturity models were found and current practices were discussed, respectively. Then, hypotheses and supportive model were created. The model was tried to be verified by interviews with experienced personnel who worked in different phases of aircraft development lifecycle in both Customer and Contractor sides. In the conclusion, other important and workable issues that are not included in the model have been highlighted.

Keywords: Aircraft Development, Lifecycle, Maturity Model, Systems Engineering, Project Management, Technology Readiness Level (TRL)

ÖZ

HAVA ARACI GELİŞTİRME PROJELERİNDE
ÜRÜN OLGUNLUK YÖNETİMİ METODOLOJİSİ

ÇAYKENARI, Harun

Yüksek Lisans, Bilim ve Teknoloji Politikası Çalışmaları Bölümü

Tez Danışmanı : Doç. Dr. Serhat ÇAKIR

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Bu çalışma, çok disiplinli ve kompleks bir ürün olan hava aracının yaşam döngüsü boyunca teknik olgunluğunun takibine yönelik modelin oluşturulmasını hedeflemiştir. Sorunsal Türkiye’de yürütülen hava aracı geliştirme projelerinde görülen ortak zorluklar dikkate alınarak oluşturulmuştur. Platform seviyesinde teknik olgunluğun takibinde yaşanan eksiklere çözümler aranmıştır. Sırasıyla, kavramsal çerçeve incelenmiş, mevcut olgunluk modelleri bulunmuş, mevcut uygulamaar ele alınmıştır. Sonrasında hipotezler ve destekleyici model oluşturulmuştur. Müşteri ve Yüklenici tarafında, farklı fazlarda tecrübeli uzmanlar ile yapılan mülakatlar ile model doğrulanmaya çalışılmıştır. Sonuç bölümünde modelde yer almayan diğer önemli ve çalışılabilecek konulara dikkat çekilmiştir.

Anahtar Kelimeler: Hava Aracı Geliştirme, Ürün Ömür Devri, Olgunluk Modeli, Sistem Mühendisliği, Proje Yönetimi, Teknoloji Hazırlık Seviyesi (THS)

To My Dear Parents, Beloved Wife & Lovely 3 Littles

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LIST OF ABBREVIATIONS

AC	Aircraft
ASR	Alternate System Review
CA	Configuration Audit
CDR	Critical Design Review
CI	Configuration Item
CMMI	Capability Maturity Model Integration
CoA	Certificate of Airworthiness
CoC	Certificate of Conformance
CS	Certification Specifications
DAL	Design Assurance Level
EIRD	Equipment Interface Requirement Document
FCA	Functional Configuration Audit
FTRR	Flight Test Readiness Review
HP	Hypothesis
HW	Hardware
IRL	Integration Readiness Level
LLTI	Long Lead Time Item
M	Milestone
MC	Means of Compliance
MoD	Ministry of Defense
MOE	Measure of Effectiveness
MOP	Measure of Performance
MOS	Measure of Suitability
MRL	Manufacturing Readiness Level

MRO	Maintenance Repair and Overhaul
OCD	Operational Concept Document
PCA	Physical Configuration Audit
PDR	Preliminary Design Review
PLM	Product Lifecycle Management
PM	Project Management
PMMM	Product Maturity Management Model
PRR	Production Readiness Review
QC	Quality Control
R & D	Research and Development
SFR	System Functions Review
SIRD	System Interface Requirement Document
SOI	Stage of Involvement
SPS	System Performance Specification
SRD	System Requirement Document
SRL	System Readiness Level
SRR	System Requirements Review
SSB	Presidency of Defence Industries (Savunma Sanayii Başkanlığı)
SSIK	Defence Industry Executive Committee (Savunma Sanayii İcra Komitesi)
StDD	Structural Design Description
StRD	Structural Requirement Document
SVR	System Verification Review
SW	Software
TA	Turkish Aerospace
TC	Type Certificate
TLAR	Top Level Aircraft Requirements
TPM	Technical Performance Metrics

TRL	Technology Readiness Level
TRR	Test Readiness Review
TstRL	Test Readiness Level
USAF	United States Air Forces

CHAPTER 1

INTRODUCTION

1.1 Technology Management Conceptual Framework

1.1.1 Relation Between Management Levels and Technology Management

There are over a hundred definitions of technology in the literature (“Technology”, t.y.). According to Prof. John Kenneth Galbraith, one of the most important economists of the last period, it is defined as the systematic application of scientific or other organized knowledge to practical tasks. In view of the definition of Research and Development (R & D) in the Frascati Guideline, it will not be wrong to define technology as an output of R & D studies (OECD, 2015). According to the Frascati Guideline, R & D activities are divided into three (3) basic scopes as standard practice; Basic Research, Applied Research and Experimental Development. It can also be said that the scope of Experimental Development includes Product Development studies. By transforming the technological competences gained as a result of basic and applied research activities into components and products, a new technology emerges.

It is seen that the definition of technology management has different definitions in the literature and it cannot be said that its scope is clearly defined yet (Çetindamar, Phaal and Probert, 2013). When the scope of this study was evaluated, the following first and last definition made by the US National Research Council in 1987 was used (NRC, 1987, pg.15).

“Management of technology links engineering, science, and management disciplines to plan, develop, and implement technological capabilities to shape and accomplish the strategic and operational objectives of an organisation.”

The definition is consistent with the PDCA (Plan-Do-Check-Act) cycle created by W. Edwards Deming and used as standard in management models (Livarçin and Kurt, 2014). Management systems divide their activities into sub-processes, define their internal and external relationships systematically and then improve their processes by controlling them around the PDCA cycle. In the technology management conceptual framework of this study, the six most basic and common accepted processes defined by Gregory (1995) have been chosen; *Identification, Selection, Acquisition, Learning, Exploitation and Protection* (Çetindamar et al., 2013; Gregory, 1995). Although these processes interact with each other, they are not considered as sequential activities (Çetindamar et al., 2013).

If we go back to definition, it is seen that technology management has spread to two levels as strategic and operational on an organisational scale. Although technology management processes are of varying intensity, they are spread across both management levels (Çetindamar et al., 2013).

In brief, strategic management at the corporate level consists of determining the market place with new products or services by acquiring the necessary technological competencies after presenting the existing technological capabilities and analyzing the possible markets. Establishing the organization around the basic processes and values and finding the necessary intellectual or capital resources are carried out from a strategic management perspective. The management of external collaborations and relationships is more likely to occur at this level. Strategic management focuses on basic and applied research areas. Experimental development activities are carried out in selected areas, and the opportunities to take place in the market are challenged according to the commercialization speed and superiority of the products in this management level (Baktır, 2015).

At the operational level, efforts are made to orient existing technological capabilities and acquire new ones to produce products that are directly requested by the selected target, market or customer. Figure-1 attempts to describe the activities on an organisational scale in general.

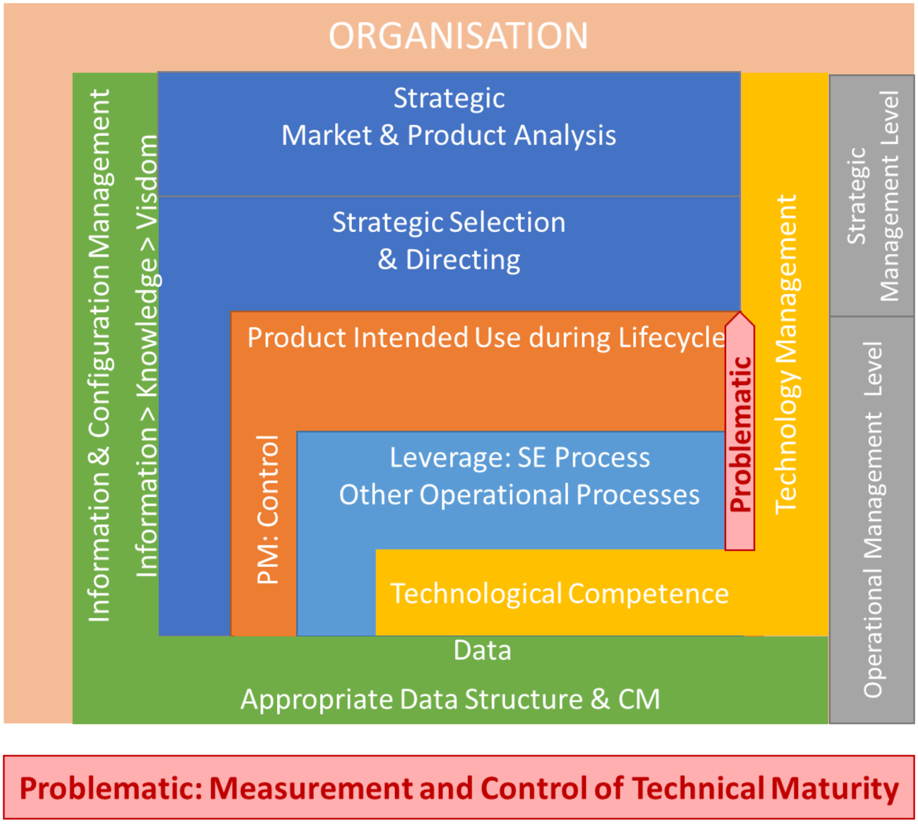

Figure 1. *Organisational Management and Technology Management*

The System Engineering approach has a leverage effect in transforming technology management processes into products that meet the needs. Experimental development activities are supported with the technological capabilities obtained as a result of basic and applied research by system engineering processes. Project management basically aims to use the right resources for the commercialization of technological capabilities. It is necessary to identify and operate other compatible main and sub-processes which will support the project management and system engineering processes at the operational level.

Considering the uncertainties and risks of R & D activities, the high cost of advanced and complex technologies, the superiority of critical technologies in economic and military other global developments; it is not possible for the technology management ecosystem to remain on an institutional scale. Developing science and technology policies and establishing innovation systems with high cooperation and communication at national level presents many challenges (Baktır, 2015). In order to overcome these difficulties, the working method consisting of government, industry and academia is defined as triple helix partnership structure (Etzkowitz and Leydesdorff, 1995). Although different structures (national, regional, sectoral, etc.) and tools (formation of legal infrastructure, funding, commercialization, etc.) are used in the technology management activities at national scale, thesis has not been elaborated on the grounds due to weak relationship with the focus area of this study. The main scope of the thesis covers new product development activities in defense and aerospace sectors.

Considering the size of the ecosystem, the relationships in the triple helix model, information-intensive activities, the follow-up of dynamic management capabilities and the frequency of decision steps; information management infrastructure needs to be established. Especially at national scale, a dynamic and systematic information management tool is also considered important which will serve many purposes such as defining the technological capabilities of companies, determining the technologies to be acquired, determination of technology ownership and maturity levels, establishing technological interfaces, measuring the intellectual and organizational competencies and creating the outputs to support the decision system.

Within the scope of aircraft product development projects, system engineering management and technology maturity definitions play an active role in monitoring the technical targets, status accounting, directing the technical course and managing risks. It is practically impossible to monitor a large number of horizontal and vertical spread and diversified technical activities by decision-makers at all levels in real time. For this reason, the definition of a lifecycle emerges especially with the experimental development phase, in which technological capabilities begin to turn into products. This lifecycle hosts important milestones and decision gates at certain times, just like in people's lives.

The contracts of development projects in the aerospace and defense sector in Turkey are based on many methods which has been experienced by leading companies and standardized on global scale at the end. However, it is considered that there are some gaps for tailoring and commonization of the methods for Turkey applications. Especially, as a result of failure to follow technical processes, status monitoring and change control due to lack of an effective information management infrastructure; in many projects decision stages cannot be passed at appropriate maturity, risks cannot be seen clearly and calendar extensions, user dissatisfaction and budget overruns can occur. Therefore, the aim of the thesis is to select, adapt and combine the best practices for the monitoring of product technological maturity in aircraft development projects.

1.1.2 Technology Management Main Areas of Activity

As mentioned earlier, technology management activities consist of the main areas of activity that are related to each other, but not very sequential; *Identification,* *Selection, Acquisition, Learning, Exploitation and Protection*. Since the thesis problem is related to defining the technological scope of development of aircrafts and determining technical maturity and selecting the direction to be reached at the operational management level, the focus will be on Identification and Selection activities.

In order to support the activities at all levels at organisational level within a technology management perspective, it is essential to define the company's competence and technology portfolio, establish the necessary technology taxonomy, establish technology-product-market prediction and systematically report the results (Çetindamar et al., 2013). Technology taxonomy is one of the basic tools of identification activity and is formed by the classification of technological capabilities in different ways. Lindsay classifies technologies according to their competitive potential (Lindsay, 1998).

Basic technologies are necessary but not discriminating technologies for a firm to do business in the market in which it operates. However, the core technologies are used in several type of products, thus enabling these technologies addresses more than one market. Figure 2 shows the hierarchical structure and variety of activities adapted from Bilbro's product structure and Prahalad and Hamel's core technological competence-product-market relationship. Technologies categorized as critical provide competitive advantage in the market or have strategic importance in the military or macroeconomic area, especially those technologies need to be protected on a national scale. A technology may be subject to multiple classifications as of its characteristics.

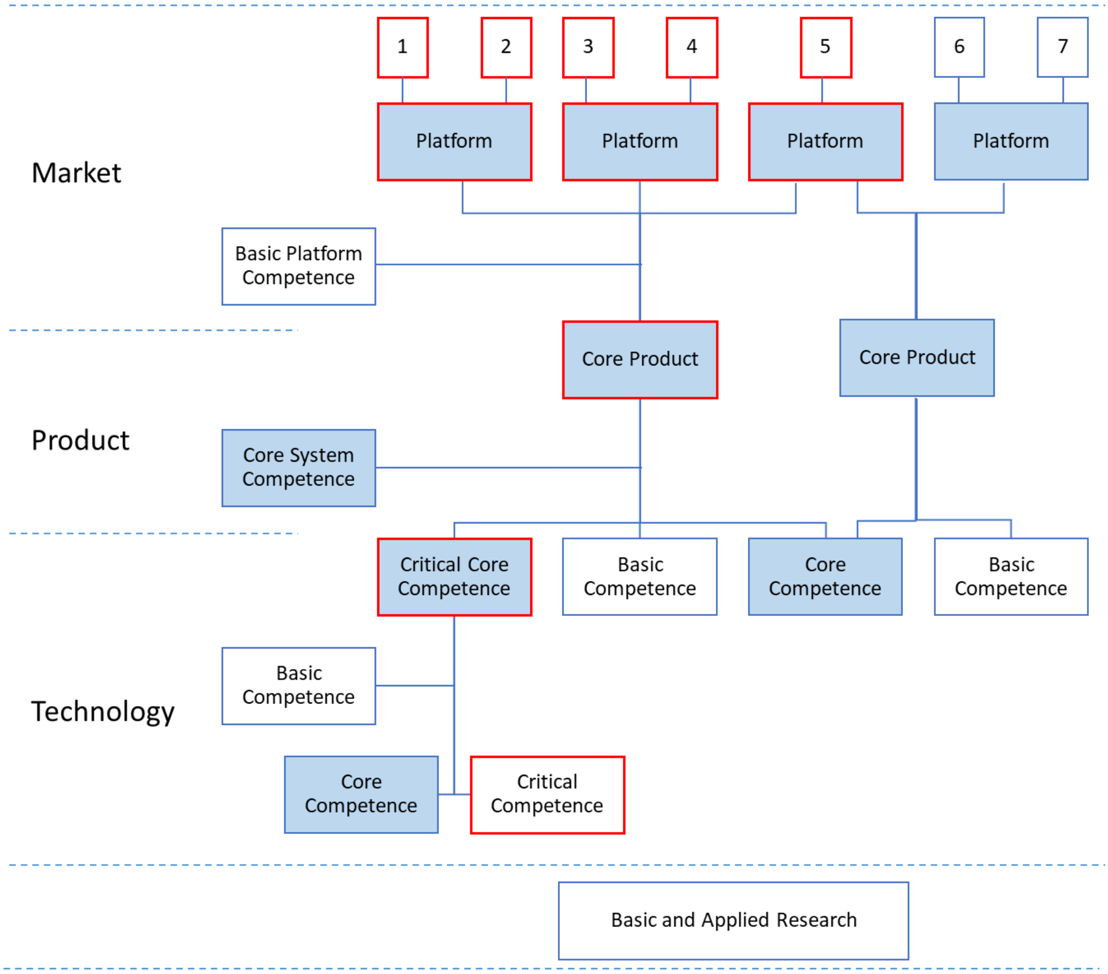

Figure 2. *Core Technology-Product and Market Relationship*

After establishment of technology taxonomy, different levels and models have been developed in order to measure the capabilities of existing and emerging technologies. Information on mentioned methods is discussed in Chapter 2.

Selection process in Technology Management is the ability to form strategy. *Selection* is to bring together internal and external resources to create a competitive advantage, to use them harmoniously and as a result to select and develop technology and business models.

Although *identification* process largely establishes technology competence, component, product and market relationship, determining the destination to choose from among alternatives requires a series of strategical analysis-based decisions.

When technology portfolio and market analysis are used together, commercialization decisions and project definitions can be made more accurately. The competence of companies in research and development as well as the size and diversity of the technology portfolio give information whether the company can be a technological leader or follower (Baktır, 2015). This situation before entering a market is the pusher force in introducing new technologies and products to the market. For technology-leading companies, accessing to wide gaps in a market with new technologies means a large rate of commercialization, a broad range of activities and revenue. Technology followers with limited R & D capabilities and technology portfolio can respond to the highly saturated market with slow commercialization speed and low profit shares. Follower companies are able to achieve rapid commercialization and profit sharing through innovation policies and accurate market analysis in technology development and services. While the existing basic technologies and emerging technologies are the pusher forces for product development activities, the market and customer expectations are leading to the selection of technologies to be acquired. In some sectors such as the defense and aerospace, customer/user expectations may take precedence of strategic analysis.

Although it is seen that it is very important to carry out market analysis correctly and determine the strategies with available technology portfolio, the selection of the projects and managing them with appropriate dynamics are also required for effective management (Baktır, 2015). Not only initiation of project that are non-prioritized, incompatible with strategy and sometimes started only as customer demand, but also inadequate management of those projects will lead to disruptions in projects and product. At this point, it is important to classify the projects and commercialize products with appropriate methods. According to Wheelwright and Clark (1992), four types of projects have been identified considering the impact of the change in existing products; *derivative, platform, breakthrough, research & development projects*. It can be said that the processes for each project type should be adapted to the project or product type. The process mentioned here refers to the technologies in the implementation and integration processes rather than the development processes. Labor-intensive workshop processes are operated for prototype or low-volume products while sequential factory processes with associated and assembly lines are operated in mass production (Hayes and Wheelwright, 1984). It is deemed necessary to consider business share points that includes product development activities with partners or sub-contractors in the project planning phase for a successful result. In Figure 3, the relationship of changes in products and processes with project types is given together with sample product portfolio (Wheelwright and Clark, 1992).

It is essential to acquire the necessary technologies for the company's effectiveness or product release. Considering the relationship between the strategic impact power of technology and the cost of technology development; Floyd mentioned that technology can be acquired through one or more of the methods of acquiring, developing in-house or establishing alliances (Çetindamar et al., pg. 157). This gain can be realized through internal *make* decisions and R & D studies, or it can be sustained through collaborations in many different scenarios called open innovation. Collaborative R & D models are also used extensively in high cost and complex platform development projects. For technological competencies with high priority and low cost, purchasing method is used. Acquiring or learning intellectual knowledge is important in terms of obtaining implicit knowledge in technology acquisitions through purchasing.

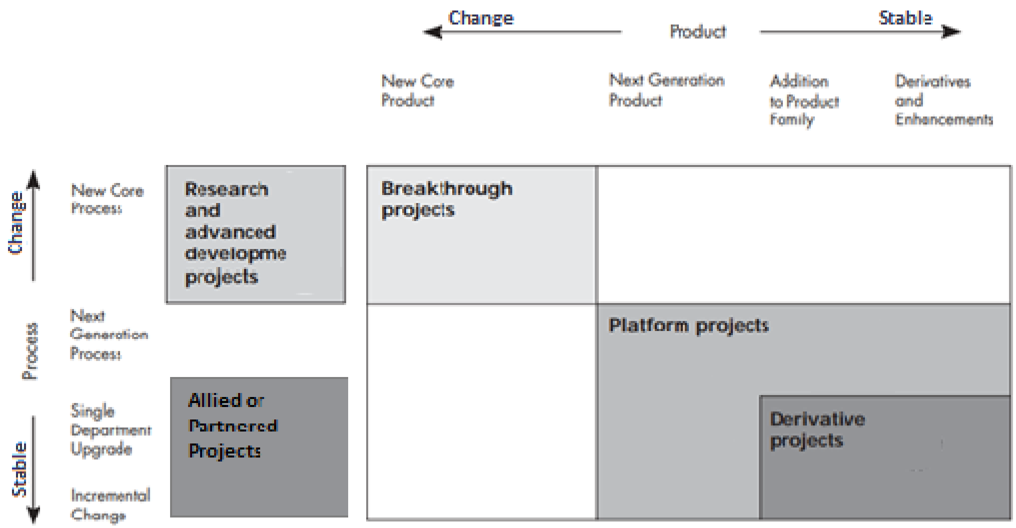

Figure 3. *Changes in Products and Processes related to Project Types*

1.2 Characteristics of Defense and Aviation Projects in Related Context

In this section, the main activities of technology management are reviewed from the perspective of Defense and Aviation sector and the differences or prominent points are mentioned. There are differences in many areas especially in the economic field at national level for the defense and aerospace sector. In order not to distract the focus of this study, the effects of the institutional dimension were examined.

Although military strategy and operations concepts are important in winning wars, technological advances in weapons play a major role in ensuring superiority in the battlefield and in the evolution of wars.

In the defense industry, market is dominated the state as a role of customer. The fields of activity are shaped according to national strategies and priorities. Therefore, instead of seeking the appropriate market and customer by taking advantage of the *repulsive or pusher force* of the technology portfolio; companies prefer to determine the product, project model and technology portfolio according to the wishes of the single customer owning the market. In the shaping of the market, rather than the pusher force of the technology, the customer's wishes are felt as an *attractive or pulling force*. Market analysis is used as a weaker tool in the defense industry than in the civil sector, with dominant customers identifying the product characteristics. Technology management strategies take the form of meeting the new and advanced technological expectations of technologically saturated customers and users instead of filling technological gaps in the market.

According to the findings of Serdar GÖKPINAR, the market supply in the defense industry is covered by a smaller number of main contractors compared to the civilian sectors. The main contractors are large in size and power, but work is completed in a vertical hierarchical agreement framework with a large number of approved subcontractors. Public institutions may be shareholders of the contractors. This situation makes the state effective in organization management and financial decisions of contractors. Contractors operate in compliance with government policies with technological and industrial benefit, low profit share and high employment compared to the civilian market (Akçomak, Erdil, Pamukçu and Tiryakioğlu, 2016). The fact that the customer / user, university and main contractor capitalists are the sole source of state contribution has made the triple helix model and other network structures more complex. Public-guided technology development can be mentioned in this scope.

The impact of the customer on the product characteristics and the technologies used is also effective in the product developments projects with high R & D scope. The high costs caused by uncertain R & D activities are funded by customers. This leads to the customer monopoly of determining the management structure, control points, cost and calendar budgets of the project.

Defense and Aerospace products can be derivatives, enhanced products, or same class-new generation products or completely new products as referred in Figure 3. The product portfolio is dispersed, where the position of hybrid platform projects in the product portfolio is decisive. These projects have a high budget in the financial portfolio. Hybrid platform development projects add existing new technologies to the product features while at the same time gaining the destructive superior technologies supported by R & D studies. Since the aim is to provide absolute superiority to threats, the developing products are constantly fed with destructive technologies (Akçomak et al., 2016). Although product variety and production volume are low compared to civilian sectors, unit costs are high (Akçomak et al., 2016). Low production rates and high R & D costs are effective in high unit costs. However, the high-budget defense industry market, which is under the support of the state, is becoming attractive for suppliers that can be considered as monopolies in the market. Reasons such as macroeconomic balances, security concerns, sustainability in the war situation make local-national suppliers advantageous. Considering the relationship between the strategic impact of technology and the cost of technology development, business models in high-impact and high-cost situations require alliances such as collaborations or partnerships (Çetindamar et al., 2013, pg. 157). In addition, where critical technology transfer is limited during learning and using technology, consortium or cooperation models are often used. Although, the technological value and the high cost of platform development projects in the defense industry force the scenario of collaborations, in some cases technology acquisition is mainly achieved by R & D projects for 2 reasons; i) the need to maintain the developed strategic capability; or ii) the inability to purchase the existing strategic capability in other hands (Akçomak et al., 2016). Unlike civil sectors, the acquisition of strategic capabilities in defense industry is a necessity despite its high cost. Defense products include technologies that have not yet proven as well as intensive use of known technologies (Akçomak et al., 2016, pg. 493). This situation points to product development processes with high technical and market risks including R & D activities. The products include complex, multi-component and multi-disciplinary, critical and core technologies, as well as other technologies that have not yet matured.

While the protection of technology in the civil sector takes place with commercial concerns, the fact that technology provides military strategic superiority for the defense industry is the main reason for protection. Methods of technology protection also vary. Although patents are used as a protection method in the civil sector, hiding and guarding is used as a more effective method for the defense sector.

Product development process and product lifecycles are long. Each product has its own technological challenges. This leads to the incorporation of specific processes belongs to product development and development planning into the project scope. In contrast, many standards or guidelines are used to simplify complex processes, systematize basic approaches, and create a common language. Procedures such as project management methods, system engineering approach, product development process planning, R & D process planning are used extensively as standard. The analysis, elaboration, validation and verification of customer requests is the main touchstone in monitoring the course.

Monitoring and control tools are needed to reveal technological improvements in the development of product development process that has multi-disciplinary, multi-component and undefined technical risks with complex interfaces. These tools also are necessary for risk determination and reduction techniques related to financial, schedule or technical issues, and used for keeping customer expectations in focus. The standard procedures include mentioned control activities. Different maturity monitoring models are used within the scope of technology management. In the next section, these maturity models and their applications will be discussed after brief definitions of project management and systems engineering procedures.

CHAPTER 2

POLICY AND LITERATURE REVIEW

2.1 Project Management and Systems Engineering Processes

Project management and system engineering management tools were mentioned at the organisational level. These management tools used in the defense and aerospace industries are also widely used in other sectors with high budget and complex products. Over time, best practices were standardized and published by different commercial and academic institutions. Standards and guidance documents regarding to project management and engineering of systems management addressed in the defense and aerospace projects in Turkey are listed below.

- IEEE 1220 Standard for Application and Management of Systems Engineering
- ANSI/EIA 632 Processes for Engineering Systems
- ISO 15288 Systems Engineering--System Lifecycle Processes
- ARP 4754 Guidelines for Development of Civil Aircraft and Systems
- PMBOK A Guide to the Project Management Body of Knowledge

2.1.1 Project Management

Regular control and improvement of processes can be defined as Process Management. Process Management can be made possible by the continuous improvement approach seen in Edwards Deming's PDCA (Plan, Do, Check, Act)

Cycle, who is considered the father of Total Quality Management (Livarçin and Kurt, 2014). It is possible to talk about Process Based Management by defining the activities in a Management System with processes and managing them in the structure. The Project Management approach described in PMBOK and PRINCE2 is based on the basic processes. It can easily be said that these guides exhibit *Process Based Management* (PMBOK, 2015; Dertli, 2015).

As reference of PMBOK, five basic Project Management Processes have been defined; (1) Project Initiation Process, (2) Planning Process, (3) Execution Process, (4) Monitoring and Control Process, (5) Project Closure Process. This interaction can be seen in Figure 4 considering the extent to which these processes are used throughout the project lifecycle, in other words how much resources the processes consume. It is seen that planning activities have a large share and spread to the lifecycle which is not only in the first phases. It can be said that planning activities do not consist of only the publication of a Project Management Plan document. Another noteworthy process is that Monitoring and Control process is not used only in executive activities. It covers all of the project processes to the extent that it interacts with other processes.

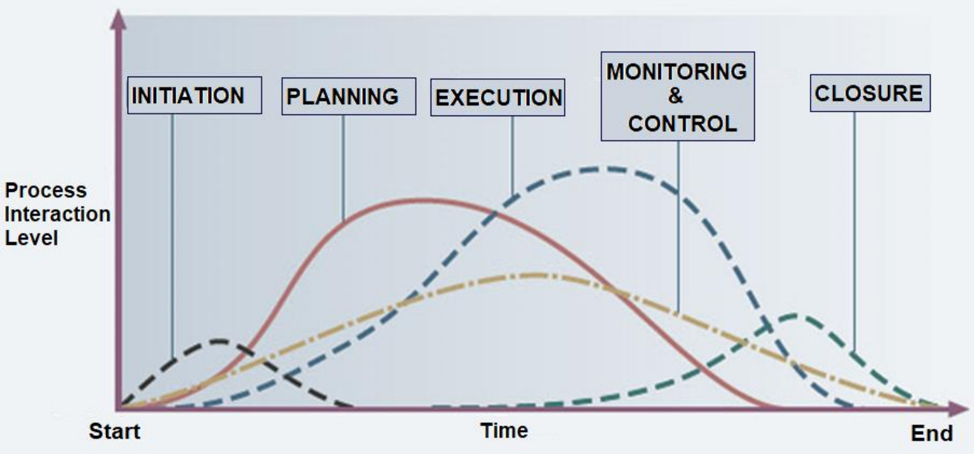

Figure 4. *Project Management Processes and Resource Distribution*

Table 1. *(PMBOK Guide) PM Process Group and Knowledge Area*

Knowledge Areas	Project Management Process Groups				
	Initiating Process Group	**Planning Process Group**	**Executing Process Group**	**Monitoring and Controlling Process Group**	**Closing Process Group**
4. Project Integration Management	4.1 Develop Project Charter	4.2 Develop Project Management Plan	4.3 Direct and Manage Project Work 4.4 Manage Project Knowledge	4.5 Monitor and Control Project Work 4.6 Perform Integrated Change Control	4.7 Close Project or Phase
5. Project Scope Management		5.1 Plan Scope Management 5.2 Collect Requirements 5.3 Define Scope 5.4 Create WBS		5.5 Validate Scope 5.6 Control Scope	
6. Project Schedule Management		6.1 Plan Schedule Management 6.2 Define Activities 6.3 Sequence Activities 6.4 Estimate Activity Durations 6.5 Develop Schedule		6.6 Control Schedule	
7. Project Cost Management		7.1 Plan Cost Management 7.2 Estimate Costs 7.3 Determine Budget		7.4 Control Costs	
8. Project Quality Management		8.1 Plan Quality Management	8.2 Manage Quality	8.3 Control Quality	
9. Project Resource Management		9.1 Plan Resource Management 9.2 Estimate Activity Resources	9.3 Acquire Resources 9.4 Develop Team 9.5 Manage Team	9.6 Control Resources	
10. Project Communications Management		10.1 Plan Communications Management	10.2 Manage Communications	10.3 Monitor Communications	
11. Project Risk Management		11.1 Plan Risk Management 11.2 Identify Risks 11.3 Perform Qualitative Risk Analysis 11.4 Perform Quantitative Risk Analysis 11.5 Plan Risk Responses	11.6 Implement Risk Responses	11.7 Monitor Risks	
12. Project Procurement Management		12.1 Plan Procurement Management	12.2 Conduct Procurements	12.3 Control Procurements	
13. Project Stakeholder Management	13.1 Identify Stakeholders	13.2 Plan Stakeholder Engagement	13.3 Manage Stakeholder Engagement	13.4 Monitor Stakeholder Engagement	

In addition to processes, PMBOK has identified ten (10) knowledge areas in which it grouped the activities carried out in these processes. These knowledge areas and processes are given in the following matrix in Table 1.

The success of the project is directly proportional to the importance to be given to Stakeholder Management in all processes and the effectiveness at this point (Young, 2007). At this point, the most important activity of the initiation process is the determination of the success criteria of the project, especially customer requirements.

Many multidisciplinary and interdisciplinary activities are performed in the planning process. In PMBOK, there are two groups of factors that affect the planning process; *Organizational Process Assets* and *Enterprise Environmental Factors*.

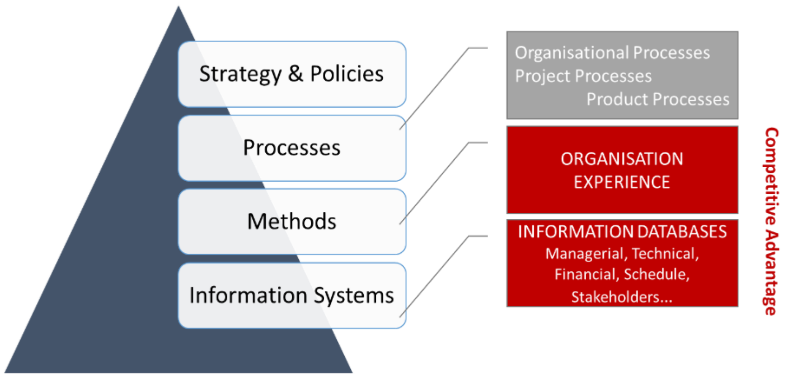

Figure 5. *Organizational Process Assets*

Organizational Process Assets refers to the system infrastructure that helps a company to manage its activities with its unique methods used in the realization of strategies, policies and processes within a hierarchical structure and allows the systematic collection of the obtained information. Methods and system infrastructures are the assets where the operational knowledge and experience of the companies are reflected and privatized. Factors that increase the competitiveness and probability of success of firms are hidden in these assets. A firm can have a wide range of processes in relation to the breadth of the its field of activity.

Environmental Factors have a wide scope such as geographical location, international and national legal regulations, customer expectations, other players in the market, the situation of suppliers and subcontractors or industry in the country.

Project Execution Process is the most resource consuming process of the project. A large part of the project outputs related to the delivery occurs in this process. Figure 6 shows the representation of the resources spent by three different projects. A red project can be a project that tries to introduce a product to the market where the product has completed the development phase, or a blue project that has realized mass production of a product accomplished growth or maturity phase. Considering the ups and downs in the purple project it can be a complex project involving the lives of different technologies through and product development phases where more phases are passed.

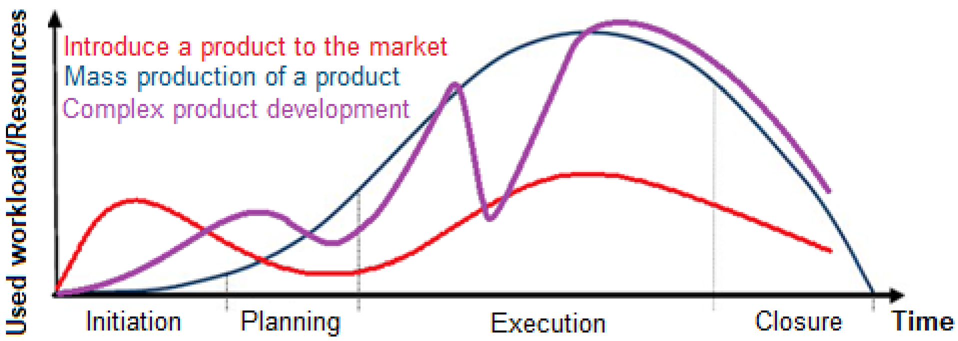

Figure 6. *Resources in Different Project Types*

Project lifecycle can be improved with new phases according to the scope of the project. For instance; for the project in which a product development is carried out, the execution phase of the project can be divided into sub-phases such as *conceptual design phase, preliminary design phase, detail design phase, prototype production and verification phase, and mass production phase*.

The content, which starts with customer requirements at the center, is covered with many components such as design, procurement, analysis, production, deviation, testing, assembly, delivery, time, cost, workload, plans, subcontracts. In order to manage all this content, a complex but regular structure similar to a spider web must be established. The criteria that will provide this systematic are; the phases that define which level will be created with which content, the statuses that allow the data to be tracked, and the traceability information that provides integrity. In this way, configuration management process and project monitoring and control process activities are supported. And also, reporting and change management can be performed effectively.

Closing process is a relatively short and simple process at the end of the project. It is repeatable process similar to the initiating process and can be operated at the end of the each phase. The first activity of this process is the creation of checklists, establishment of transition-completion procedures and determination of performance criteria.

The Planning and Execution Process may consist of a wide range of activities depending on the nature of the project. Sub-processes, methods and infrastructures appropriate to these activities should be planned, tailored, compiled and activated specific to the project. For an organization engaged in technology-based product development, system engineering as well as other product development processes and design support processes can be considered as organizational process assets.

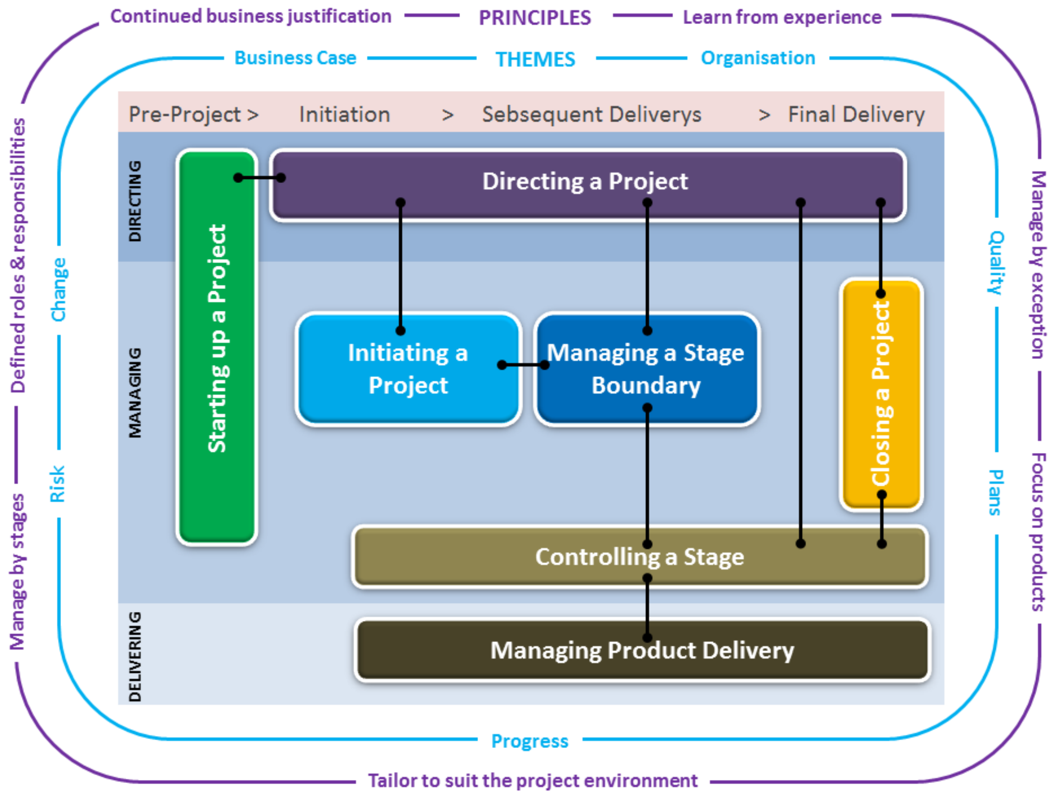

Figure 7. *PRINCE2 Project Management Model*

PRINCE2 is another project management approach that is limited to use in Turkey besides PMP. PRINCE2 focuses more on Project Management Processes than PMBOK. Emphasis is placed on the implementation of processes that are tailored to the project dynamics. PRINCE2 Project Management Model is based on 7 processes, 7 themes and 7 principles as given in Figure 7 (PRINCE2, 2019).

2.1.2 Systems Engineering

When the US Air Forces (USAF) examines the problems experienced in the use of the completed and commissioned systems, it shows that deficiencies and errors were made during the development phase. In addition to this course, the complexity of the new systems to be developed suggests that the potential risks are high and arouses concern. As a result of this, MIL STD 499A standard was published for the first time in 1974 to be applied in product development processes in order to provide a systematic and standard approach. This standard was revised as a draft in 1993 but in 1995 it was repealed without being replaced. As of March 2017, the US Department of Defense (DoD) has agreed to reference ISO / IEC 15288 instead of MIL STD 499A. IEEE 1220 (1994, 1998, 2005) and ANSI / EIA 632 (1994, 1999, 2003) has been derived from the MIL STD 499 standard. With the harmonization of these standards, internationally accepted ISO / IEC 15288 (2002, 2008, 2015) has been published. ISO / IEC 15288, the most comprehensive of the mentioned standards, grouped the system engineering activities for an enterprise into 4 main processes.

A handbook about the application of system engineering has been also published by INCOSE (INCOSE Systems Engineering Handbook, SEHB (2004, 2006, 2007)).

All of these standards set out corporate systems engineering processes for a product development company and provide a systematic detailed roadmap. However, specialized and narrower guidance documents have emerged in the field of civil aviation when airworthiness certification and flight safety were incorporated into system engineering processes; such as "*SAE ARP 4754A Guidelines for Development of Civil Aircraft and Systems (21 December 2010)"* ve *"DOT/FAA/AR-08/32 Requirements Engineering Management Handbook (June 2009)"*.

Figure 8 shows the main processes defined by ISO/IEC/IEEE 15288 and the scope of SAE ARP 4754. SAE ARP 4754 is a different definition of technical processes with safety approach.

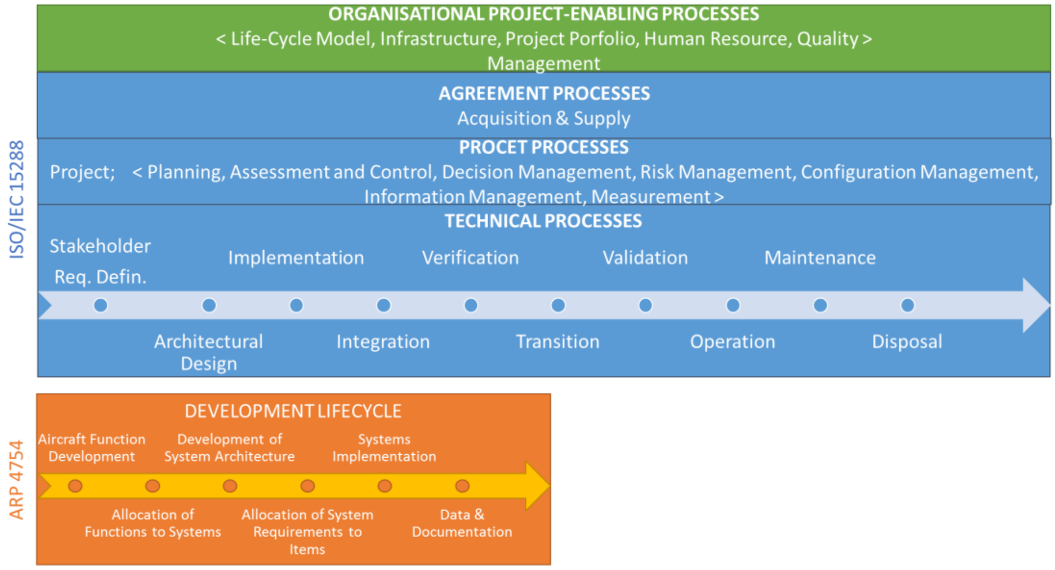

Figure 8. *Timeline and Scope Relations-ISO/IEC/IEEE 15288 & ARP 4754*

Project management endeavors to gather the stakeholders to implement the product/system to meet customer/user expectations, to use the resources correctly and to deliver the system to the users on time.

Systems engineering focuses on identifying requests from stakeholders and distributing them to systems, subsystems and components, then converting requests from lower level up to product that means technical integration.

Both management models try to meet the product requested by the customer or user. Both management models have many similar areas of activity that support each other (Vezzetti, Violente and Marcolin, 2014). Technical processes management sub-activities within the scope of system engineering management intersect with integration and scope management sub-activities within the scope of project management. The processes other than the technical processes described in ISO /

IEC 15288 and the process and information fields defined in the PMBOK are actually overlapping even if they are handled in different ways.

At this point, following the customer requests and the risks that prevent them from fulfilling these requests are among the most important common areas of activity within the scope of this thesis. The project monitoring and control activities operated within the scope of *PM Integration and Scope Management*, and the *SE Technical Reviews* used to monitor system/product maturity and to monitor technical risks serve similar purposes and can be used interchangeably.

2.2 Maturity Models

When we look at maturity models within the scope of technology and product development activities, it can be said that there are basically two different approaches. The first approach focuses on the technology itself and the product, while the other approach focuses on development processes and management systems. Both approaches have common criteria and methods. In the first approach, the Technology Readiness Levels (TRL), first introduced by the American Space Agency (NASA) in the 1980s, found extensive literature and application. In the second approach, the concept of Capability Maturity Model Integration (CMMI) was created by the Software Engineering Institute of Carnegie Mellon University in 1986 and came into effect in many different applications.

The use of uncertain technologies in the product involves high risk in all respects, such as performance, cost and calendar. For this reason, NASA has developed TRL criteria in order to keep track of risks and control them in revealing space vehicles incorporating R & D studies (Mankins, 1995). Figure 9 shows the most general representation of nine levels of defined TRL criteria.

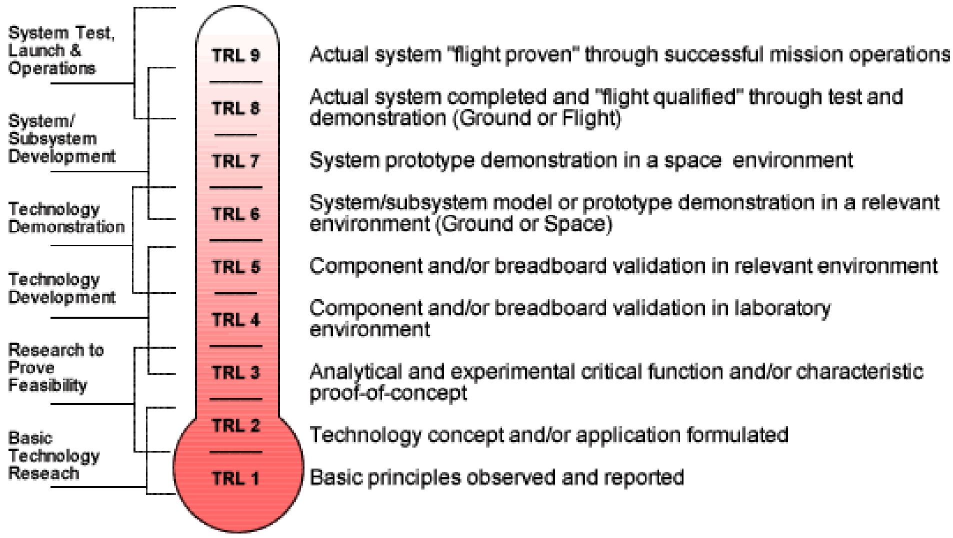

Figure 9. *Technology Readiness Levels*

When the relationship between US DoD system lifecycle and TRL levels is examined, the use of technologies that reach TRL 6 level in the product development has been adopted as a method to reduce the risks caused by uncertainty (Nolte, 2005). However, even though the product is being developed with mature basic technologies, it is insufficient to measure product maturity. In complex multidisciplinary projects, TRL is also not considered sufficient and at this point system maturity stands out. Between 2006 and 2011, several studies have been conducted on the definitions and calculations of System Readiness Level (SRL). During these studies, the determinations made by Sauser and Ramirez came to the fore and came to the point of reference of other studies. On the grounds that the TRL criterion gives an idea about a single technology and that inter-technology integration is not addressed; The SRL model has been proposed for maturity monitoring of multi-component and disciplined products (Sauser et al., 2006). After the concept definition of SRL, TRL and IRL values were normalized and grouped between 0 and 1 at five levels for SRL calculation (Ramirez-Marguez and Sauser, 2009; Tan et al., 2011). Table 2 shows the aforementioned SRL metric paired with US DoD Acquisition Phases.

Table 2. *System Readiness Levels*

SRL	Name	Definitions
0.90 to 1.00	Operations & Support	Execute a support program that meets materiel readiness and operational support performance requirements and sustains the system in the most cost-effective manner over its total lifecycle.
0.80 to 0.89	Production & Deployment	Achieve operational capability that satisfies mission needs.
0.60 to 0.79	Engineering & Manufacturing Development	Develop system capability or (increments thereof); reduce integration and manufacturing risk; ensure operational supportability; minimize logistics footprint; implement human systems integration; design for production; ensure affordability and protection of critical program information; and demonstrate system integration, interoperability, safety and utility.
0.40 to 0.59	Technology Development	Reduce technology risks and determine and mature appropriate set of technologies to integrate into a full system and demonstrate CTEs on prototypes.
0.10 to 0.39	Materiel Solution Analysis	Assess potential materiel solution options

Tan, Sauser and Ramirez-Marquez (2011) tried to describe the TRL, IRL and SRL criteria in the structure as seen in Figure 10 for products with multiple systems.

Tetlay and John also made evaluations on the concepts of System Maturity and System Readiness and emphasized the definition of Capability Readiness Level (CRL) (Tetlay and John, 2009). Although a metric has not yet been introduced within the scope of the CRL, Tetlay and John have linked the concepts of "V-Model" in System Engineering with System Maturity and System Readiness as mentioned in Figure 11 (Tetlay and John, 2009). System Maturity covers the production and verification of the product according to system requirements, while System Readiness shows the availability of the product to user requirements.

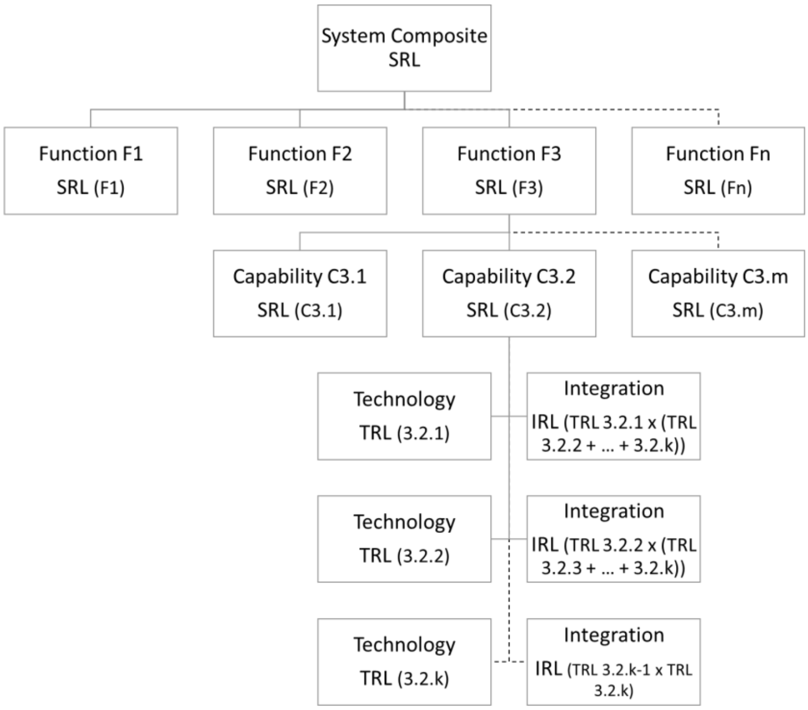

Figure 10. *TRL, IRL and SRL Relation*

In various studies, research has been carried out to eliminate weaknesses related to SRL scale and calculation methods. Between 2010 and 2014, IRL definitions have been studied and methods have been sought for accurate calculation of SRL levels for complex systems. In a study conducted in Turkey in 2014, literature review has been studied on the subject, and it can be said that the study is valid in current situation (Babaçoğlu et al., 2014).

For research and development programs involving software and hardware technologies, SwRL and HwRL concepts and criteria are also studied for software and hardware technologies at the lowest level in the product hierarchy.

A similar criterion by the Joint Defense Manufacturing Technology Panel, established by US military and defense industry representatives under the

Department of Defense, was introduced in 2001 to measure the maturity of production activities. MRL has been defined at 10 levels in correlation with TRL levels. A guide document called MRL Deskbook was prepared and the latest version was published in 2018.

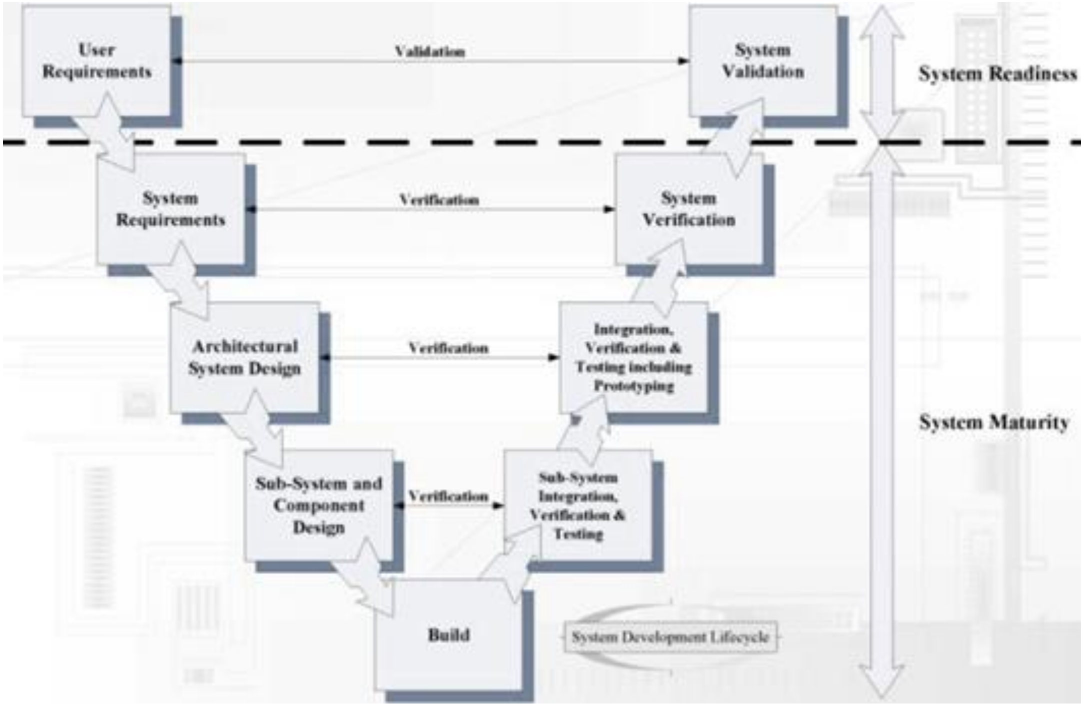

Figure 11. *V-Model Relation with System Maturity and System Readiness*

All readiness levels are subjective due to the flexibility of metrics, the ability to derive or rearrange criteria (Tetlay and John, 2009). In order to be used correctly, it requires expert personnel to evaluate. The level of readiness can be decided with the participation of relevant stakeholders. The presence of software infrastructure or guidance documents to allow evaluations is required (Sauser et al., 2006).

In product development projects, project execution processes regarding technical coverage are carried out by using system engineering processes. Systems engineering tools support project management activities in the management of other areas of knowledge as well as technical scope. Technical performance management procedures for monitoring and controlling the technical progress of the project are also used to assess system maturity. The technical performance is followed up in the iterative product development process and verified and reported. Technical performance metrics can be selected at different levels in the requirement hierarchy. Numerical metrics used to validate operational scenarios are defined as Measure of Effectiveness (MOE) and Measure of Suitability (MOS). And they are determined to measure how close the system is to its intended use. Measure of Performance (MOP) metrics that complement the MOE & the MOS metrics are determined for the performance that the user expects from the system. Functional requirements that support usage scenarios and performance requirements are broken into subsystems and components and technical budgets are distributed at lower levels. The Technical Performance Metrics (TPM) is also determined for these technical budgets distributed at a lower level. It is possible to vary or increase these technical metrics horizontally and vertically in the hierarchy of requirements. The metrics defined by the Austrian Ministry of Defense are given as follows in Figure 12 (Defense Capability Development Manual, 2006).

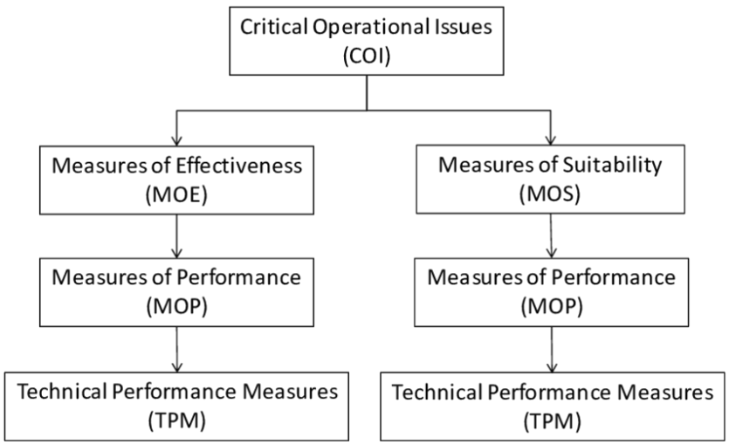

Figure 12. *Systems Engineering Technical Performance Measures*

The development activities are guided by the verification activities and maturity in the V-Model with TPM and MOP while MOE metrics have been used to validate user expectations. Lower and upper limits are determined for each metric and these metrics are collected over time to predict future trends. As a result, these metrics are also used as a project management tool in determining the direction to go by identifying critical trends and values. In this way, the situation between customer expectations and system realizations can be monitored.

Capability maturity models provide information on how active and comprehensive the relevant processes are used in an organization or project. In this study, organisational or project management process maturity models are not emphasized since the focus is on system / product maturity and technological maturity of the components. To put it briefly, CMMI makes two different evaluations: capability and maturity measurement ("Capability and Maturity Levels", t.y.). Maturity measurement is used to measure the effectiveness of how much the organization defines and can control defined areas of activity. Maturity is defined at six levels from 0 to 5. On the other hand, capability measurement is concerned with the consistency and predictability of the process outputs for each defined process/activity area and with the continuous improvement. Considering that the process outputs are spread over the normal distribution, it is expected that the deviations in a skilled process will be low and the outputs will gather around the peak. Capability is measured in four levels from 0 to 3.

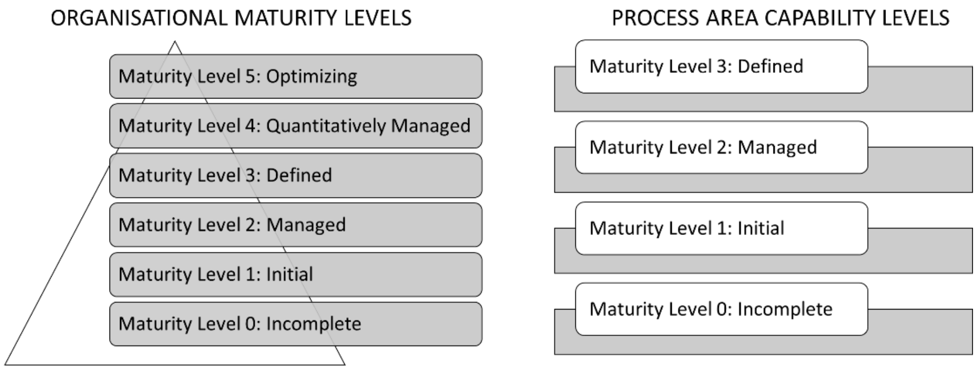

Figure 13. *CMMI Maturity Levels and Capability Levels*

Apart from the software development processes, CMM approach has many areas where it is adapted, especially project management and system engineering management. In this context, there is also rich literature. It is seen that SE-CMM study emerged in 1995 for system engineering processes. It was then standardized in 2002 as *EIA-731 Systems Engineering Capability Model* standard. Improvement of the standard is underway.

2.3 Working Maturity Models

Radical innovations are aimed in Defense and Aviation Industry. As a result, technological complexity and inter-component interaction are expected to be high. This also leads to complexity of engineering activities and engineering processes. In order to manage the complexity and technical difficulties and to support the project calendar and budget targets, institutions and companies establish their own technical management, control and monitoring processes.

AIRBUS defined the Product Lifecycle Cycle, in which it can synchronize its engineering processes with 5 main phases and 14 milestones as shown in Figure 14

(Pardessus, 2004). The associated activities in this lifecycle utilize a concurrent engineering approach and digital product infrastructure to operate together to improve effectiveness and efficiency. It has managed to combine different product-specific information (product requirements, design data, production planning, maintenance data, etc.) around the product tree at different levels.

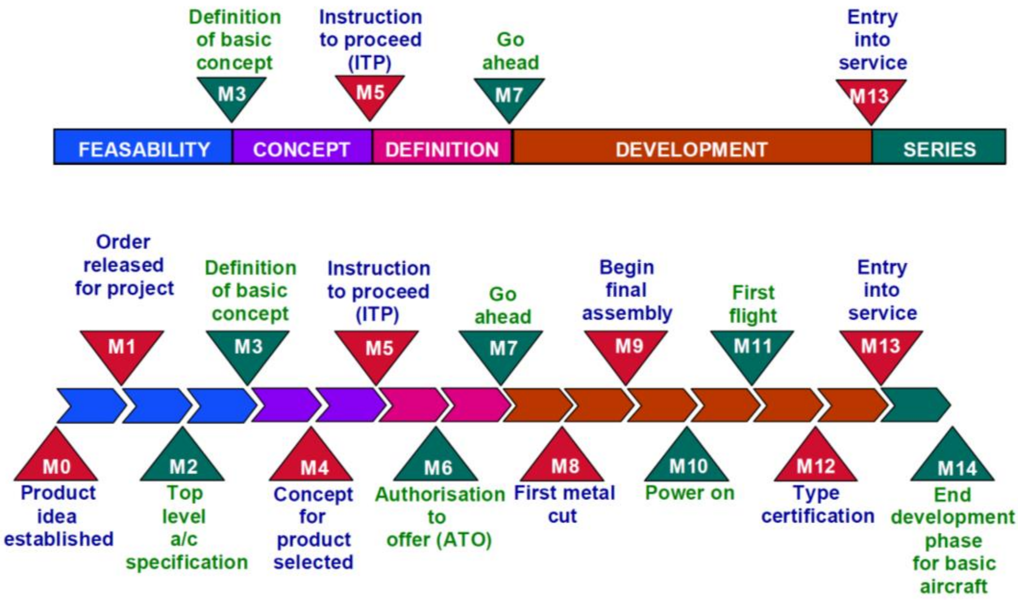

Figure 14. *AIRBUS Product Lifecycle; Phases and Milestones*

Evaluation of product maturity and making future decisions are based on this product lifecycle. In order to monitor the design activities between M3 and M7 and to achieve maturity in the product as a whole, their additional Development Maturity Levels are defined in 3 scales. By capturing the mentioned maturity, it is aimed to design the products which can be produced, assembled or maintained in operational phase. Due to gathering experts from different disciplines around data of a certain maturity, interactive exchange of information may provide development of the data. In this way, instead of sequential activities, simultaneous engineering approach enables shorter development times. Definitions of *Development Maturity Levels* are summarized below. These levels are complemented by engineering reviews through digital workflows for each design solution and component.

Maturity A: It aims at dimensioning and space allocations in accordance with the concept of the aircraft and determining the scope of design solutions to meet the required functions. Critical measurements and structural interfaces are determined. Rough alternative design solutions are created in different configurations to meet the requirements. Requirements and conceptual engineering reviews are conducted with data of this maturity. A level maturity contributes to the determination of the optimal solution.

Maturity B: In this maturity, key characteristics and tolerances (KC&T) are defined in the context of structural design and system integration. Specific zones or components are reviewed in detail and improvements are made to the most suitable alternative solutions. System layouts are completed dimensionally, main electrical and flow routes are detailed. Preliminary design maturity is sought. The parameters that will enable mold and tool designs for production and assembly infrastructure are tried to be put forward.

Maturity C: Finalization of final dimensions to be used in load analysis, finalization of structural interfaces between parts and regions, and finalization of interfaces with assembly tools and production molds are expected in this maturity. Production and installation infrastructure is aimed to be ready. Definition of flight test instrumentation is also expected. The main touch points for production and assembly are revealed. In summary, the critical maturity of design data is sought for the maturity of production and assembly, and for structural load analysis.

A similar approach is seen when examining ISO / IEC 15288 and NATO AAP-20 NATO Lifecycle Model documents referring to this standard. In the system engineering approach, the maturity and technical progress of the systems are tried to be monitored. The relevant product lifecycle consists of 7 consecutive stages as shown in Figure 15. However, the flexibility that the stages can be operated simultaneously is also seen on the figure. Each stage is divided into sub-phases by the milestones defined within itself. The transition between the stages is enhanced by the decision steps by meeting defined input and output criteria. The scope of each stage and phase is defined, and also expectations for product maturity at milestones and decision points are defined.

The NATO AAP-20 standard envisages the creation of a common language among members and the integration of technical management at the Product Lifecycle approach. It is evaluated that wide perspective of Product Lifecycle approach will increase integration between acquisition, usage and maintenance. Moreover, time and cost can be used more efficiently because different activities support each other. With this approach, it is mentioned in NATO AAP-20 that industries of member countries will be able to work integrated with each other. Due to this integration, it is also mentioned that quality will increase globally considering common defined processes.

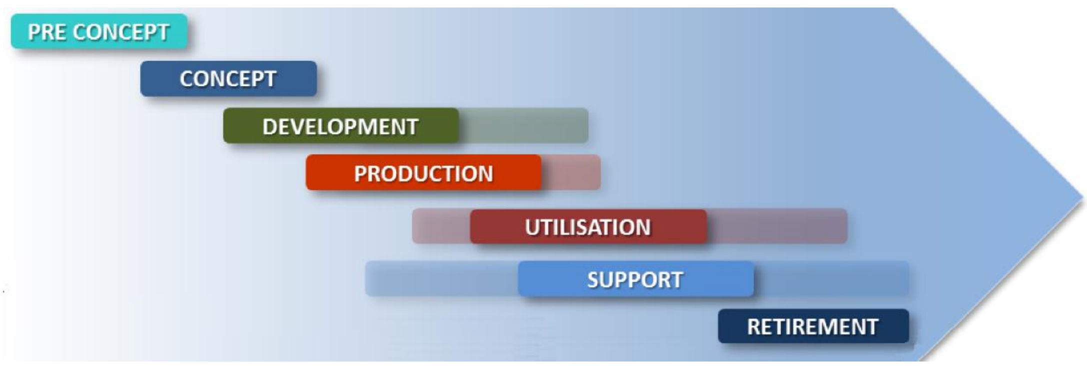

Figure 15. *NATO AAP-20 System Lifecycle*

The IEEE 15288.2 “Reviews Technical Reviews and Audits on Defense Programs” standard is adapted from the ISO/IEC/IEEE 15288 standard for military applications. Instead of the product lifecycle definition in this tailored standard, an evaluation approach with input-output criterion has been established with 4 technical outlines and 10 technical reviews. In IEEE STD 15288.2, relevant decision-making is seen as the basic building block for an effective system engineering approach and strong technical evaluation process. These decision points enable the determination of the technical maturity, uncertainties and risks of the product. They allow to examine the effect of the current situation on project/acquisition schedule, product total cost and product usage characteristics. If the current maturity is acceptable, the decision to move to the next phase is taken.

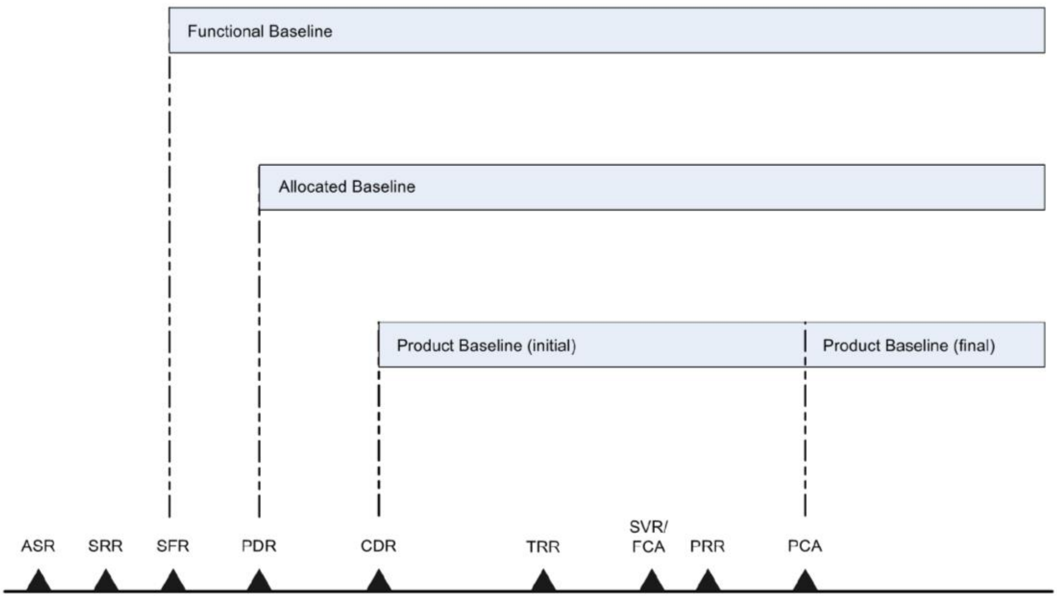

Figure 16. *IEEE15288.2 Technical Reviews, Audits and Baselines*

As mentioned before with the Development Maturity Levels in AIRBUS, product development has been monitored to support production, assembly, and flight testing. Similar to AIRBUS but in a more systematic way, when the product lifecycle management is examined in the US Department of Defense, manufacturing readiness is closely focused with defined criteria. In addition, technologies are followed through technology readiness levels in lower detail in product breakdown.

MRL Deskbook provides a holistic view of the US DoD's view of product maturity and acquisition processes as in Figure 17.

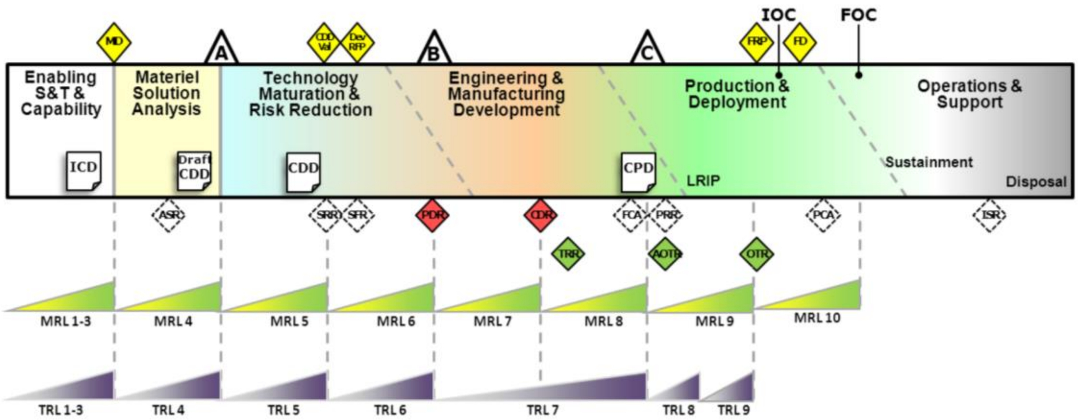

Figure 17. *Acquisition Lifecycle, TRL and MRL Relations*

2.4 Traditional Studies about Technology Maturity in Turkey

Four studies were found in literature researches. Considering the limited number of academic studies, it may be said that there may be a need for further studies.

Altunok and Cakmak (2010) started the study in 2008 and aimed to develop an algorithm for the calculation of Technology Readiness Level for companies in Ankara, Turkey. After this study, a TRL calculator was formed as a software tool. Firstly, a literature search was made for TRL calculations and then the models used in calculating TRL in civil and military fields were examined. In this study, system development and technology development activities are handled separately. It has been revealed that technology maturity should be reached before the system development programs started. However, it has been determined that the methods used in TRL calculations can be subjective and that a common application method cannot be operated.

In the second stage, Altunok and Çakmak tried to understand the awareness on the issue through the company up to 17 in Turkey. TRL applications were seen in only 3 companies working closely with universities.

The main part of the study is the development of a TRL calculation algorithm for Turkey Defense Industry sector. A software for executing this algorithm was also developed. The technologies related to hardware, software and production processes can be collected and classified according to certain criteria (nationality, confidentiality, usability of technology in different areas, funding type etc.) by the developed tool. Then, in four categories (technology related, manufacturing related, programmatic related 6 integration related) questions were asked respectively and the status of the technology is determined by four colors (gray, red, yellow and green) according to the answer. The questions had a classification as critical and not critical. Critical knowledge of the questions could be adapted according to the project with the initiative of the project manager. The technology that responds positively to all critical questions turns green and means that the technology has reached the relevant TRL level. This method was operated iteratively for each TRL level in the study.

Evidence supporting the answers can be associated with questions by the technology developer. It has been emphasized that this feature would provide a more objective assessment environment. The criticality of the project-specific questions is mentioned among the weaknesses of the algorithm.

Altunok and Çakmak evaluated that their TRL calculator can be used after the validation of the algorithm at the level of software and hardware. However, it has been considered that the calculator will be insufficient to monitor the technological maturity of the aircraft in conclusion of the study.

A comprehensive literature search that made in Turkey was conducted by Babaçoğlu, Akgün and Kayhan (2014) about monitoring the technological maturity. It would not be wrong to say that the study was handled in two contexts.

The first scope includes studies on technology definition, TRL, SRL, IRL and MRL. The ways in which these criteria are handled by the US DoD and OK MoD are mentioned. Acquisition processes, in other words, their usage with product lifecycle are discussed. Critics about the usage areas of the scales and calculation methods are included in the study. It has been mentioned that TRL can obtain information about individual technologies and it is insufficient in evaluating system maturity. Taking TRL level as a risk value from the opposite point of view is not appropriate for accurate risk determination. Because technologies at the same level may different amount of resources and labor to reach the full maturity. Similar weaknesses have also been addressed for MRL. Furthermore, progress and efforts on the SRL approach have been addressed. Normalized SRL levels paired with US DoD acquisition processes have been also emphasized. At this point, it has been emphasized that SRL is an average value of the numerous technologies that make up the system. According to the study, combining a complex, immature high-risk technology and simple and high-mature technologies under a single scale was insufficient to determine system maturity and future risks. The second scope of the study focuses on defining the level of risks and future effort with a view of maturity levels. At this point, the R & D difficulty levels introduced by Mankins (1995) has been mentioned.

Recent evaluations of Babaçoğlu et. al. are important. In order to evaluate the maturity of the system with different mature technology, decision makers should have knowledge about the whole system. It has been mentioned that maturity assessment tools are inadequate to identify risks and future challenges. At this point, it is mentioned that new methods are needed. It has been pointed out that group or multi-criteria decision-making mechanisms should be established for an accurate assessment in which the existing tools remain subjective. It has been recommended that follow-up maturity evaluations should conducted through a central unit and database.

The third research was prepared in collaboration with the university and industry which revealed a product-based technology management methodology (Temiz, Özkan and Üçer, 2016). It aims to provide methodology for the selection, prioritization and planning of product technologies by using the technological capabilities of nations. In the study detail, technology, system and product pyramid have been established similar to previous ones. It has been mentioned that conceptual design activities come to the forefront in the selection of technologies. Attention has been drawn that it is important to acquire the technologies that can be used in diversifying or increasing the product capabilities. It has been said that technology and product development stages are separate, and that product development can be started after reaching a certain technological maturity. The TRL approach has been used in the selection and monitoring of critical technologies to be used in the product in the the study. However, it has been stated that this metric should be supported with evidence in order to be reliable. Finally, it has been evaluated that the acquisition of critical technological capabilities in the field of defense and aviation prevents the use of national capabilities. There is also reference to the lack of a systematic risk assessment process in the study.

The latest study on technology maturity assessments is mostly a handbook rather than an academic research as *Technology Readiness Levels for the Defense Industry* which was prepared by Presidency of Defense Industry (SSB) as a guide (Savunma sanayii için teknoloji hazırlık seviyesi kılavuzu, 2015). The guideline has been created by compiling TRL definitions. It is aimed to raise awareness in the sector. In conclusion, some weaknesses in TRL approach have been mentioned. It is remarkable that the TRL focuses on a particular technology that is defined as critical and also leaves the system integration process backward. The subjective aspect of TRL assessments has been also emphasized. At this point, it has been given importance to expert evaluation to be done as a group in determining the maturity level. It is said that the usage of technology readiness assessment and risk management processes are limited in Turkey so that there is a necessity in this context.

Considering difficulties in monitoring the technical maturity in project management processes, limited studies conducted in Turkey in this regard and determinations made as a result of current studies; technological maturity assessments are a subject which should be studied. Despite criticism, the TRL metric and assessment methods have been widely accepted and widely used at the level of software and/or hardware components. However, the studies at the system or product level remained theoretical and have not come to life in practice. It is evaluated that the real situation can only be revealed with the determination of product maturity. At this point, there is a need for a more holistic, multi-criteria and expert group decision-making process beyond the SRL approach. The creation of methods that can be used to limit the subjectivity is considered important as it will increase the reliability and accuracy of the evaluations. Information management and change management approaches are also needed to create and monitor product information in a healthy way. These mentioned issues are taken into consideration in the model which is determined within the scope of this thesis.

CHAPTER 3

RESEARCH METHODOLOGY AND MODEL DEFINITION

3.1 Rationale for the Research Method

The relationship between the main areas of activity compiled by Çetindamar, Phaal and Probert and the technology management methods is given in the table below. (Çetindamar et al., pg. 170).

Table 3. *TM Main Activity Areas and Methods*

Methods / *Activity*	Patent Analysis	Portfolio Management	Road Map	S-curve	Stage-Gate	Value Analysis
Acquisition	X					X
Exploitation			X	X		
Identification				X	X	
Learning		X	X			
Protection	X				X	
Selection		X				X

As highlighted in Section 1.1.2 in the thesis, *Identification* and *Selection* activities come to the forefront. *S-curve*, *Stage-Gate*, *Value Analysis* and *Portfolio Management* are among the commonly used methods for these areas of activity.

S-curve approach is defined by metaphor from the lifecycle of living things. Horizontal axis can be defined based on different stages such as embryo, birth, growth, maturity, old age and death. This approach is similar to the concept of product lifecycle, which has been also mentioned in working models. In the vertical axis, technology performance parameters are included. While the S-curve can be designed for the whole product, defining the vertical axis with a single parameter for the whole product is an academically studied research in literature but is not an easy issue to deal with practically. The S-curve can be used as a useful method for identifying existing or individual new sub-technologies. (Çetindamar et al., 2013, pg. 206). In this study, the idea of a lifecycle is adopted for the whole product similar to the S-curve.

According to Cooper, the stage-gate method is defined as the project management tool used in new product development projects (Çetindamar et al., 2013, pg. 213). The project duration is divided into specific phases or stages and gates are formed during stage transitions., Many multidisciplinary activities are performed during the stages. In the gates, decisions, such as *go on, return to the beginning, return to the previous or cancel the project,* are made after a multi-parameter decision process. The method is coordinated with product lifecycle phases and technical review approaches. Stage-gate method is considered as the main method in this study.

The value analysis tool is the method used to increase the value of the product since the past. The market value of the product is defined by how much of the expected benefit from the product can be taken from it. The financial definition is defined as the ratio of product profit to product price (Çetindamar et al., pg.223). The definition of value and the definition of validation have similarities. Validated product means a product that meets customer requirements. At this point, efforts are made to ensure that the ratio of “product usage characteristics” per “customer usage characteristics” is at least “1”. When the sectoral structure of the defense and aerospace industry and value concept are considered together, it is seen that the Customer / User follows the activities in stages and acts as the decision responsible in the gates. In this study, value definition which is close to *validation* is used rather than *profit / price* definition. There are many compliance methods for verification of expected value of the product during long aircraft development lifecycle such as usage of simulators, mock-ups, prototypes and user flights and other criteria belongs to gates.

The thesis focuses on the development and maturity of a single aircraft. So that, *portfolio analysis* has not been used in the study.

When constructing the product maturity model, it has been evaluated that the life approach in the S-curve method and the Stage-Gate method could be used together. The vertical axis in the S-curve is divided into technical processes in different layers in this study. Qualitative or quantitative process outputs are spread along the vertical axis. Gate points on product life are defined on horizontal axis, too. Performance parameters and verification targets for value estimation are also included in the model.

The interview technique will be used as a research method to evaluate the accuracy of the model designed with reference to working models and with guidance of technology management methods.

3.2 Definition of A Model

3.2.1 Hypothesis

When the theoretical framework, best practice standards and guide documents and sample models are examined together in terms of discussion in this thesis; the following hypotheses have been formed in order to define technological maturity at system / product level and to follow the maturity.

HP1: Product Lifecycle model provides a systematic common approach about interoperability in product acquisition and operation phases to complete the whole product life in a cost-effective and timely manner in accordance with the realities of the project. So that a Product Lifecycle Model needs to be established or selected.

HP2: The decision gates and review points which are passed jointly by different stakeholders or by relevant responsible individual staff should be defined in the Product Lifecycle. By this way, phase transitions can be realized by relevant decisions.

HP3: The desired capability of the product with the necessary functions can be realized by completing the sequential and simultaneous technical processes, sub-processes and activities carried out within the scope of these processes and by creating interfaces between them.

HP4: Progress in technical processes need to be supported by qualitative expert opinions and quantitative objective metrics at relevant decision points.

HP4.a: Each activity should be associated with the product phases and sub-stages and the outputs of the phases should be determined.

HP4.b: The MOP, MOE and TPM definitions, used to support monitoring and control activities in system engineering and project management, provide information about the capability readiness level.

HP4.c: Compliance verification methods and completion states of them provide quantitative information about the maturity of the stages.

HP4.d: It is practically impossible to use SRL as a rational measurement method without a strong technology management and taxonomy infrastructure for the whole product. However, it can only be used as a tool for system integration of focused technologies.

HP4.e: It is appropriate to use the TRL approach to monitor the maturity of focused individual technologies under the Systems Engineering processes.

HP5: Associating data collection and change control procedures with product lifecycle and decision points / milestones is important for recording, reporting and guiding system maturity.

3.2.2 Model Establishment

Under this title, solutions that support hypotheses have been tried to be selected and a model has been put forward by adapting some solutions.

The MIL-STD-499: 2017 standard was revoked by the US DoD and replaced by IEEE 15288.1: 2014. IEEE 15288.1: 2014 is an adaptation of the ISO / IEC 15288: 2008 standard. AAP-48: 2013 NATO standard is also built on the basis of ISO / IEC 15288. ISO / IEC 15288 has been chosen by the US DoD and NATO as the basis of operation and has a broad technical scope compared to equivalent system engineering standards / manuals so that it has been chosen as the first reference in creation of the model. The system lifecycle concept, which is required by ISO / IEC 15288, is defined and customized by AAP-20: 2015 for NATO applications. Technical review and audit principles and criteria are included in the study methods with the IEEE 15288.2: 2014 standard for US DoD applications.

Considering practices of Turkey Aerospace and Defense Industry sector, adaptations have been made at some point on the basis structure during establishment of the model. In the last stage, other source standards, guidance documents, academic studies and technology maturity level approaches have been used to determine the technical processes, phase input-output criteria and exact inputs and outputs in the sub-detail.

3.2.3 HP1: Definition of Product Lifecycle

According to the first hypothesis, Product Lifecycle can be formed in 6 sequential phases. When selecting the names of the phases, the terminology in the reference standard or guidance documents is partially excluded. Considering the executed current project progresses and stages in Turkey, new terminology and definitions have been added.

1. **Operational Concept Definition & Feasibility:** The *Pre-Concept* phase in the AAP-20 standard and the *Feasibility* phase in the AIRBUS model are defined in similar scope.

   The operational needs of the users and the usage scenarios of the product are determined in this phase. The functions required to realize the scenarios and the performance values that define the effectiveness of these functions are defined at a high level, taking into account the capabilities of competing or threatening systems. After these benchmarking, alternative products or product families that can meet operational needs are identified. Then, the requirements are derived and overview of the product definition that meets the needs is tried to be completed. Feasibility studies are carried out for the development and realization of the product. Pre-concept design studies are carried out with separate feasibility contracts or public internal resources for validation of needs and benchmarking of competitors or solutions. Technological needs and roadmap are tried to be identified and selected. Technology development and demonstration sub-contracts may be used in high budget aircraft development programs to support the main program and aircraft level design activities with extension of the schedule of the first phase. Development and lifecycle costs are tried to be determined for the products that are decided to be developed. Finally, Presidency of Defense Industry is instructed about investigation, development, prototype production, advance payments, long-term orders and financial and economic incentives for Defense Industry Executive Committee approved products (Savunma Sanayii ile İlgili Bazi Düzenlemeler Hakkında Kanun, 1985). The decision to start the project is taken with this instruction. The next step for the products to be developed is to define the administrative and technical execution processes and to make the technical requirements more defined and verifiable. The call for proposals and contracts are finalized by the Presidency of Defense Industry. The next phase is passed after the selection of the contractor and the signature of the contract with all technical requirements, administrative and technical requirements .

2. **Concept Definition:** AAP-20 and AIRBUS lifecycle models are also discussed in similar scope for this phase.

   In this phase, it is ensured that the technical requirements defined by the contract are understood correctly by the stakeholders especially the Contractor. The Contractor identifies features that he / she considers to be incomplete. Afterwards, the validation of the requests with the customer and the user is completed. In this way, the top level requirements for the product are introduced at the beginning of the phase. After this point, according to the ARP-4754 document which was established as a guide document for the development of aircraft and its systems, following activities should be performed; i) determination of the aircraft functions, ii) assignment of the functions to the systems expected to be in the product, iii) establishment of the system alternative architectures for how the systems will perform these functions, and iu) setting out of the requirements for the subcomponents of the architectures in the product sub-detail or in the component top level. In brief, it is expected that system and component level requirements and alternative architectural solutions will be created to meet these requirements. The airworthiness requirements mandated by the relevant aviation authority, which must be applied to the conceptual designs are understood. It is considered that this phase can be completed by focusing on an option among conceptual designs in line with customer-user demands.

3. **Design Definition:** The scope of the *Development* phase described in the AAP-20 standard is evaluated too wide. It is known that development activities are an iterative process and that current development projects can never be reached verified and validated products at once. Because of that the *Design Definition* phase is defined similar to the AIRBUS approach. The phase covers the development activities up to the time when the first design data comes out for starting prototype production.

   In this phase, it is expected that very small number of special cases which have not been finalized due to alternatives and the lack of detailed design solutions should be agreed with the aviation authority.

   It is the phase in which the selected optimal conceptual design is studied in detailed study, and in which sub-system and system level procurement and implementation begin. After this phase, it is aimed to gain functionality of many systems and disciplines, to complete the first cycle of product level integration design and to create design details ready for manufacturing, assembly and testing. It is expected that design verification activities are begun by design description and analysis documents. Trial manufacturing and capability demonstrations can be done in the system and in the lower detail. At the level of software and hardware components, verification activities may be partially initiated. Manufacturing and installation planning and the establishment of the test infrastructure begin intensively in this phase. It is envisaged that this phase will be finalized by making a manufacturing decision for prototypes based on verification.

4. **Development Phase:** This phase is needed in order to make the transition more defined between *Development* and *Production* phases in AAP-20, and it includes common activities from both phases. It is the phase in which prototype products are implemented and integrated, test validations are started on these prototypes, and design corrections and improvements are applied. It is suitable for the approach in the AIRBUS model. Customer and user involvement is expected to intensify and to be more involved in design decisions. Provisional / conditional acceptances can be completed and validation of the trial products under the actual usage conditions by cooperation of the Contractor and the User. It is considered that this phase can be completed by verifying all customer and airworthiness requirements, and making the product ready for operational use and mass production.
5. **Deployment & Modification:** This phase is needed in order to make the transition more defined between *Production* and *Utilization* phases in AAP-20, and it includes common activities from both phases. It overlaps the *Series* phase in AIRBUS model but is defined in a narrower scope. When the acceptance and guarantee clauses in the contracts and the applications of conditional acceptance and acceptance are taken into consideration, *Deployment & Modification* phase has emerged as an intermediate phase in the transition from production to use. It is more similar to the objectives of the *Production & Deployment* phase in the US DoD lifecycle model. The difference in the new model is that, important manufacturing activities have already started within the *Development* phase. In particular, the length of this phase may vary depending on the complexity of the product and the magnitude of the risks it carries up to this phase.

The completed products are accepted by the customer, taken into the user inventory and started to serve in the actual operational environment in this phase. If there are infrastructures needed for use of the product in the real environment, it will be completed. User trainings are completed. Possible product modifications and modernisations can be maintained in this phase as well. This phase is completed by the user's full validation of the product and the completion of the acceptance for the products unconditionally. The start of the warranty process for each product is also a completion requirement of this phase.

6. **Operation & Support:** It includes the common activities in the last 3 phases of the AAP-20 after the *Production* phase is completely finished. It is similar to *Operations & Support*, the last phase in the US DoD. This phase is not clearly defined in the AIRBUS model.
   the product is operated under the responsibility of the user and the logistics, maintenance, repair and renewal activities are coordinated in the phase. Under the supervision of the aviation authority, the Contractor shall maintain product support for situations affecting flight safety. Product life and last phase are completed with disposal of the products.

The completion of the phases will not occur at a point in time for the whole product; maturing system, subsystem or component will be completed relevant phase in a transition period. In 4th phase *Development* the products are integrated and realized; in other words, the embryo period was finished and the product was born. From this point on, it is considered that the product lifecycle should be monitored separately for each physical product or defined product group.

3.2.4 HP2: Definitions of Decision Gates and Technical Reviews

Throughout the Product Lifecycle, there are joint decision points where all or some of the user, customer, design organization, production organization and aviation authority participate. As a result of the stakeholders' opinions, decisions are taken by responsible belongs to the relevant gate. In addition, there are decision points that companies or institutions operate in their own internal structures. All decision steps in the model are defined by a single terminology as in the AIRBUS model as *Milestone*.

First of all, in order to make the definition of this hypothesis, a decision gate / milestone has been defined for the initiation of each phase. Then, the points considered important from the working applications have been added to the milestones. As a result, 13 milestones in Table-4 have been reached. Based on the IEEE 15288.2 standard, joint technical reviews and audits within the scope of system engineering are also positioned according to the milestones in the Table.

In IEEE 15288.2, technical review or audit points have been defined especially for the public side in order to monitor the project, identify risks and analyze the effects of risks on calendar, budget and usage. The following 10 technical review or audit points aim to pave the way for the next stage in the project.

1. Alternative systems review (ASR)
2. System requirements review (SRR)
3. System functional review (SFR)
4. Preliminary design review (PDR)
5. Critical design review (CDR)
6. Test readiness review (TRR)
7. Functional configuration audit (FCA)
8. System verification review (SVR)

9. Production readiness review (PRR)
10. Physical configuration audit (PCA)

In the AIRBUS model, 15 milestones were similarly identified during the transition of the stages in phase and transition of the phases in lifecycle. The description of AIRBUS milestones under Section 2.3 Figure-14 was given earlier.

US DoD continues its product lifecycle with 3 milestones and 4 decision gates. These decision points are supported by 9 technical reviews. Milestones characterize decisions to reduce technological risks, initiation of product development and production, respectively. They are usually started execution with separate contracts. Program management, product development process and system engineering planning and activities are carried out by the public with the participation of relevant contractors.

With M3, the remaining life of the product can be monitored under a single contract or progress can be carried out in separate contracts, especially by dividing from phase transitions. The exponential growth of technical risks will be prevented and a new planning will be provided by the sequential contract structure. In addition, returning to previous phases for missing verification and validation issues and the application of an iterative development approach with a focus on problem areas may result in more mature and verifiable products at the end. In this case of sequential contract structure, the returned phases will be handled in a limited scope and will be passed more quickly. Additive contract management will help achieve results with low controllable budgets.

Table 4. Milestones

Milestones	Rational 1	Rational 2	Rational 3
M1: Capability Requested	Operational Concept Definition & Feasibility Phase Start Decision		Capability Request
M2: Project Initiated		ASR	Project Decision
M3: Contract Time Started	Concept Definition Phase Start Decision		Start of Contract
M4: Top Level Aircraft Requirements Defined		SRR	A/C Functions Defined (ARP 4754)
M5: Design Solution Selected	Design Definition Phase Start Decision	SFR PDR	Systems Functions Defined (ARP4754) Start of Design & Development Contract
M6: Production Released	Development Phase Start Decision	CDR	Initial Production within QC (AIRBUS Model)
M7: Lab / Ground Tests Released		TRR	
M8: Flight Test Released		FTRR	
M8a: User or Authority Flight Released		FCA SVR	Validation Flight Conditional Acceptance TC Released
M9: Type Certificate Held	Deployment & Modification Phase Start Decision	PRR PCA	Start of Production Contract
M10: High Rate/Serial Production Released			High Rate Production within QC

Table 4 Cont'd

M11: Final Acceptance Completed	Operation & Support Phase Definition		Final Acceptance End of Contract
M13: Service Life Completed			Disposal Decision
Rational for related milestone *Rational 1: Phase Start* *Rational 2: Systems Engineering Technical Reviews* *Rational 3: Important Points from Working Models*			

Overview of completion criteria for each milestone or in other word outputs of ecah milestone is given below in Table 5 considering phase definitions and objectives of technical reviews. Additional inputs and outputs of technical process should be added to this content.

Table 5. *Completion Criteria Related to Milestones*

Milestone	Completion Criteria or Outputs
M1	Receiving of the request for new product/capability derived from User's opeartional concept analysis
M2	Operational concept definition Benchmarking report of rakip ve tehdit Definitions of Measures of Effectiveness, Sustainability and Performance Technological capability requirements Definition of technology development programs Feasability report Development and lifecycle cost estimations Defense Industry Executive Committee Approval

Table 5 Cont'd

M3	Provisions of technology development programs Technical spesifications of the aircraft Plans for investigation, development, prototype production, advance payments, long-term orders and financial and economic incentives Signed contract
M4	Market analysis report Safety analysis report at aircraft level Definition of aircraft functions Definition of verifiable requirements from technical spesifications, market analysis and design decisions at aircraft level (TLAR - Top Level Aircraft Requirements) Manufacturing readiness at MRL4 Technological readiness at TRL4 for all sub-systems or equipments
M5	Definition of functions of systems Definitions of aircraft design variants Definitions of architectural design for systems with alternatives Safety analysis reports at system level Definitions of Design Assurance Levels for hardware and software Definition of structural and systems requirements with installation provisions Approval of certification basis by the Authority Definitions of TPMs at aircrfat and system levels Manufacturing readiness at MRL5 Technological readiness at TRL5 for all sub-systems or equipments SOI#1 outputs for hardware and software developments
M6	Approval of first revisions of design data belongs to structure, systems, system installations and harness for manufacturing of prototype aircraft (Design descriptions & drawings) Analysis reports as a proof of compliance Revised safety analysis reports Approval of equipment list and receiving of COTS Manufactured parts and sub-assemblies

Table 5 Cont'd

	Manufactured installation tools and jigs Manufacturing and installation plans Laboratory test procedures Technological readiness at TRL6 for all sub-systems or equipments SOI#2 outputs for hardware and software developments
M7	Initial manufacturing and implementation of parts with quality and configuration records Almost integrated prototype aircraft Laboratory test reports Ground test procedures Manufacturing readiness at MRL7 SOI#3 outputs for hardware and software developments
M8	Fully integrated prototype aircraft Ground test reports Flight test procedures Equipment qualification evidences Flight limitations and safe flight envelope Authority approval of flight contions & flight release Flight manual Maintenance manual & log book Technological readiness at TRL7 for all sub-systems or equipments Delta SOI#3 outputs for hardware and software developments
M9	Flight test reports Equipment qualification reports Inspection records Functional Configuration Audit report Delivery of at least one aircraft to the User for IOC validation Verification report Type Certificate Authority approval of Aircraft Flight Manual Authority approval of Aircraft Maintenance Manual & AC log book

Table 5 Cont'd

	Technological readiness at TRL8 for all sub-systems or equipments Manufacturing readiness at MRL8 SOI#4 outputs for hardware and software developments
M10	Physical Configuration Audit reports for low rate integrated aircrafts conform to TC Delivery of aircrafts to the User for FOC validation Authority approval of Type Design changes Validation report of the product/aircraft and manuals Technological readiness at TRL9 for all sub-systems or equipments Manufacturing readiness at MRL9 Delta SOI#4 outputs for hardware and software developments
M11	Investigation reports related to occurences or accidents Authority approval of modifications and integrations Acceptance of serial production aircrafts with Certificate of Conformity (CoC) or Certificate of Airworthiness (CoA) Completion of personel tarinings and their certificates Acceptance reports of facilities Closure of development contract with final acceptance report Warranty agreements for each delivred aircraft Manufacturing readiness at MRL10
M12	Investigation reports related to occurences or accidents Authority approval of modifications and repairs Maintenance and operational log books Closure of warranty contract per each physical aircraft
M13	Retirement of aircraft from service
Note: Detailed inputs and outputs of technical process should be added to this content. Sample study is reached in Section 3.2.6 for Structural & System Installation Design Process and Interfaces of the Process.	

3.2.5 HP3: Definitions of Technical Processes and their Interfaces

According to IEEE 15288 reference, 4 groups of processes are defined; *Agreement, Organisational Project-Enabling, Project and Technical*.

Agreement Processes

The Agreement process can be defined as the management process for all product-specific contracts. It covers service, raw material and sub-component contracts with suppliers to develop, implement, integrate and support the product. In addition, the management of the commitments to customers is carried out under this process.

Organisational Project-Enabling Processes

Aviation products must be certified by the relevant aviation authorities in order to use them safely and to keep the possible risks at an acceptable level (Airworthiness of Aircraft, 1944). Therefore, it requires that the aviation authorities as well as the customer and the user be added to the processes as a stakeholder. For aviation projects, it is considered beneficial to add the Certification Management process to the Organization Project-Enabling process group similar to the Quality Management process. The Lifecycle Management process is discussed under HP1 and HP2. Other processes under the Project-Enabling group have not been considered because of poor relations with this thesis problem.

Project Processes

Technical review activities are mentioned within the scope of the project processes. In parallel with this activity, the technical reviews and configuration audits in IEEE 15288.2 were added to the model in addition to the milestones created within the scope of HP2. Other planning activities related to labor force, schedule and budget planning activities are not elaborated because of their weak relationship with the thesis.

The main problem for this study is the difficulties to perform the Project Assessment and Control process and the inability to operate the Decision Management process effectively. Considering the multidisciplinary, long lifecycle and complex technical scope of aircraft development projects, monitoring of technical maturity becomes quite difficult. It is also impossible to make an accurate assessment of the project schedule and budget, and to run the Decision Management process without technical maturity, risks and operational status. Configuration and Information Management processes also come to the forefront in order to ensure that the decision makers in the project are formed correctly and that the feedback can be controlled in case of possible changes. In this context, configuration baselines are defined and integrated to the model.

According to this hypothesis, in order not to lose the real focus and to limit the study, the technical processes have been focused. 11 technical processes are defined in this context; *Stakeholder Requirements Definition Process, Requirement Analysis Process, Architectural Design Process, Implementation Process, Integration Process, Verification Process, Transition Process, Validation Process, Operation Process, Maintenance Process, Disposal Process*. In IEEE 15288.2 standard, it is emphasized that the processes can be run sequentially or simultaneously, moreover the companies can add additional technical processes. The overview image of the model created in this thesis is given in Figure-18. In order to ensure the common understanding of terminology, the definitions in the references have been adhered to as much as possible.

Technical Processes

The *Requirement Definition* process starts with the definition of the requirement and continues with the creation of usage scenarios. Subsequently, the basic functions and performance characteristics are handled as annexes to the development contracts. A top level aircraft requirement set is created by completing the remaining deficiencies in user and customer expectations and collecting operational environment requirements. This process continues to be used in assigning the lower level requirements according to customer and user expectations and updating the requirements.

Requirement Analysis and *Architectural Design Processes* are repetitive processes at the aircraft, system and component level. It is a multidisciplinary and interactive design process. In addition to architectural design, aircraft and system level other design activities will be discussed in this process. For this reason, it is defined in the model as *Design Process*. According to the certification specifications that define the minimum safety requirements, it is understood that design activities are performed approximately in 20 disciplines (MIL-HDBK-516C, 2014). These disciplines can be expanded vertically and horizontally. In the model, design activities are grouped to simplify.

Specialized system design activities and flight safety approach for aircraft are integrated and defined in the ARP-4754 guidance document. The expectations of the aircraft are gathered, and their functional and architectural provisions are distributed to the systems within the safety perspective. These activities can be considered the beginning of aircraft system design activities. As an output of the activities criticality data shapes the lower level system, hardware and software design processes.

Design activities continue at the aircraft level, especially in the field of flight technologies. These design activities are aimed at meeting flight performance requirements. Aircraft characteristics, external geometry and dimensions, weight and balance ranges, flight loads are studied. Outputs are vital for structural design and flight mechanics system design activities, which are sub-design processes. Moreover, aircraft and system level requirements analyzes and verifications are carried out by conducting analyzes in the scope of special engineering areas such as flight science, supportability and maintainability, weight and balance, material and process, loads, safety, reliability and testability, electromagnetic and environmental effects.

Structural design and system layout design activities are performed to ensure the structural integrity of the aircraft. Structural components and system interfaces which are designed to withstand loads from aircraft level and system level, and to support lifespan and environmental conditions, are designed in this phase.

Many systems that perform flight and mission functions are also designed to perform the expected functions in the desired performance and reliability in accordance with the budgets coming from the aircraft level related to the loads, environmental conditions, weight and balance. The power and data cabling of the systems is a joint design activity. The manufacturing and installation procedures of harness are also different than others. For this reason, it would be beneficial to show the model separately under the design processes. However, it may also be considered in system design process.

In first phase of the lifecycle design activities are performed to identify the characteristics and technologies of the aircraft. Aircraft concepts that meet operational needs are studied considering threats and support elements in pre-concept design process. This process mainly consists of aircraft and structural level design activities. Some space allocation models can be created to prove engine or system installation provisions.

When the aircraft BOM is considered, hardware and software are system subcomponents. At this point they are part of the system design. Although the hardware and software development processes are integrated among themselves, they are partially separated from the system design after receiving the system requirements. Many capabilities other than aircraft structural and aerodynamic performance are acquired in technology-intensive software and hardware design development processes. For this reason, the latest hardware and software design activities in the development schedule and BOM hierarchy are handled as an additional technical process as *Technology Development* in the model.

Implementation is the process of preparing detail parts and components. The compilation of software, and manufacturing or purchase of hardware and structural components are made available through implementation process. *Integration* refers to bringing together the functionality of the systems in sub-assembly and final assembly lines. The process includes the establishment of manufacturing and assembly lines, preparation of support tools and equipment, determination of operation sequence, determination of manufacturing quality and inspection steps and procedures. Activities Supported by various additional processes such as shipment, supply of raw materials and storage.

Validation and *Verification* processes extend throughout the lifecycle. Equipment, laboratory, ground and flight tests are part of the verification and validation processes, except manufacturing and assembly compliance tests. Simulations are also considered in this context. Development of test environment include a small development lifecycle and technological maturity management in itself. Test environment requirements are collected and analyzed then design, production and validations of test devices are performed. No academic studies have been reached at this point. Test Readiness Levels (TstRL) may be handled in a similar and integrated manner to TRL, SRL and MRL approaches. In the scope of this thesis, TstRL is described in the model but the details are not studied.

Transition process involves the establishment of the necessary infrastructure for operations of the product, shipment and installation of support equipment, and activation of many additional activities such as operator and maintenance trainings. *Operation* process includes activities such as aircraft safety monitoring, MRO (maintenance repair and overhaul), training and operation. These activities have many interrelations with each other and with air traffic and aerodromes. Activities in this phase are subject to intensive regulations and inspections determined by the aviation authorities. While the contribution of this phase to the technological maturity of the product is limited, the technological experienced gained at this point is valuable for the development of new products and technologies. In order not to enlarge the scope of the thesis, this phase is not elaborated.

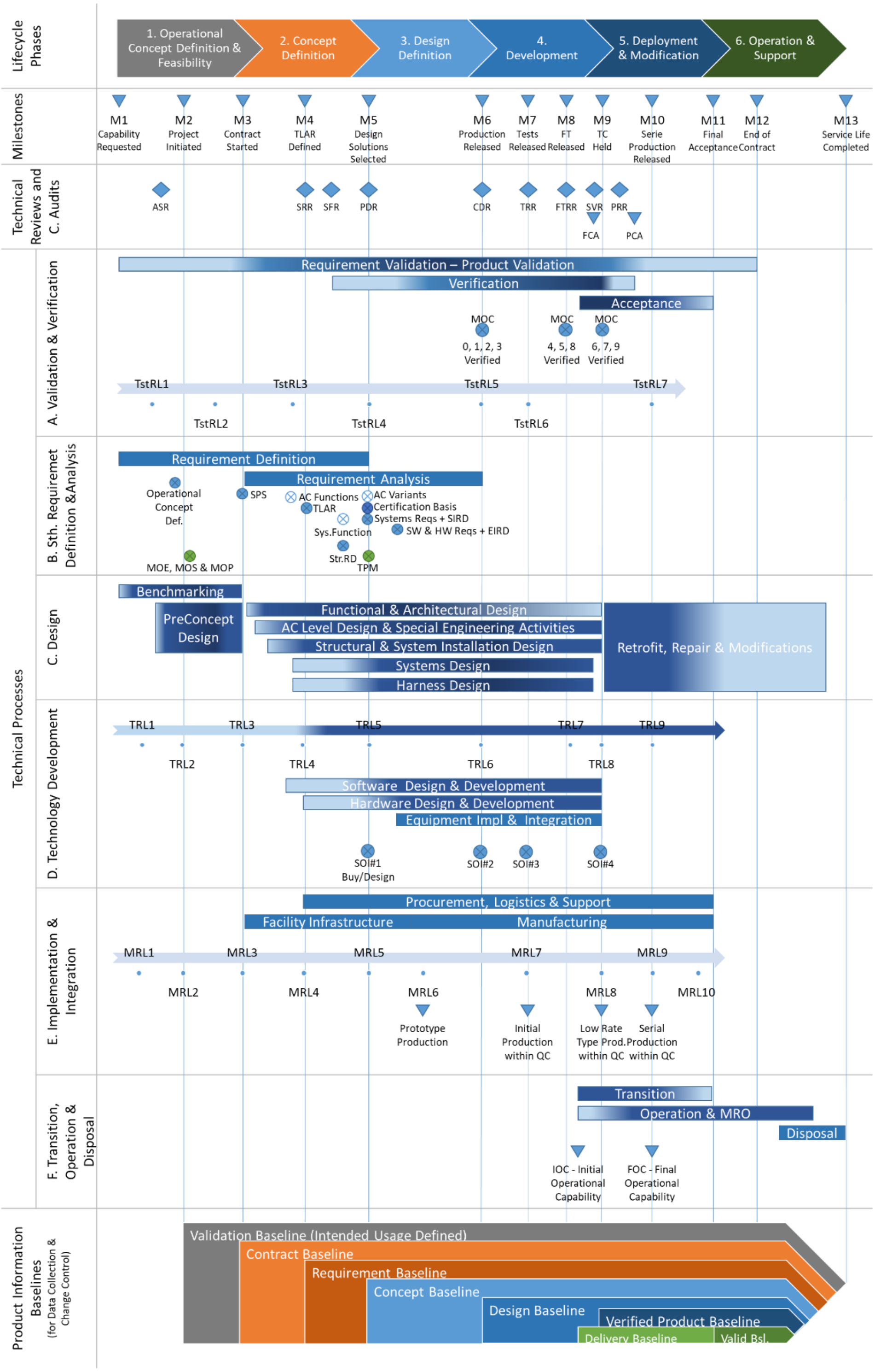

Figure 18. Product Maturity Management Model Overview

3.2.6 HP4: Definition of Qualitative and Quantitative Criteria

Progress in technical processes need to be supported by qualitative expert opinions and quantitative objective metrics at relevant decision points. It requires an extensive study that determining the inputs and outputs of all technical processes for a complex and multidisciplinary product such as an aircraft, and the assignment of adequacy criteria of the inputs and outputs. In order to keep the work at a manageable level and to define the HP4 scope, the model is detailed only around the *Structural and System Installation Design* technical process in *Concept Phase*. The process outputs and the adequacy of the outputs constitute the output criteria of the relevant stage and phase. The exit criteria are associated with milestones and their qualifications can be determined qualitatively by expert opinions.

HP4.a

Structural and System Installation Design process and its relations with other technical processes are defined in Figure-19 according to HP4.a phrase.

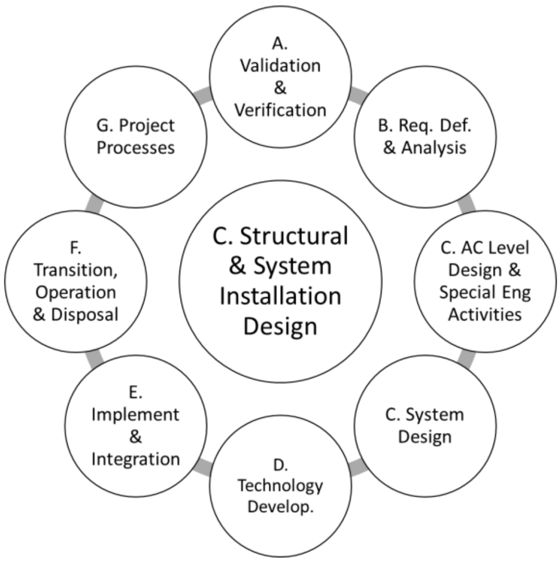

Figure 19. *Structural & System Installation Design*

Unless specifically cited; the activities, inputs and outputs of the process have been created by tailoring AIRBUS and Turkish Aerospace design guidelines.

Table 6. *Sample Detailed Technical Process and Its Inputs/Outputs*

<table>
<tr><td colspan="4">Phase 2: Concept Definition (M3 - M5)
Structural & System Installation Design Process and Its Interfaces with other Technical Processes</td></tr>
<tr><td>Process</td><td>Activity 2c1 2c2</td><td colspan="2">Inputs/Outputs</td></tr>
<tr><td rowspan="2">C. Structural & System Installation Design</td><td>M3 > M4
2C : Estimating the weight of the structural parts by dimensioning the main structure. Initial dimensions are made using the main points on the main geometry, taking into account the center of gravity envelope.</td><td>•Master Geometry
•Weight Envelope-A</td><td>•St. Weight Assumption
•Initial rough sizing
•Rough SysSpace Allocation</td></tr>
<tr><td>M4 > M5
2C: Sizing of Primary Structural Element and determination of Secondary Structural parts are provided. In the fail-safe design concept, space and caps are provided for accessibility requirements.

2C: Initial sizing of the critical regions is completed to verify the stress spectrum.

2C: Alternatives in part types are eliminated. Part types (composite, sheet, extrusion, etc.) are decided. Although material assignments are not finalized, they are assigned for next load verifications.

2C: Space allocations are made according to the weight budgets and sizes of the systems whose equipments are determined and the system interfaces are modeled. The main routes are determined, space allocation is made for systems with cable, hose or tube components.

2C: Equipment parts list and models are prepared with the current data. The connection interfaces of the equipments and pipes are paired with the Master Geometry. Preliminary design data is generated.

2C: Structural Configuration Items (CIs) are determined. The first revision of the Structural Design Document is created.</td><td>•StRD
•Master Geometry
•Weight
•Envelope-B Critical Structural Parts</td><td>•Preliminary Structural Sizing and Parts
•Preliminary SysSpace Allocation
•Rough equipment and interface models
•StDD</td></tr>
</table>

Table 6 Cont'd

C. AC Level Design & Special Eng Activities	2C : Aerodynamic surfaces and forces are computed numerically and analyzed with experimentally to create external geometry and main geometry. 2C : An initial estimate is made for the weight envelope and weight budgets to support flight performance. 2C : Initial loads for aerodynamics, structural, weight, maneuver, flutter, vibration, ballistics, separation, etc. are calculated.	•CAT	•Initial Loads-A •Weight Envelope-A •Master Geometry
	2C: The second cycle of the load analysis is completed with the design data formed after the concept definition and the other analyzes such as updated performance, weight, maneuver. 2C: Critical regions are determined by stress accumulation analyzes that will also validate life requirements in SPS and OCD. Safe-life concept is created. Design parameters are determined (Candan, 2016). 2C: Primary Structural Element definitions and Fail-Safe Design concept are determined (Candan, 2016). 2C: Damage Tolerance & Crack Propagation concepts are created (Candan, 2016). 2C: Corrosion Prevention Concept is created to fulfill the operational requirements in SPS and OCD. 2C: Load conditions, damage tolerance and crack propagation concept, environmental usage conditions (heat / pressure cycles, vibration, corrosion etc.) technical requirements, the existing capabilities of the company, new material and process laboratory test data are used to create a material database. A list of frequently used materials is created to limit material diversity in usage. Critical processes and inspection points are identified.	•SPS •OCD	•Loads-B •Weight Envelope-B •Approved material database and frequently used material list •Critical process and inspection points •LLTI & unqualified material list •Fail-Safe Design Concept •Damage Tolerance & Crack Propagation concept •Corrosion Prevention Concept •Stress critical regions and design parameters •Critical Structural Parts

Table 6 Cont'd

C. AC Level Design & Special Eng Activities	2C: Raw materials and fasteners that are long lead time or are not qualified for supply are identified. Risk and mitigation are defined. 2C: A critical parts list is created for parts that are susceptible to stress accumulation, damage or corrosion. The monitoring of these components continues from this phase to the end of the product lifecycle (Candan, 2016). Fatigue Fracture Critical (FFC) parts can be added to this list in the following phases. Although safety is not a concern, parts that are critical to procurement, production, infrastructure or logistics need to be realized. They can be added to the list with a separate description.		
C. System Design	2C : Systems that perform aircraft functions are roughly identified and Systems CIs are created. Outlines are specified for systems that require piping or wiring.	•AC Functions and Allocation	•Sys.CIs
	2C : Aircraft functions are assigned to systems. System architecture and equipment components are defined after analyzing issues such as system functions, function and equipment design assurance levels, redundancy requirements (ARP4754A, 2010). 2C: System Interface Requirements are created.	•AC Functions and Allocation	•SIRD •Sys. Equipment List
A. Validation & Verification	2A1: Life requirements are validated with existing dimensions in accordance with the maintenance concept (Çelik, 2017).		•Proof of compliance belongs to life requirements •Proof of compliance belongs to the loads
B. Req. Def. & Analysis	M3 > M4 2B1: Identification of requirements and formation of Configuration Allocation Table (CAT) is completed. Aircraft functions are studied. The aircraft level requirement set is generated from SPS and OCD. 2B2: Assignment of functions to systems and system definitions are determined.	•SPS •OCD	•AC Functions and Allocation •TLAR

Table 6 Cont'd

B. Req. Def. & Analysis	M4 > M5 2B3: Structural Requirement Document is created and updated as required after the inputs from TLAR analysis, load analysis, weight budget allocation, production and assembly tolerances and parameters, machine capacities, material and process list. 2B4: System functions are determined. Systems requirements are published for the first time (SRD-A) to design system layout and equipment layout. 2B5: Aircraft fixed and plug-in configurations are optimized and possible variants are identified. 2B6: As a result of the type certification, the safety requirements from the certification specifications are added to the structural requirements.	•AC Functions and Allocation •TLAR •Initial Loads A & B •Fail-Safe Design Concept •Stress critical regions and design parameters •Weight Envelope A & B •Maximum machinable part sizes •Manufacturing and assembly tolerance values and parameters •Approved material database and frequently used material list Certification Specifications	•StRD •Systems Functions •SRD-A •SIRD-A •AC Variants
D. Technology Development	*An interface could not be established for this phase with the Structural & System Installation Design process.* *Manufacturing maturity is discussed under Implementation & Integration processes.* *Material maturity is discussed under AC Level Design & Special Eng activities.*		

Table 6 Cont'd

E. Implement. & Integration	M3 > M4 2E1: MRL 4 maturity is aimed; a. New manufacturing technologies required to realize TRL4 and above technologies are analyzed and identified. b. Possible manufacturing risks and mitigation actions for prototype production are analyzed. c. The facility, the material, the need for new talent is determined. Manufacturing cost items and target budget forecast are evaluated. 2E2: The initial tolerance values for the manufacturability are determined. Maximum sizes of structural parts are determined by considering machine capacities.		•Initial tolerance values •Maximum machinable part sizes
	M4 > M5 2E3: MRL 5 maturity aimed; a. Identification of newly needed support and critical manufacturing technologies are finalized. b. Risk and mitigation processes in manufacturing technologies are finalized. c. The new materials, tools and personnel qualification are tested in the manufacturing test environment, but many processes and procedures have not been ready yet. d. The manufacturing cost is introduced for the first time. 2E4: Assembly and tool concept is created. The carriage, interface and geometric control points between the tools and parts are determined. Critical measurements and parameters are determined. Tool orders for prototype production are published.	•Critical process and inspection points •Approved material database and frequently used material list •LLTI & unqualified material list •Implement critical parts	•List of new manufacturing technologies •Assembly and tool concept •Product-tool interfaces •Tool orders •Manufacturing cost definition •Manufacturability risks and mitigations
F. Transition, Operation & Disposal	*An interface could not be established for this phase with the Structural / System Installation Design process.*		

HP4.b

Quantitative criteria may benefit the closure of subjective disagreements by supporting the qualitative completion criteria in the previous section. At this point, the definitions of MOP, MOS, MOE and TPM used to support system engineering and project management monitoring and control activities will provide important information about the level of readiness of capabilities. Related metrics can be defined under the *Requirement Definition process*. It is considered appropriate that the MOE and MOP metrics are the basis for validation and could be selected from the top-level user requirements or within the OCD. Defining MOE, MOS and MOP at the *M2: Project Initiated* milestone will make a significant contribution to understanding the expectations at the beginning of the project and creating a common technical language. These metrics must be understood at the *M3: Contract Started* milestone and validated for the last time at the *M4: TLAR Defined (SRR Technical Review)* milestone. In this way, a healthy design and development environment can be created for the company and an effective monitoring method can be used by the public.

TPM metrics appear during the distribution of budgets from aircraft level to lower levels of numerical targets during the analysis of requirements. It will be important to consider these values after the relevant verifications to determine the direction in which the design is going. A combination of different TPM metrics will also help to optimize the design. It is considered that the TPM list may occur during the determination of system requirements.

It is important to note that TPM metrics are not part of validation and do not constitute a constraint for alternative design solutions.

HP4.c

Determination of system functions and architectures starts after passing the *M4: TLAR Defined (SRR Technical Review)* milestone. Later on, first verification activity is performed verification of the safety objectives with logical mathematical analyzes (ARP4754A, 2010). Although the verification activities are almost complete with the issuance of the Type Certificate (TC), there may be ongoing design improvements due to the requirements that cannot be verified. Therefore, verification activities continue partially after the TC until the unconditional acceptance of the product. It is important to distinguish verification activities and acceptance processes, and to see verification activities as part of the design cycles.

It can be said that the verification activities consist of analytical and numerical analysis, experimental analysis in the laboratory, ground and flight tests, respectively (Çelik, 2017). European Aviation Safety Agency (EASA) has determined the compliance verification methods in Table 6 by adding design identification, equipment conformity documents and physical examinations methods (AMC & GM to Part 21, 2012). It is considered that these methods can be used to monitor verification activities.

The verification activity proceeds iteratively in coordination with the design cycle. It is not possible to say that a complete verification can be completed before the design. However, leaving all verification activities to an end makes it impossible to monitor the adequacy of the design. Many of the outputs described at the beginning of this hypothesis also correspond to a compliance document. It is considered that the relevant milestones output criteria can include compliance documents. Completion percentage of compliance documents with a certain percentage can be also added quantitatively as output criteria.

It is considered that engineering evaluations (MC0-MC3) may be completed in high percentage until the *M6: Production Released (CDR)* milestone. In this gate, almost first issuance of all applicable compliance documents will be published.

It is thought that laboratory tests, ground tests and simulations (MC4, MC5 & MC8) should be completed with a high rate at the *M8: Flight Test Released (FTRR)* milestone. Assessments of the impacts of the remaining tests on flight tests are expected by aviation authorities. Equipment qualification (MC9) may be distributed throughout the development process (AMC & GM to Part 21, 2012). Prior to flight tests, inspections (MC7) and equipment qualifications (MC9) are checked and the impacts of possible deficiencies on the flight are assessed, however no full compliance verification is expected. Verification of all safety requirements should be completed at the *M9: TC Held* milestone. M9 gate may also be referenced for verification of whole product specifications. Verification of a small number of requirements will be completed at the final acceptance of the product. These exceptions should also be followed after M9 milestone.

Table 7. *Means of Compliance Codes for Verification*

Types of Compliance	Means of Compliance	Associated Compliance Documents
Engineering evaluation	MC0: - Compliance statement - Reference to Type Design documents - Election of methods, factors .... - Definitions	- Type Design documents - Recorded statements
	MC1: Design review	- Descriptions □ Drawings
	MC2: Calculation/ Analysis	- Substantiation reports
	MC3: Safety assessment	- Safety analysis
Tests	MC4: Laboratory tests	- Test programs - Test reports - Test interpretations
	MC5: Ground tests on related product	
	MC6: Flight tests	
	MC8: Simulation	
Inspection	MC7: Design inspection/ audit	- Inspection or audit reports
Equipment qualification	MC9: Equipment qualification	Note: Equipment qualification is a process which may include all previous means of compliance.

HP4.d

As mentioned before in Section 2.2, it will not be easy to calculate the technological maturity of a multidisciplinary and multi-system product such as aircraft with IRL and SRL mathematical calculation methods. These calculations require a complex data collection and monitoring infrastructure. The applicability of the methods without information technology and process infrastructure is not considered possible in practice. The IRL and SRL models can only correspond to real life for several systems desired to be monitored, taking into account the interfaces associated to the systems. It is considered that the stages, decision gates, qualitative and quantitative evaluations created within the scope of this study may be barely sufficient for monitoring product maturity and technical risks.

HP4.e

A new technical process has been added to the model besides defined ones in the ISO / IEC 15288 standard. The maturity of software and hardware components consisted in lower level of the BOM can be considered under *Technology Development* process. The progress of this process can also be made by TRL assessments in relation to the aircraft lifecycle. It is assessed that technologies that have reached at least TRL3 level at the point of *M3: Contract Started* decision gate can be used in the aircraft development studies. Decisions can be taken to develop these technologies.

At the *M4: TLAR Defined (SRR)* milestone, product expectations are agreed. After this gate, it is expected that aircraft functions and safety objectives will be set. However, it is too early to define requirements for equipment level. After the *M4: TLAR Defined (SRR)* milestone, the aircraft and system functions are subject to safety assessments as required by ARP4754. Design assurance levels (DAL) are assigned to flight critical functions and equipment that meets these functions. DAL levels shape the procedures and principles that must be carried out for the systematic elimination faults from software and hardware components. The activities and objectives to be followed for each DAL are defined by the documents DO-178 and DO-254. DO-178 and DO-254 require the initial planning of software and hardware development processes, respectively. These planning activities can be started for the technologies which have proven their functionality in the laboratory and have achieved TRL4 level. Plans will help adapt existing technology to aircraft.

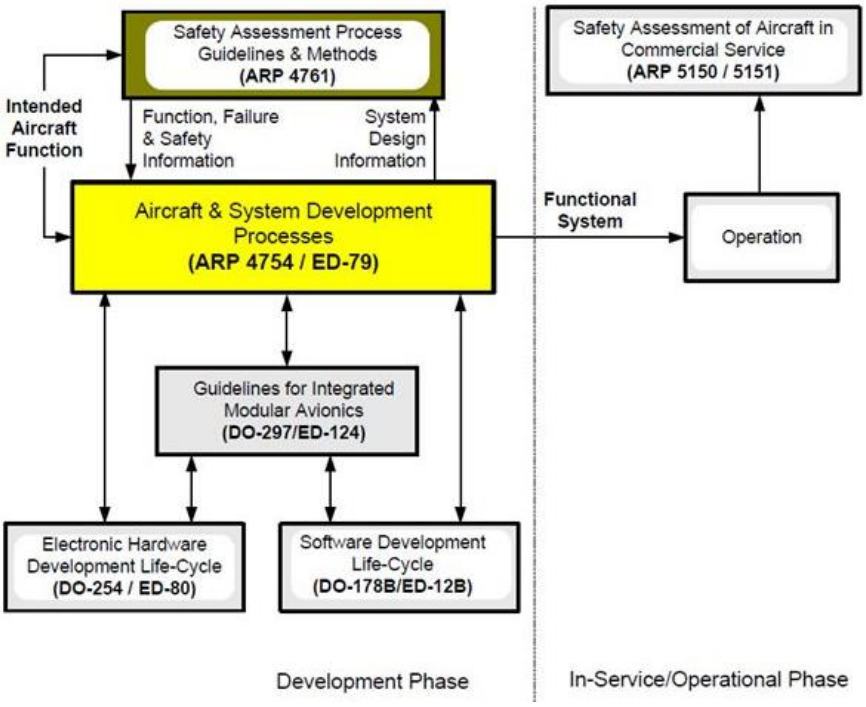

Figure 20. *Guideline Documents related to SAE ARP 4754*

The activities to be completed in accordance with the DO-178 and DO-254 standards are monitored by the aviation authorities through four stages as Stage of Involvement Review approach (Software Approval Guidelines, 2018; Software Aspects of Certification, 2012);

- SOI#1 Planning Review: This phase aims the completion of planning and standard-setting activities to support development. Future activities are determined to develop equipment in consisting with aviation standards.
- SOI#2 Development Review: Requirements, design and codes are reviewed. Details about completeness, accuracy and traceability are examined. This review may commence upon completion of at least half of the relevant activities of the end product.
- SOI#3 Verification Review: Reviews may begin with the completion of at least half of the activities for requirement verification and testing.
- SOI#4 Final Certification Review: This review can be done after the final eligibility reviews, software compilation and verifications are completed. It aims sufficient maturity for system certification approval.

At the *M5: Design Solution Selected (PDR) milestone*, it is decided that the development will continue with one of the design alternatives. Hardware and software strategies need to be determined for systems to be developed and implemented. At this point, system alternatives and system components are also determined in high percent. The expectations of the subcomponents have been almost ready and development decisions can be made if there is technological maturity to meet these expectations. Otherwise, it is considered appropriate to continue with the procurement of ready on the shelf equipments in order not to add higher technical risks to the product development process. In order to integrate technology into the aircraft and to negotiate supply agreements, verification of basic functions and minimum performance on the bench at TRL5 is considered important. There will be intense development activities related to the improvement of technology and adaptation to aircraft in the following phases.

In this context, additional control steps required for aircraft certification have been added to the *Technology Development* process and TRL approach in the model.

When the *M5: Design Solution Selected (PDR)* milestone is reached, SOI#1 authority audits are expected to be completed for the software and hardware components which were decided to develop.

Similar mappings between milestones, TRL levels and SOI controls are made in the model and summarized in the table below. The relevant assessments may not be a single point. They may be combined or often completed over time as repetitive reviews. The points defined in the lifecycle indicate the completion status of the reviews.

Table 8. *TRL, SOI & Milestones Matching*

SOI#	Milestone/ Review	TRL	Importance of Maturity for Interface with System Design
1	5/PDR	5	Basic functions and minimum performance are verified on the table at TRL5 level. Emerging technology has been chosen as the system component to be used in aircraft. Necessary planning and standards have been prepared in order to reconsider hardware and software development process in aviation standards.
2	6/CDR	6	Requirements from TRL5 level have been reassessed and equipment (software, hardware, and integration) requirements have been redefined to match system requirements. The design at TRL5 level has been reconstructed by harmonizing with the aircraft. Verification activities continue at software and hardware levels. Physical and functional aircraft interfaces have been completed. TRL6 level prototype equipment has emerged.

Table 8 Cont'd

3	7/TRR	6-7	Software and hardware components have been tested together and verification activities have been largely defined. System integrations of prototype products are ready to be made. The maturity to be able to start the system tests has been reached. Almost TRL7 level can be mentioned for equipment which has completed the tests despite the remaining nonconformities coming from ground and flight tests.
4	9/SVR	8	Nonconformities resulting from system ground and flight tests have been corrected. Delta reviews were repeated. The hardware, software, equipment and system tests were completed on the ground and in flight, respectively. Functional, performance and environmental verifications have been completed. TRL8 level has been reached. Verification of reliability features in the operational environment will continue. There is no obstacle to aircraft certification.

3.2.7 HP5: Identification of Baselines

The main subject for many processes under the *project processes* (Assessment and control, configuration management, information management, measurement) is related to the systematic collection and identification of data. Status monitoring, analysis and reporting enable data to be converted into information and gained value. Real-time status monitoring has been almost reached with current information technology with well integrated systems and infrastructures. However, in practice, there is no need for instant decision-making. Status reporting at milestones is more meaningful for decision-makers. An effective data sharing and change control take place at the detail of status monitoring. At this point it is important to determine the baselines and to identify responsible for each baseline (EIA649C, 2019).

Standards offer general baselines. However, decision gates in contract and milestones in the lifecycle require adaptation of these baselines. The baselines that will enable this infrastructure are defined and associated with the product lifecycle and milestones in the model as seen in Figure 21.

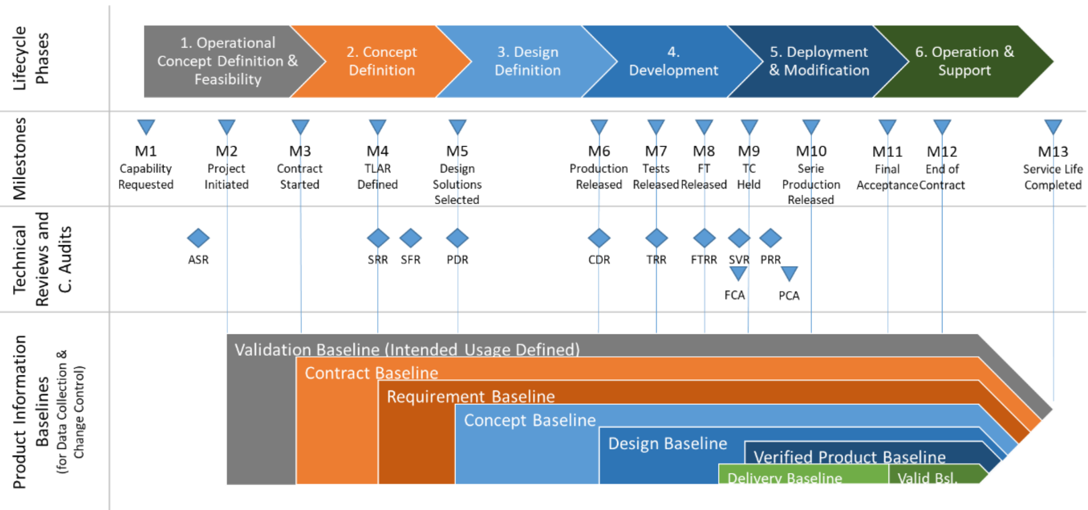

Figure 21. *Product Information Baselines in relation with Lifecycle Phases*

At the end of each phase, the data collected during that phase is expected to be recorded and published. If there is a change in the data that is the output of the completed phase, the corresponding baseline is affected. The relevant data needs to be assessed by the responsible stakeholders of the baseline.

3.3 Validation of the Model

The qualitative data collection method, *Interview*, will be used for the verification of the Aircraft Development Maturity Management Model described in Chapter 3.2. The interview was designed in a semi-structured manner. The peer review questions listed in the Annex of this study and model were shared with participants before. The interview is planned to complete around the research problem, hypotheses and model. However, new methods and improvements suggested by the participants about the hypotheses are considered important for the elaboration of a working model. At this point, there is no restriction and the interview will be supported by open-ended questions.

Interviews will be held individually, not collectively, to limit the interaction between participants. The interview will begin with a description of technology management, its methods and existing maturity models. The interviewer will then provide brief information on hypotheses and solutions. Finally, the interviewer will ask the questions to the participants in a chat or sequential manner.

Expert or technical managers from Turkey, who worked long time on indegeous aircraft development projects and especially took duties and responsibilities about monitoring of technological product maturity, were selected during determining participants. Most of the participants have experience in both side as a customer or contractor.

CHAPTER 4

CONCLUSIONS

In this section, the interview results used to validate the model are shared. After the semi-structured interviews, the adequacy and accuracy of the solutions presented in the model have been evaluated. During these evaluations, it has been examined whether the problematic was accepted by the participants. At the end of the chapter, the topics that need to be updated in the model and the important issues that can be studied in the upcoming period are summarized which is obtained from the interview results.

4.1 Validation of the Problematic

The problematic is given at the end of Sections 1.1.1 and 2.4 in the thesis. In summary, it is said that there are deficiencies in the development of high-tech aircraft, such as monitoring of technical maturity, defining technical risks, advancing the project with rationally formed objective decisions, evaluating the retrospective effects of possible changes and accepting the results. The first interview question in the Appendix A has been prepared for the interviewees to understand the problematic and to get their opinions about the problematic. The problematic has been owned by the participants. The following evaluations have been collected from the interviewees regarding the source of the problem and the environment in which the problematic has been experienced.

The project and technical plans are prepared according to internationally accepted standards to meet almost all the needs. However, there are cases where inefficiencies occur in practice. The main contractors have largely achieved PM-SM integration. Technical processes are run in a way that supports the project processes. However, the Customer and the User side have not been able to capture this synergy. The main reason for this is strongly and jointly highlighted by interviewees as the lack of knowledge and expertise on both Customer and User project groups who should follow the plans and processes. It was also mentioned in the interviews that frequently changing assignments have a negative effect on this situation. The technical processes under Systems Engineering cannot be used sufficiently by the Customer and the User as supportive elements during contract preparation and project management decisions. In addition, the delay in users' involvement in technical decisions causes the risks to be shifted to the end of the projects and felt higher. On the other hand, the customer has a weakness in correcting the deficiencies on the user side and creating numerical metrics to monitor the progress.

In addition, the Customer cannot adequately monitor the technical maturity during the preliminary and detailed design phase. The awareness begins with testing and verification activities. In this case, the calendar and cost effects are incrementally increasing towards the end of the development. Sub-contractors and main contractors tend to avoid problems and risks if they find that the technical follow-up on the Customer side is insufficient. The reasons for this behavior are about concerns related to the Customer. According to the interviewees Contractors think that Customer will not support them, but it will go to some restrictions during contract. An other reason is mentioned as the convenience of Contractors about accepting the products with their deficiencies at the end of the day.

Technological components cannot capture the aircraft integration from the development maturity point of view. Some of these risks can be identified before the contract. However, responsibility for resolving technical risks identified by the customer is often left to the main contractors within the scope of contracts. And no joint action plan belongs to technology development can be determined in time. At this point, it is considered useful to create long-term strategic action plans rather than spreading technological risks to the aircraft development program. If maturity monitoring of sub-technologies is to be carried out within the scope of the main contract, it is deemed beneficial to perform subcontractor management with Customer and User participation if necessary by the participants. It has been considered appropriate that the manage should be performed closely in accordance with the model created for the aircraft.

4.2 Confirmation of Hypotheses and Solutions

In the conclusion secondly, hypotheses and evaluations of the solutions presented in the model are given. The key outputs collected from the participants for each hypothesis are given below.

Hypothesis 1

The presented phases were accepted by all participants. Interviewees expressed that completed aircraft modification and development projects in Turkey by Presidency of Defense Industry (SSB) and Turkish Ministry of Defense (MSB) have formed a common language. There may be different terminologies and approaches which are not common and are applicable to some contractors.

As we are used to seeing in some US-based aircraft development projects, the first phase in the model can be divided into two parts depending on the complexity of the product. *Technology Demonstration and Validation* phase may be added for prototype development before the *M3: Contract Started* milestone. It is considered that the implementation of this phase is not practical due to the limited availability of domestic aircraft developers and the lack of their own financial resources other than government funding At this point, a opposite opinion has not been taken from the other participants. It has been proposed that new proposed *Technology Demonstration and Validation* phase and *Operational Concept Definition & Feasibility* phase can be passed faster or in a combined way for previously developed similar products. In the case of development projects with high technological innovation and complexity, proposed new phase will help to better describe the progress, to minimize risks in advance and to mature high-level requirements.

An additional suggestion was received from participants who are experienced in acceptance activities. The interval between approximate M9 milestone with start of conditional acceptance and start of serial production activities with M10 milestone may be separated into *Operational Test and Evaluation Phase* and expanded in the lifecycle. As a second method, it has been found useful to include the definitions of *Initial Operational Capability (IOC)* and *Final Operational Capability (FOC)*. These points have been integrated to the model under the *Transition, Operation & Disposal* technical process after the interviews.

Hypothesis 2

The following evaluations were obtained from the answers received under hypothesis 2. The common opinion of the participants is that the decision makers are well defined in the lifecycle. It is concluded that if the main criteria of Milestones are defined in the contract, the efficiency will increase and the transitions will become easier. Otherwise, it is considered that the criteria may be determined despite the contradictions and conflicts, too. Moreover, it is emphasized that the outputs of the milestones should be recorded. It is considered important to standardize or to determine criteria by contract like the model studied in this thesis.

For all participants, the consensus opinion is that the milestones are passed to the next stage before the objectives are met. The remarkable comments at this point are that sub-technology maturities are not monitored and controlled as well as at platform level. In all experience, the sub-technology maturity does not reach the technical maturity of aircraft. The participants suggested that the criteria should include requirements for the monitoring of the technological maturity of the sub-components and that additional milestones could be defined in the sub-detail. It is emphasized by most of the participants that the maturity follow-up of the sub-technology and components remained highly subjective. The reason is sometimes good faith and sometimes inadequacy with lack of experience and knowledge. This situation causes risks to be brought to the platform level and causes cost and schedule impacts towards verification activities. Rather than passing reviews such as SRR, PDR, CDR and TRR with contractor declarations and analyzes in a short period of time, broader reviews are recommended as a more rational approach. Decisions should be spread over the process. The experiences gained in the projects should be transferred to practice. The progress and results of the process should be recorded. A proposal that attracts attention by most participants is that decisions should be supported by risk management plans and processes. It is emphasized that a process for the management of technical risks should be added to the model. It is emphasized that risks related to open issues are considered among exit criteria of the associated milestones.

Milestones were deemed sufficient by all participants. However, there have been comments that the technical reviews can be simplified. In this context, according to the level of familiarization and maturity of the product it has been proposed that i) ASR can be extracted, ii) SRR and SFR can be combined, iii) SVR and PRR can be combined or completely removed and TC document can be used instead of SVR and PRR.

There were many different proposals for discrete and complementary contract concept. As a result of the negotiations and ideas, it has been concluded that the lifecycle can be continued with new contracts by PDR and PRR or M9 milestone. PDR is the stage where technological maturity of subcomponents is evaluated and maturity at least TRL5 is aimed with reduced risks. At PRR, it can be mentioned that a safe aircraft with initial operational capability has completed its initial acceptance. New contract as a clean white sheet is deemed appropriate for the separation of technical risks and significant financial impacts at these points.

Hypothesis 3

Technical coverage was found appropriate and sufficient by most of the participants. Technology Development process has been accepted innovative and beneficial because it reflects the contract models used in Turkey. It has been deemed valuable to combine different stakeholders and technical scope for decision-makers. The criticisms of this process are more about scope of contracts than the maturity model. Management of subcontractors' designs under the Technology Development Process has been considered appropriate. However, the separation of development of technologies and aircraft development activities in contract fictions is emphasized as a need by the interviewees as a common opinion.

It was stated by the participants that technology development projects should be carried out in institutes and small scale scientific units in product independent environments. Existing platform developers adopt product-based approaches and are result-oriented. So that they do not pay enough attention to innovations and new technologies due to technical risks. In this case, it is seen that integrators use existing components or ready solutions in stead of new technologies. This situation increases the dependence on foreign sources.

Hypothesis 4

The scope of the technical processes has been deemed appropriate with the assumption that subcontractor technical interfaces will be operated under the *Technology Development Process*. The activities, inputs and outputs of the technical processes have been found to be worth working in the future for the development of the model. The scope and progress of the documents assigned as the inputs and outputs of the processes can be followed through the checklists prepared specifically for the document type.

Usage of means of compliance and their verification status as a tool for monitoring of the aircraft development maturity is considered as an innovative approach since they provide important clues about the completeness and accuracy of technical activities. The common opinion of the participants is that it will be a useful method. However, it has been mentioned that difficulties can arise in practice due to the fiction of the contract. At this point, criticism has been brought against the existing contractual content, although not to the model. It is stated that the contracts should be designed in a way to provide and point out the time and budget required especially for laboratory tests and simulations in support of compliance methods. The inclusion of engineering and verification prototypes for ground and flight tests into the contracts has been considered important.

It is evaluated that mappings from SOI audits to Technical Reviews & Milestones will increase efficiency in the integration of sub-technologies into the product. By this manner Aviation Authorities will contribute to the technical evaluations and the progress of the products in lifecycle. It is also mentioned that the resolution will increase at the component level and the relevant decision gates can be passed more precisely.

The SRL method is initially appreciated by the interviewees as an easy mathematical tool for platform-level technology follow-up. However, it is not seen as practical in a short time during interview. Similar to the results in the literature, similar criticisms have been brought that technical risks will not be eliminated despite the high SRL value. Because SRL defines an average value Moreover, SRL may not always produce reliable results due to a small number of immature low-level critical technologies. Considering the effects of IRL, the use of SRL metric does not provide confidence. The use of TRL metric has been found useful for technological components at software and hardware level.

Hypothesis 5

The baselines have been seen as an important tool for product data integrity and consistency. Additional baselines besides the current referenced ones (Requirement, Allocated and Product Baseline) from guidance documents are approved by the participants. It is emphasized that additional defined baselines will improve traceability, reportability and reduce data loss. The common and strong emphasis is that the baselines are philosophical and conceptual content and not used correctly in practice. At this point, there are some comments on the current contract structure.

The product data and the decisions based on the milestones are not recorded adequately and effectively during establishment of baselines. Two main reasons for this situation emerged in the opinions. The first one is that the decision points are not passed effectively and appropriately so that the subsequent changes are not questioned by all relevant stakeholders. In general, stakeholders are constantly focused on the final product and outcome. The additional timetable implications of this situation have become customary. The second reason is that the financial risks of the amendments are left to the Contractor due to the fixed price contract. The baseline structure, which does not include financial and schedule coverage and is not questioned by the managers, is weakening. This situation also leads to weaknesses in recording the technical content.

Although contractual comfort is provided, it has been seen that the financial effects should be monitored in the defense industry sector due to the capital structure of the main contractors. For this reason, the necessity of adding some mutual sanctions into the contract structure is expressed by some of the participants. What is seen more accurately is the sound decision-making process. In these decision gates, when necessary, returns should be taken into consideration as in the spiral product development model. It is necessary to establish an environment within the scope of technical management in which the authorities and responsibilities to support technical activities are distributed correctly.

4.3 Suggestions for Future Studies

Finally, suggestions will be made for points that need to be updated in the model and other side studies that will support the model.

The current model is developed to address the product lifecycle of new aircraft development. Within the scope of modernization and modification projects, there will be simplification or shorten stages in the product lifecycle. At this point, adaptation of the model seems to be beneficial. The risk management process, which is also emphasized by the participants, is described as a separate process to support decisions. Using the risk levels to be defined at this point as an entry or exit criterion at the milestones is considered worthy of the future studies.

The comments on the *Technology Development & Demonstration* phase were given above. In this context, feasibility of the implementation of *Technology Development & Demonstration* activities experienced in foreign applications to the aircraft development contract structure used in Turkey, may be studied.

The adequacy of test infrastructures is a matter of concern, considering the development and procurement processes of test infrastructures. At this point, metric and criterion studies may be performed under the title of *Test Readiness Level* integrated to the model or completely independent of the model.

It is considered that a separate model can be formed regarding the cost estimations related to this model.

Another issue that will support the above-mentioned future studies and is open to continuous improvement may be the creation of contract scope and fiction.

Finally, the lack of technical managers and expert resources especially on the Customer and User sides is frequently emphasized by the participants as an important issue that should be studied.

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APPENDICES

Appendix A: PEER REVIEW QUESTIONNAIRE

Location :

Date :

Interviewee :

Interviewer : Harun ÇAYKENARI

Research responses will not be shared directly and will only be used to validate, improve and reveal the shortcomings of the model.

Research Question: What kind of product maturity management can be used to define the technological maturity to support project evaluation and decision-making processes in aircraft development projects and to determine the direction of destination?

SCOPE OF INTERVIEW

A. Introduction

Sharing the aim of the research with the participants.

Listening to the academic background and work experience of the participants.

B. Information on Working Technical Framework by Interviewer

Technology management and tools, problematics, hypotheses, important terminologies used in the model and model - suggested solutions

C. Questions

1. 1. Do you think that the technical maturity can be adequately monitored by the Contractor and the Customer in the development projects you are involved in? Can you tell us about strong and weak points?

   i) Do you think that project management activities are sufficiently structured in terms of technical monitoring and directing? Can you evaluate separately from Customer, User, Main and Subcontractor aspects?
   ii) What is your level of system engineering management compared to ISO / IEC 15288? What can you say about the competence of the applied processes?
   iii) Did you run a procedure for identifying the technological components that should be included in the product and monitoring maturity? Can you explain interfaces with PM and SEM?
2. Did you use the product lifecycle approach in your projects? If so, how did you use it?
   i) Do you think that a common language and terminology defined in the defense and aerospace projects in Turkey including Customer, User and Contractor?
   ii) What do you think about the product lifecycle set out in Hypothesis # 1? Do you have any additional determinations about the appropriate and open aspects?
3. How the stages and decision gates were determined in the projects you worked?
   i) Were the decision makers defined?
   ii) Could the decision criteria be established with a common understanding?
   iii) At the beginning of a new phase, were the objectives of the previous phase fully and maturely achieved? If there are any deficiencies you have seen, are the effects felt after these deficiencies in next steps?
   iv) Do you consider the milestones created under the Hypothesis # 2 sufficient? Do you see any need to add new ones or combine the current ones for different purposes?
   v) What decision points would you prefer to sign a new contract, even if you were given the opportunity to complete the shortcomings from the previous period and start with a clean page?

4. Within the scope of Hypothesis # 3, the ISO / IEC15288 reference is selected for the definition of technical processes due to its broad scope, integration with project and organization management processes. Do you find this scope sufficient? For what purposes would you like to narrow or expand the scope?
   i) What is your assessment about additions to the model? (such as expanding the Architectural Design Process as a Design Process, adding Technology Development Process and separating software and hardware development processes by harmonizing with TRL)
5. In order to determine sub-processes, interfaces and exit criteria under Hypothesis # 4;
   i) Do you think that the sample approach (*Concept Definition Phase, Structural & System Installation Design Process*) can be extended to other technical processes to define the qualitative criteria of decision points?
   ii) Do you think that MOE, MOS, MOP and TPM approaches may be sufficient for quantitative targets? Do you think there are additional metrics that can be added?
   iii) Do you think that status of requirement verifications may be an effective way of monitoring technical progress? If so, what improvements do you consider important?
   iv) How do you evaluate SOI mappings from software, hardware and equipment level to system and product level?
   v) Do you find it appropriate to apply the TRL criteria at the equipment level? How do you evaluate the addressing of system engineering processes rather than SRL at the product level in terms of monitoring technology maturity?
6. Do you think that there is a common understanding and application within the scope of Hypothesis # 5? If so, how would you describe the concept of the baselines? Do you see baselines as an important tool?
   i) Are technical baselines appropriately established?
   ii) Can the impact of the changes to the baselines be assessed appropriately?

iii) What do you think about the suitability of the baselines identified in the model?

7. What are your additional criticisms about the overall model?

Thank you for your valuable contribution and support…

Appendix B: DEFINITIONS

The meanings of the terminologies which are frequently repeated in the thesis and which have different definitions in the literature are used in this study are given below.

Product : It means the physical system whose integration is complete. In this study it refers to aircraft (AC) in the specifically. The definition is used synonymously with the *System* definition in ISO/IEC/IEEE 15288.

System : It refers to the integrated functional components or sub-components (eg: landing gear system, main landing gear system; electrical system, power supply system; etc.) at upper levels that make up the product. The definition is used synonymously with the *Sub-System* or *Main Component* definition in ISO/IEC/IEEE 15288.

Equipment : It refers system component which is made up with software, hardware and structural elements that can be replaced on the product with their own functionality if its power and data connections are provided.

Implementation : It refers to the production process of the detail parts that form a certain level in the BOM hierarchy.

Integration : It refers to the assembly and functional integration of subcomponents for equipment, system and product levels in the BOM hierarchy.

Validation : It refers to the activities carried out with the participation of the User or Customer to ensure that the system has the intended usage characteristics.

Verification : It refers to the activities carried out with the aim of checking that the design data is formed according to the requirements. Within the scope of the thesis, 10 *Means of Compliance* (MC) have been defined according to aircraft certification regulations.

Acceptance : It refers to the contractual delivery, registry to inventory and commissioning of products that have almost completed the verification process by the approval of User/Customer. Conditional acceptance can be made for each product or product group whose full verification and validation is not completed. Final acceptance is finalized separately for each product or product group whose verification and validation has been completed.

Appendix C: TURKISH SUMMARY / TÜRKÇE ÖZET

HAVA ARACI GELİŞTRME PROJELERİNDE

ÜRÜN OLGUNLUK YÖNETİMİ METODOLOJİSİ

Türkiye'deki savunma ve havacılık sektöründeki geliştirme projelerin sözleşmelerinde küresel ölçekte lider şirketler tarafından tecrübe edilmiş ve sonunda standartlaştırılmış birçok yöntem esas alınmaktadır. Ancak, bu yöntemlerin uyarlanmasında ve Türkiye uygulamaları için ortaklaştırılmasında eksikliklerin olduğu değerlendirilmektedir. Özellikle; teknik süreçlerin izlenememesi, durum takibi ve değişiklik kontrolünün etkin bir bilgi yönetimi altyapısı ile yapılamaması neticesinde karar aşamalarının uygun olgunlukta geçilemesi, birçok projede risklerin görülememesi, takvim uzamaları, kullanıcı memnuniyetsizliği ve bütçe aşımları ile sonuçlanabilmektedir. Bu sebeple çalışma; hava aracı geliştirme projelerinde ürün teknolojik olgunluğunun izlenmesi için en iyi uygulamalardan yöntemlerin seçilmesini, uyarlanmasını ve ortak bir modelde birleştirilmesini amaçlamaktadır.

Tezin giriş bölümünde teknoloji yönetimi kavramsal çerçevesi ele alınmıştır. Teknolojinin literatürde yüzün üzerinde tanımı bulunmaktadır ("Technology", t.y.). Frascati Klavuzu'nda yer alan Araştırma ve Geliştirme (ArGe) tanımı dikkate alındığında teknolojiyi ArGe çalşmalarının bir çıktısı olarak tanımlamak yanlış olmayacaktır (OECD, 2015). Frascati Klavuzu'na göre ArGe faaliyetleri standart uygulama olarak üç (3) temel kapsama bölünmüştür; Temel Araştırma, Uygulamalı Araştırma ve Deneysel Geliştirme. Deneysel Geliştirme kapsamınına Ürün

Geliştirme çalışmalarının da yer aldığı ayrıca söylenebilir. Bu çalışmanın kavramsal çerçevesinin oluşturulmasında teknoloji yönetimi için Gregory (1995) tarafından tanımlanmış en sade ve ortak kabul görmüş altı ana süreç tercih edilmiştir; *Tanımlama, Seçme, Edinme, Öğrenme, Ticarileşme ve Koruma* (Çetindamar et al., 2013; Gregory, 1995). Bu süreçler birbirleri ile etkileşim içerisinde olmakla beraber sıralı aktiviteler şeklinde düşünülmemektedir.

Teknoloji yönetiminin kurumsal ölçekte stratejik ve operasyonel olmak üzere iki seviyeye yayılmış olduğu görülmektedir. Teknoloji yönetim süreçlerinin ihtiyaçları karşılayacak şekilde ürüne dönüştürülmesinde Sistem Mühendisliği yaklaşımı kaldıraç etkisine sahiptir. Proje yönetimi temelde teknolojik yeteneklerin ticarileşmesi için kaynakların doğru kullanılmasını hedeflemektedir. Operasyonel seviyede proje yönetimi ve sistem mühendisliği süreçlerini destekleyecek temel süreçler ile uyumlu diğer ana ve alt süreçlerin belirlenmesi ve işletilmesi gerekir.

Çalışmanın giriş bölümünde teknoloji yönetimi ana faaliyetleri, Savunma ve Havacılık sektörü bakış açısı ile yeniden gözden geçirilmiştir. Farklılıklar ve dikkat çeken noktalara değinilmiştir. Savunma ve havacılık sektörü için ulusal ölçekte başta iktisadi alanda olmak üzere birçok alanda farklılıklar yer almaktadır.

Bu bölümün şekillenmesinde Serdar GÖKPINAR'ın değerlendirmelerinden büyük ölçüde faydalanılmıştır (Akçomak, Erdil, Pamukçu and Tiryakioğlu, 2016). Savunma sanayii pazarında devletin müşteri rolü ile egemenliği söz konusudur. Faaliyet alanları ulusal boyutta belirlenen stratejilere ve önceliklere göre şekillenmektedir. Pazarın şekillenmesinde teknolojinin itici gücünden ziyade müşterinin istekleri çekici güç olarak daha kuvvetli hissedilmektedir. Savunma sanayininde pazar arzı sivil sektörlere kıyasla daha az sayıda ana yüklenici tarafından karşılanır. Ana yüklenicilerin büyüklükleri ve gücü fazladır ancak çok sayıda onaylı alt yüklenici ile dikeyde hiyerarşik anlaşma içerisinde işler tamamlanır. Yüklenici sermayedarları içerisinde kamu kurumları yer alabilir. Bu durum devletin yüklenici organizasyonlarında ve mali kararlarında etkin olmasına neden olur. Savunma sanayiinde amaç tehditlere karşı mutlak üstünlük sağlamak olduğu için geliştirilen ürünler sürekli olarak yıkıcı teknolojiler ile beslenir (Akçomak et al., 2016). Ürün çeşitliliği ve üretim hacmi sivil sektörler ile karşılaştırıldığında düşük olmasına rağmen birim maliyetleri yüksektir. Birim maliyetlerin yüksek olmasında düşük üretim hacmi ve yüksek ArGe maliyetleri etkilidir. Savunma sanayiinde platform geliştirme projellerinin teknolojik değeri ve yüksek maliyeti işbirliklerine gitme senaryosunu zorlasa da sivil sektörlerden farklı olarak stratejik kabiliyetlerin kazanılmasında yüksek maliyetine rağmen bazı durumlarda temelde 2 nedenle ARGE yolu ile edinilmesine gidilmektedir; i) geliştirilen stratejik kabiliyetin korunması ihtiyacı veya ii) başka ellerdeki mevcut stratejik kabiliyetin satın alınamamaması (Çetindamar et al., 2013, pg. 157; Akçomak et al., 2016). Ürünler; karmaşık, çok bileşenli ve çok disiplinli, kritik ve çekirdek teknolojilerin yanında, olgunluğunu tamamlamamış başka teknolojileri de barındırır. Sivil sektörde teknolojinin korunması ticari kaygılar ile gerçekleşirken savaunma sanayii için teknolojinin askeri stratejik üstünlük sağlıyor olması başlıca koruma sebebidir.

Ürün geliştirme süreci ve ürün ömür devirleri uzundur. Her ürün kendine has teknolojik zorluklar barındırır. Bu durum ürün geliştirmeye özel süreçlerin ve planlamaların proje kurgusu içerisine dahil edilmesine neden olur. Bunun aksine karmaşık süreçlerin basitleştirilmesi, temel yaklaşımların sistematik bir hale getirilmesi ve ortak bir dil oluşması için birçok standart veya rehber süreçten yararlanılmaktadır. Proje yönetim metotları, sistem mühendisliği yaklaşımı, ürün geliştirme süreci planlaması, ArGe süreci planlaması gibi araçlar standart olarak yoğun şekilde kullanılmaktadır. Müşteri isteklerinin analizi, detaylandırılması, geçerlenmesi ve doğrulanması gidişatın izlenmesinde temel kontrol noktasıdır. Savunma ve havacılık sektöründe çok disiplinli, karmaşık arayüzlere sahip, çok bileşenli, teknolojik berlirsizliklere sahip ürün geliştirme sürecinde gelişmelerin ortaya konabilmesi, mali, takvim ya da teknik konularda risk belirleme ve risk azaltma tekniklerinin kullanılabilmesi, müşteri beklentilerinin odakta kalabilmesi için izleme ve kontrol araçlarının kullanılmasına ihtiyaç vardır. Sözü edilen standart usuller arasında bu kontrol faaliyetleri de yer almaktadır. Teknoloji yönetimi kapsamında farklı modellerde olgunluk izleme araçları kullanılmaktadır. Çalışmanın ikinci bölümünde daha çok bu olgunluk modellerine ve kullanım alanı bulmuş uygulamalarına yer verilmiştir.

Savunma ve havacılık sanayiinde kullanılan proje yönetimi ve sistem mühendisliği yönetimi araçları yüksek bütçeli ve karmaşık ürünlere sahip diğer farklı sektörlerde de yaygın olarak kullanılmaktadır. Zamanla en iyi uygulamalar ticari ve akademik farklı kurumlarca standartlaştırılarak yayımlanmıştır.

Proje yönetimi müşteri/kullanıcı beklentilerini karşılayacak ürünü/sistemi gerçekleyecek paydaşları bir araya toplamaya, kaynakları doğru kullanmaya ve zamanında sistemi kullanıcılara teslim etmeye çabalar.

Sistem mühendisliği yönetimi ise paydaşlardan gelen isterleri tanımlamaya ve sistem, alt sistem ve bileşenlere dağıtmaya sonrasında alt seviyeden yukarıya isterleri ürüne dönüştürmeye ve teknik entegrasyona odaklanır.

Her iki yönetim modeli müşterinin veya kullanıcının talep ettiği ürünü karşılamaya çalışır. Her iki model birbirini destekler nitelikte pek çok benzer faaliyet alanına sahiptir. Sistem mühendisliği yönetimi kapsamında teknik süreçlerin yönetimi alt faaliyetlerinin ise proje yönetimi kapsamında entegrasyon ve kapsam yönetimi alt faaliyetleri ile kesiştiği noktalar bulunmaktadır. Bu noktada müşteri isteklerinin takibi ve bu istekleri gerçekleştirmekte mani olan risklerin takibi bu çalışma kapsamında dikkat çeken en önemli ortak faaliyet alanları içerisine girmektedir. Entegrasyon ve kapsam yönetimi altında işletilen proje izleme ve kontrol süreci ile sistem/ürün olgunluğunun takibi ve teknik risklerin izlenebilmesi için kullanılan teknik gözden geçirmeler benzer amaçlara hizmet etmektedir ve birbirleri yerine kullanılabilmektedir.

Teknoloji ve ürün geliştirme faaliyetleri kapsamında olgunluk modellerine bakıldığında temelde iki farklı yaklaşım olduğu söylenebilir. İlk yaklaşım teknolojini kendisine ve ürüne odaklanırken diğer yaklaşım geliştirme süreçlerine ve yönetim sistemlerine odaklanmaktadır. Heriki yaklaşımda da yaygın kullanılan ölçüt ve yöntemlerin olduğu görülmektedir. İlk yaklaşımda ilk kez 1980'lerde Amerika Uzay Ajansı (NASA) tarafından ortaya atılmış Teknoloji Hazırlık Seviyeleri (Technology Readiness Level - TRL) ölçütü geniş literatür ve uygulama alanı bulmuşken; ikinci yaklaşımda Yetenek Olgunluk Modeli Entegrasyonu (CMMI, Capability Maturity Model) kavramı Carnegie Mellon Üniversitesi bünyesindeki Yazılım Mühendisliği Enstititüsü tarafından 1986 yılında oluşturulmuş ve birçok türevi uygulamada hayat bulmuştur.

TRL ölçütünün tek bir teknoloji hakkında fikir veriyor olması ve teknolojiler arası entegrasyonun ele alınmıyor olması gerekçeleri ile Sistem Hazırlık Seviyeleri (System Readiness Level - SRL) modeli ve ölçütü çok bileşenli ve disiplinli ürünlerin olgunluk takibi için teklif edilmiştir (Ramirez-Marguez and Sauser, 2009; Tan et al., 2011). Bu ölçüt sonrasında TRL ve Entegrasyon Hazırlık Seviyelleri (Integration Readiness Level – IRL) değerleri normalize edilmeye ve 0 ila 1 arasında gruplandırılarak 5 seviyede SRL değeri hesaplanmaya çalışılmıştır.

Sistem Olgunluğu (System Maturity) ve Sistem Hazırlık Durumu (System Readiness) kavramları üzerine Tetlay ve John ayrıca değerlendirmelerde bulunmuş ve Yetenek Hazırlık Seviyeleri (Capability Readiness Level - CRL) tanımı üzerinde durmuşlardır (Tetlay and John, 2009). CRL kapsamında henüz bir metrik ortaya konmamış olmasına rağmen Tetlay ve John yaptığı çalışmalarda Sistem Mühendisliğindeki "V-Model" ile "Sistem Olgunluğu (System Maturity)" ve "Sistem Hazırkık Durumu (System Readiness)" kavramları Şekil 11'de verilmiştir.

Farklı çalışmalarda SRL ölçeği ve hesaplama yöntemleri ile ilgili zayıflıkları gidermeye yönelik araştırmalar sürdürüldüğü görülmektedir.

ABD Savunma Bakanlığı altında asker ve savunma sanayii sektör temsilcileri tarafından oluşturulmuş “Joint Defence Manufacturing Technology Panel” tarafından benzer bir ölçüt de üretim faaliyetlerinin olgunluğunu ölçmek için 2001 yılında TRL yaklaşımı ile ilişkili olarak ortaya konmuş ve Üretim Hazırlık Seviyeleri (Manufacturing Readiness Level - MRL) 10 seviyede tanımlanmıştır. Konuya ilişkin MRL Deskbook isimli rehber doküman hazırlanmış olup son versiyonu 2011 yılında yayımlanmıştır (MRL Deskbook, 2018).

Projenin teknik kapsamdaki ilerlemenin izlenmesi ve kontrolü için teknik performans yönetimi usulleri ayrıca sistem olgunluğunu değerlendirmek için kullanılmaktadır. Teknik performans iteratif olarak ürün geliştirme sürecinde takip edilir ve doğrulanarak raporlanır. Teknik performans metrikleri gereksinim hiyerarşisinde farklı seviyelerden seçilebilir. Operasyonel senaryoları geçerlemekte kullanılan sayısal metrikler Etkinlik Ölçütü (Measure of Effectiveness - MOE) ve Uygunluk Ölçütü (Measure of Suitability - MOS) olarak tanımlanır ve sistemin kullanım amacına ne kadar yaklaştığını ölçmek için belirlenir. Kullanıcının sistemden beklediği performans için MOE metriklerini tamamlar nitelikte Performans Ölçütü (Measure of Performance - MOP) belirlenir. Kullanım senaryolarını destekleyen fonksiyonel isterler ile performans isterleri alt sistem ve bileşenlere kırılarak alt seviyede teknik bütçeler dağıtılır. Daha alt seviyede bu teknik metrikleri gereksinim hiyerarşisinde yatayda ve dikeyde çeşitlendirmek veya arttırmak mümkündür. Bu teknik bütçeler karşılığı ayrıca Teknik Performans Ölçütleri (Technical Performance Metrics - TPM) belirlenir.

Yetenek olgunluk modelleri bir kurumda veya projede ilgili süreçlerin ne kadar aktif ve kapsamlı kullanıldığı ile ilgili bilgi verir. Organizasyonel süreçlerdeki olgunluk ya da proje süreçlerindeki olgunluktan ziyade geliştirme süreçlerinde sistem/ürün olgunluğu ile sistemi oluşturan bileşenlerin teknolojik olgunluğuna odaklanıldığı için bu çalışmada süreç olgunluk modelleri üzerinde durulmamıştır.

Savunma ve Havacılık Sanayiinde radikal yenilikler hedeflenir. Bunun bir sonucu olarak teknolojik bileşen ve bileşenler arası etkileşimin yüksek olması beklenir. Bu durum mühendislik faaliyetlerinin ve mühendislik süreçlerinin de karmaşıklaşmasına sebep olur. Karmaşanın ve teknik zorlukların yönetilebilmesi, proje takvim ve bütçe hedeflerinin de desteklenebilmesi için kurumlar ve şirketler kendi teknik yönetim, kontrol ve izleme süreçlerini oluşturmaktadırlar. Bu kapsamda AIRBUS, NATO ve ABD Savunma Bakanlığı'na (US DoD) ait çalışan modeller incelenmiştir.

AIRBUS mühendislik süreçlerini senkronize edebileceği Ürün Ömür Devrini Şekil 14'te yer aldığı hali ile 5 ana faz ve 14 kilometretaşı ile tanımlamıştır (Pardessus, 2004).

ISO/IEC 15288 ve bu standardı referans alan NATO AAP-20 "NATO Life Cycle Model" dokümanları incelendiğinde benzer bir yaklaşım ile sistem mühendisliği yaklaşımı içerisinde sistemlerin olgunluğu ve teknik ilerlemeler izlenmeye çalışır. Bu uygulamalarda sistem ve sistemin faal kalması için gereken destek sistemler beraber tüm ömür devrini kapsayacak şekilde ele alınır. İlgili ürün ömür devri Şekil 15'te görüldüğü gibi birbirini takip eden 7 aşamadan oluşmaktadır. NATO AAP-20 standardında Ürün Ömür Devri yaklaşımı ile üyeler arasında ortak bir dilin oluşması ve teknik yönetim noktasında entegrasyonun sağlanacağı öngörülmüştür.

ISO/IEC 15288 standardından askeri uygulamalar için uyarlanan IEEE 15288.2 "Technical Reviews and Audits on Defense Programs" standardında ürün ömür devri tanımı yapılmamış bunun yerine 4 adet teknik anahat ve 10 adet Teknik Gözden Geçirme ile giriş-çıkış kriteri tanımlı bir değerlendirme yaklaşımı oluşturulmuştur. IEEE STD 15288.2'de, etkin bir sistem mühendisliği yaklaşımı ve sağlam teknik değerlendirme sürecinin omurgası için ilgili karar aşamaları temel yapıtaşı olarak görülmektedir.

ABD Savunma Bakanlığı uygulamasında ürün ömür devri yönetimi incelendiğinde üretime hazırlık olgunluğunun yakından odaklanılarak tanımlı ölçütler ile ele alındığını görüyoruz. İlave olarak ürün kırılımında alt detayda teknoloji hazırlık seviyeleri ile teknolojilerin ayrıca ölçütlerle takip edildiği görülmektedir.

Tez kapsamında özellikle teknoloji olgunluk takibine ilişkin Türkiye'de yapılmış çalışmalar araştırılmıştır. Yapılan literatür araştırmalarında konuya ilişkin 4 adet çalışmaya rastlanmıştır. Sınırlı sayıdaki akademik çalışmalar dikkate alındığında bu husuta gelecek dönemde de çalışmaya ihtiyaç olabileceği söylenebilir

Altunok ve Çakmak (2010) tarafından 2008 yılında başlatılan çalışma ile Türkiye, Ankara'daki şirketler için Teknoloji Hazırlık Seviyesinin hesaplanmasına yönelik algoritma geliştirilmesi hedeflenmiştir. Bu çalışma sonrasında bir TRL hesaplayıcı yazılım aracı olarak şekillenmiştir.

Türkiye'de konuya teknolojik olgunluğun değerlendirilmesi ile ilgili yapılmış kapsamlı bir literatür araştırması ise Babaçoğlu, Akgün ve Kayhan (2014) tarafından yapılmıştır.

Üçüncü çalışma üniversite sanayi işbirliği ile hazırlanmış ve ürün tabanlı bir teknoloji yönetimi metodolojisi ortaya koymaktadır (Temiz, Özkan and Üçer, 2016). Ulusların teknolojik yetenekerlinin kullanılarak ürün teknolojilerinin seçilmesi, önceliklendirimesi ve planlanması için metodoloji ortaya koymayı hedeflemiştir.

Olgunluk değerlendirmeleri ile ilgili son çalışma akademik çalışmadan ziyade el kitabı olarak SSB tarafında 2015 yılında hazırlanmış *Savunma sanayii için teknoloji* *hazırlık seviyesi kılavuzudur*. Kılavuz TRL tanımlarının derlenmesi ile oluşturulmuştur. Sektördeki farkındalığın artması hedeflenmiştir.

Proje yönetim süreçlerinde teknik olgunluğun takibinde yaşanan güçlükler, bu konuda Türkiye'de yapılan kısıtlı çalışmalar ve çalışmaların sonucundaki tespitler dikkate alındığında teknolojik olgunluk değerlendirmeleri çalışılması gereken bir konudur. TRL ölçeği ve değerlendirme yöntemleri, yapılan eleştirilere rağmen, yazılım ve/veya donanım bileşenleri seviyesinde kabul görmüş ve geniş kullanım alanı bulmuştur. Ancak, sistem veya ürün seviyesindeki çalışmalar teorik kalmış ve uygulamada hayat bulamamıştır. Ürün olgunluğunun tespit edilmesi ile gerçek durum ancak ortaya konabileceği değerlendirilmektedir. Bu noktada SRL yaklaşımının ötesinde daha bütüncül, çok kriterli ve uzmanlardan oluşan grup karar mekanizmaları içeren bir yönteme ihtiyaç duyulmaktadır. Öznelliğin sınırlandırılması yönünde kullanılabilecek yöntemlerin oluşturulması, değerlendirmelerin güvenilirliğini ve dorğruluğunu arttıracağı için önemli görülmektedir. Ürün bilgisinin sağlıklı oluşturulabilmesi ve izlenebilmesi için bilgi yönetim ve değişiklik yönetimi yaklaşımlarının oluşturulmasına ayrıca ihtiyaç bulunmaktadır. Çalışma kapsamında belirlenen yöntemde bu husulara dikkat edilmiştir.

Tezin üçüncü bölümünde araştırma metodolojisine, modelin cevap vermesi gereken hipotezlere ve modelin oluşturulmasında izlenen adımlara yer verilmiştir.

Çalışma kapsamında Tanımlama ve Seçme teknoloji yönetimi faaliyetleri ön plana çıkmaktadır. Bu faaliyet alanları için S-eğrisi, Aşama-Geçit, Değer Analizi ve Portföy Yönetimi sık kullanılan yöntemler arasında bulunmaktadır. Modelin oluşturulmasında bu faaliyet alanları ve yöntemler referans alınmıştır.

Ürün olgunluk modeli oluşturulurken S-eğrisindeki ömür yaklaşımı ile Aşama-Geçit yönteminin beraber kullanılabileceği değerlendirilmiştir. S-eğrisindeki dikey eksen bu çalışmada farklı katmanlarda teknik süreçlere bölünmüştür. Nitel veya nicel süreç çıktıları dikey eksende yayılmıştır. Yatayda da ürün yaşamı üzerinde de geçit noktaları tanımlanmıştır. Değer tahmilerine yönelik performans parametrelerine ve doğrulama hedeflerine modelde yer verilmiştir.

Çalışan modellerin referansı ile ve teknoloji yönetimi araçları ışığında tasarlanan modelin doğruluğunun değerlendirilmesi için mülakat tekniği araştırma yöntemi olarak kullanılacaktır.

Bu çalışma içerisinde ele alınan teorik çerçeve, bu kapsamda en iyi ugulama örneği olarak sunulan (best practice) standart ve rehber dokümanlar ile örnek modeller incelendiğinde; teknolojik olgunluğun sistem/ürün seviyesinde tanımlanabilmesi ve olgunluk takibinin yapılabilmesi için aşağıdaki hipotezler oluşturulmuştur.

HP1: Ürün tedariğinde ve işletmesinde beraber çalışabilirlik, proje gerçeklerine uygun maliyet etkin şekilde ve zamanında süreci tamamlayabilmek için sistematik ortak bir yaklaşım ortaya koyan Ürün Ömür Devri (Ürün Yaşam Döngüsü) modelinin oluşturulması veya seçilmesi gerekir.

HP2: Ürün Ömür Devrinde farklı paydaşların ortaklaşa aldığı veya ilgili fazın sorumlusu tarafından alınan karar noktaları ile gözden geçirme adımlarının tanımlanması gerekir. Bu şekile faz geçişleri ve fazların altındaki aşamaların kararlar ile eşleştirilmesi gerçekleşebilir.

HP3: Gerekli fonksiyonlar ile istenen yetenekte ürünün gerçekleştirilebilmesi sıralı ve eş zamanlı teknik süreçlerin, alt süreçlerin ve bu süreçler kapsamında yürütülen faaliyetlerin tamamlanması ve aralarındaki arayüzlerin oluşturulması ile sağlanabilir.

HP4: Teknik süreçlerdeki ilerlemelerin ilgili karar noktalarında nitel olarak uzman görüşleri ve nicel olarak objectif metrikler ile desteklenmesi gerekir.

HP4.a: Herbir faaliyetin ürün fazları ve alt aşamalar ile ilişkilendirilmesi karara ilişkin çıktıların belirlenmesi gerekir.

HP4.b: Sistem mühendisliği ve proje yönetimi izleme ve kontrol faaliyetlerini desteklemek için kullanılan MOP, MOE ve TPM tanımlamaları yeteneklerin hazır olma seviyesi hakkında bilgi verir.

HP4.c: Uyum doğrulama yöntemleri ve tamamlanma durumları aşamaların olgunluğu hakkında sayısal bilgi verir.

HP4.d: SRL'in rasyonel bir ölçüm metodu olarak güçlü bir teknoloji yönetim ve taksonomi altyapısı olmaksızın kullanılması pratikte mümkün değil. Sadece odaklanılmış teknolojilerin sistem entegrasyonunda bir araç olarak kullanılabilir.

HP4.e: Sistem Mühendisliği süreçlerinin altında odak teknolojilerin olgunluğunun izlenmesinde TRL yaklaşımının kullanılması uygundur.

HP5: Veri toplama ve değişiklik kontrol usullerinin ürün ömür devri ve karar noktaları/kilometretaşları ile ilişkilendirilmesi sistem olgunluğunun kayıt altına alınabilmesi, raporlanabilmesi ve yönlendirilebilmesi için önemlidir.

Hipotezlerin ortaya konmasından sonra hipotezleri sırası ile destekleyecek çözümler seçilmeye çalışılmış, zaman zaman uyarlanarak ortaya bir model konulmuştur.

US DoD tarafından MIL-STD-499:2017 standardının iptal edilmiş ve yerine IEEE 15288.1:2014 geçerli kılınmıştır. IEEE 15288.1:2014, ISO/IEC 15288:2008 standardının uyarlamasıdır. AAP-48:2013 NATO standartları da ISO/IEC 15288 temeli üzerine kurgulanmıştır. US DoD ve NATO tarafından çalışma esası olarak kabul edilmiş olması ve muadil sistem mühendisliği standartları/el kitapları ile karşılaştırıldığında geniş teknik kapsamı sahip olması nedeni ile ISO/IEC 15288 modelin oluşturulmasında ilk temel referans olarak seçilmiştir. ISO/IEC 15288 ile ihtiyacı ortaya konulan sistem yaşam döngüsü kavramı AAP-20:2015 ile NATO uygulamaları için özelleştirilerek tanımlanmıştır. US DoD uygulamaları için oluşturulmuş IEEE 15288.2:2014 standardı ile teknik gözden geçirme ve denetleme esasları ve kriterleri çalışma yöntemleri arasına dahil olmuştur.

Model geliştirilirken Türkiye Savunma ve Havacılık Sanayii sektöründeki uygulamalar dikkate alınarak temel omurga üzerine bazı noktalarda uyarlamalar yapılmıştır. Son aşamada, alt detayda teknik süreçlerin, faz giriş-çıkış kriterlerinin ve elde edilen somut girdi ve çıktıların belirlenmesinde diğer kaynak standart, rehber doküman, akademik çalışmalar ile teknoloji olgunluk seviyesi yaklaşımlarından yararlanılmıştır.

HP1: Ürün Ömür Devri Tanımı

İlk hipotez karşılığı Ürün Ömür Devrinin sıralı 6 faz ile teşkil edilebileceği öngörülmüştür: *Operasyonel Konsept Tanımlama & Fizibilite, Kavramsal Tanımlama, Tasarım Tanımlama, Geliştirme Fazı, Kurulum & Modifikasyon, Operasyon & Destek*

Fazların isimleri seçilirken referans standart veya rehber dokümanlardaki terminolojinin kısmen dışına çıkılmıştır. Türkiye'deki mevcut proje ilerleyişleri ve aşamaları dikkate alınarak yeni terminoloji ve tanımlar eklenmiştir.

HP2: Karar ve Gözden Geçirme Adımlarının Tanımlanması

Ürün Ömür Devri boyunca kullanıcı, müşteri, tasarım organizasyonu, üretim organizasyonu ve havacılık otoritelerinin tamamının veya bazılarının müşterek katılım sağladıkları ve ortak görüşler neticesinde kararların ilgili noktanın sorumlusu tarafından alındığı müşterek karar noktaları yer almaktadır. Bunun dışında firmaların veya kurumların kendi iç yapılarında işlettikleri karar noktaları da bulunmaktadır.

Bu hipotez gereği tanımlamaları yapabilmek için öncelikle her fazın başlangıç kararı için bir karar noktası/kilometretaşı tanımlanmıştır. Sonrasında çalışan uygulamalardan önemli görülen noktalar kilometretaşları arasına ilave edilmiştir. Sonuçta, Tablo 4'deki 13 adet kilometretaşına ulaşılmıştır. IEEE 15288.2 standardı refernas alınarak sistem mühendisliği kapsamındaki müşterek teknik gözden geçirmeler ve denetimler kilometretaşlarına göre konumlandırılmıştır.

HP3: Teknik Süreçler ve Arayüzlerin Tanımlanması

IEEE 15288 referansı dikkate alındığında 4 grup sürecin tanımlandığı görülmektedir; *Anlaşma, Organizasyonel Proje-Gerçekleştirme, Proje ve Teknik.*

Bu hipotez altında gerçek odağı kaybetmemek ve çalışmayı sınırlı tutabilmek için sonrasında teknik süreçlere odaklanılmıştır. Bu kapsamda 11 adet teknik sürecin tanımlandığı görülmektedir; *Paydaş Gereksinim Tanımlama Süreci, Gereksinim Analiz Süreci, Mimari Tasarım Süreci, Gerçekleştirme Süreci, Entegrasyon Süreci, Doğrulama Süreci, Geçiş Süreci, Geçerleme Süreci, İşletme-Operasyon Süreci, Bakım Süreci, Kal Etme Süreci.* Standartta süreçlerin sıralı veya eş zamanlı işletilebileceği, firmaların ilave teknik süreçler ekleyebileceği vurgusu yapılmıştır.

HP4: Nitel ve Nicel Kriterlerin Tanımlanması

Teknik süreçlerdeki ilerlemelerin ilgili karar noktalarında nitel olarak uzman görüşleri ve nicel olarak objectif metrikler ile desteklenmesi gerekir. Hava aracı gibi karışık ve çok disiplinli ürün için tüm teknik süreçlere ilişkin girdi ve çıktıların belirlenmesi ile bu bilgilerin yeterlilik kriterlerinin atanması çok geniş bir çalışma gerektirir. Çalışmayı altından kalkılabilir bir seviyede tutabilmek ve HP4 gereği tanımlamaların yapılabilmesi *Kavramsal Faz* için *Yapısal ve Sistem Enstalasyon Tasarımı* teknik süreci etrafında model detaylandırılmıştır.

HP4.a

HP4.a gereği *Sistem Enstalasyon Tasarımı* içi ve modeldeki diğer süreçler ile arayüzleri tanımlanmış ve Şekil 19'da tasvir edilmiştir.

HP4.b

Nitel tamamlama kriterlerinin nicel kriterler ile desteklenmesi subjektif görüş farklılıklarının kapanmasına fayda sağlayabilir. Bu noktada Sistem mühendisliği ve proje yönetimi izleme ve kontrol faaliyetlerini desteklemek için kullanılan MOP, MOS, MOE ve TPM tanımlamalarının, yeteneklerin hazır olma seviyesi hakkında önemli bilgi sağlayacağı değerlendirilmektedir.

HP4.c

Doğrulama faaliyetleri *M4: Üst Seviye Hava Aracı Gereksinimleri Tanımlandı (TLAR Defined (SRR))* kilometretaşı geçildikten sonra sistem fonksiyonlarının ve mimarilerinin belirlenmesine başlanır.

Doğrulama faaliyetlerinin temelde sırası ile analitik ve sayısal analizlerden, laboratuvar ortamındaki deneysel analizlerden, yer ve uçuş testlerinden oluştuğu söylenebilir (Çelik, 2017). Bu yöntemlere Avrupa Havacılık Otoritesi; tasarım tanımlama, ekipman uygunluk belgeleri ile fiziksel muayeneleri de ekleyerek uyum doğrulama yöntemlerini belirlemiştir. Bu yöntemlerin doğrulama faaliyetlerini izlemek için kullanılabileceği değerlendirilmektedir.

Doğrulama faaliyeti tasarım döngüsü ile eş güdümlü olarak iteratif ilerlemekte ve tasarım tamamlanmadan tam bir doğrulamadan bahsetmek mümkün olmamaktadır. Ancak, tüm doğrulama aktivitelerini sona bırakmak da tasarımın yeterliliğinin izlenmesini imkansızlaştırmaktadır. Bu hipotezin başında tanımlanan çıktıların birçoğu aynı zamanda bir uyum dokümanına tekabül etmektedir. İlgili kilometretaşları çıkış kriterleri arasına uyum dokümanlarının da eklenebileceği değerlendirilmektedir. Çıkış kriterleri arasına uyum dokümanlarının tamamlanma kriterleri belirli bir yüzde ile nicel olarak da eklenebilir.

HP4.d

Bölüm 2.2.'de sözü geçmiş olan IRL ve SRL matematiksel hesaplama yöntemleri ile hava aracı gibi çok disiplinli ve sistemli bir ürünün teknolojik olgunluğunun hesaplanabilmesi kolay olmayacaktır. Bu değerlendirmeler için karmaşık bir veri toplama ve izleme altyapısının olması gerekir. Bilişim ve süreçsel bir altyapı olmaksızın pratikte bu yöntemin uygulanabilirliği mümkün değerlendirilmemektedir. İzlenmek istenen birkaç sistem için ilişkili olduğu arayüzleri de dikkate alarak SRL hesaplama yöntemi gerçek hayatta karşılık bulabilir. Ancak, büyük ve karmaşık ürünler için tez kapsamında oluşturulan aşamaların, karar noktaların, nitel ve nicel değerlendirmelerin ürün olgunluğunun ve teknik risklerin izlenmesinde yeterli olabileceği değerlendirilmektedir.

HP4.e

ISO/IEC 15288 standardı içerisinde tanımlanan teknik süreçlere modelde ilaveler yapılmıştır. Ürün ağacı hiyerarşisinde en aşağıda sayılabilecek yazılım ve donanım bileşenlerinin olgunluğu *Teknoloji Geliştirme (Technology Development)* süreci altında ele alınabilir. Bu sürecin ilerlemesi yine hava aracının yaşam döngüsü ile ilişkili olarak TRL değerlendirmeleri ile yapılabilir

M4: TLAR Defined (SRR) kilometretaşında ürün beklentileri üzerinde anlaşılır. Bu aşamadan sonra hava aracı fonksiyonlarının ve emniyet hedeflerinin ortaya konması beklenmektedir. Ancak, ekipman seviyesinde isterler için henüz erken bir aşamadır. *M4: TLAR Defined (SRR)* kilometretaşı sonrasında ARP4754 gereği hava aracı ve sistem fonksiyonları emniyet değerlendirmelerine tabi tutulur ve uçuş kritik fonksiyonlar ile bu fonksiyonları karşılayan ekipmanlara *Tasarım Teminat Seviyeleri (DAL – Design Assurance Level)* atanır. DAL seviyeleri, yazılım ve donanım bileşenlerinin sistematik hatalardan arındırılması için yürütülmesi gereken usul ve esasları şekillendirir. Herbir seviye için izlenmesi gereken faaliyetler ve amaçlar DO-178 ve DO-254 dokümanları ile tanımlanır.

Kilometre taşları, TRL seviyeleri ve SOI denetimleri arasındaki benzer eşleştirmeler modelde yapılmıştır. İlgili değerlendirmeler tek noktadan ibaret olmayabilir, birleştirilebileceği gibi çoğu zaman tekrarlı gözden geçirmeler şeklinde zamana yayılarak tamamlanır.

HP5: Anahatların Belirlenmesi

Proje süreçleri altında yer alan birçok süreç (Değerlendirme ve kontrol, konfigürasyon yönetimi, bilgi yönetimi, ölçme) için omurgayı oluşturan konu verinin sistematik toplanması ve tanımlanması ile ilişkilidir. Durum takibi, analizi ve raporlaması; verinin bilgiye dönüşmesini ve değer kazanmasını sağlar. Durum takibinin detayında etkin bir paylaşım ve değişiklik kontrolü yer alır. Durum raporlama ve değişiklik kontrolü veri ya da veri bütünü için anahatların çekilmesi ve ilgili anahattın sorumlularının belirlenmesi ile sağlanabilir. Modelde belirlenen 8 adet anahat ile herbir fazın bitişi ile o faz boyunca toplanan verinin kayıt altına alınması ve yayımlanması beklenir.

Bu tez kapsamında oluşturulmuş modelin genel görüntüsü Şekil 18'de verilmiştir. Terminoloji birliğini sağlamak için mümkün olduğunca referanslardaki tanımlamalara sadık kalınmıştır.

Bölüm 3.2. altında tanımlanmış Hava Aracı Ürün Olgunluk Yönetimi Modelinin doğrulanması için nitel veri toplama yöntemi olan görüşme aracı kullanılmıştır. Görüşme yarı-yapılandırılmış biçimde kurgulanmıştır. Sorular ve model öncesinde, katılımcılar ile paylaşılmıştır. Görüşmeler katılımcılar arasındaki etkileşimi sınırlı tutabilmek adına toplu halde değil bireysel gerçekleştirilmiştir.

Katılımcılar, Türkiye'deki özgün hava aracı geliştirme projelerinde uzun süre çalışmış ve özellikle teknolojik ürün olgunluğunun izlenmesi konusunda görev ve sorumluluk almış kişiler arasından şeçilmiştir.

Çalışmanın son bölümünde modelin doğrulamasında kullanılan mülakat sonuçları paylaşılmıştır. Modelin doğrulaması için kullanılan yarı yapılandırılmış mülakatlar sonrası modelde sunulan çözümlerin yeterliliği ve doğruluğu değerlendirilmiştir. Bu değerlendirmeler sırasında sorunsalın katılımcılar tarafından kabul görüp görmediğine bakılmıştır. Bölümün sonunda ise yine mülakat sonuçlarından çıkan modelde güncellenmesine ihtiyaç duyulan konular ve gelecek dönemde modele ilişkin çalışılabilecek önemli konular özetlenmiştir.

Model yeni hava aracı geliştirme ürün yaşam döngüsünü ele alacak şekilde oluşturulmuştur. Modernizasyon ve modifikasyon kapsamında ürün yaşam döngüsünde sadeleşme veya daha hızlı tamamlanan aşamalar olacaktır. Bu noktada modelin uyarlanması faydalı görülmektedir. Katılımcılar tarafından da vurgulanan Risk Yönetim sürecinin kararları destekleyecek şekilde ayrı bir süreç olarak tanımlanması faydalı değerlendirilmektedir. Bu noktada tanımlanacak risk seviyelerinin kilometretaşlarında giriş veya çıkış kriteri olarak kullanılması çalışmaya değer görülmüştür.

Yabancı uygulamalarda tariflenen *Teknoloji Geliştirme & Gösterim (Technology Development & Demonstration)* fazınının Türkiye'deki hava aracı geliştirme projeleri için uygulanabilirliğinin çalışılması ve uygun yapıda modele ve sözleşme kurgularına eklenmesi çalışılabilir.

Test altyapılarının geliştirme ve tedarik süreçleri göz önüne alınarak test altyapılarının yeterliliği ayrıca kafa yorulması gereken bir konudur. Bu noktada modele entegre veya tamamen bağımsız şekilde Test Hazırlık Seviyeleri başlığı altında metrik ve kriter çalışması yapılabilir.

Bu model ile ilişkilendirilmiş maliyet öngörülerini de içerisine alan ayrı bir modelin oluşturulabileceği değerlendirilmektedir.

Yukarıdaki çalışmaları destekleyecek ve sürekli iyileştirmeye açık bir konu da sözleşme kapsam ve kurgusunun oluşturulması olabilir.

Katılımcılar tarafından sık vurgulanan özellikle Müşteri ve kullanıcı tarafındaki teknik yönetici ve uzman kaynağının sağlanması, geliştirilmesi ve korunmasına yönelik yapılacak araştırmaların da kıymetli olacağı sonucuna varılmıştır.

Appendix D: TEZ İZİN FORMU / THESIS PERMISSION FORM

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TEZİN ADI / TITLE OF THE THESIS (**İngilizce** / English) : Product Maturity Management Methodology in Aircraft Development Projects

TEZİN TÜRÜ / DEGREE: **Yüksek Lisans** / Master X **Doktora** / PhD ☐

1. **Tezin tamamı dünya çapında erişime açılacaktır. /** Release the entire work immediately for access worldwide. X

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